FRASER RIVER ACTION PLAN

Technical Pollution Prevention Guide for Foundries in the Lower Fraser Basin of British Columbia

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TECHNICAL POLLUTION PREVENTION GUIDE
For Foundries in the
Lower Fraser Basin of British Columbia

Prepared for:
Environment Canada
Environmental Protection
Fraser Pollution Abatement Office
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DISCLAIMER

This consultant's report was funded by Environment Canada under the Fraser River Action Plan through its Fraser Pollution Abatement Office. Environment Canada is not responsible for the content of this report but has made it available for public distribution.

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FOREWORD

Pollution prevention is the judicious use of materials, process energy and practices that avoid or reduce the creation of pollutants and wastes. It focuses primarily on source reduction through product changes and process changes, and secondarily, on on-site recycling methods. Off-site recycling and waste treatment are not considered to be pollution prevention in this guide.

This guide describes an approach and methodology for preparation of pollution prevention programs and identifies and analyses pollution prevention techniques and technologies that are appropriate for foundries. It is designed to serve the needs of individuals with different levels of foundry experience undertaking the preparation of a Pollution Prevention Program for a particular facility. Individuals with a good background in foundry operations and pollution prevention techniques may wish to proceed directly to Section 5 and Worksheets in the Appendices. Users are encouraged to modify the worksheets to suit their individual needs and to duplicate all or any portion of this publication as needed for the preparation of their pollution prevention programs.

PRÉFACE

La prévention de la pollution passe par l'utilisation judicieuse des matériaux, des pratiques et de l'énergie des procédés, pour éviter ou réduire l'émission de polluants ou de déchets. Elle implique d'abord la réduction à la source, par des changements de produits ou de procédés, et en second lieu des techniques de recyclage sur place. Le recyclage et le traitement des déchets hors site ne sont pas considérés ici comme des formes de prévention de la pollution.

Le présent guide décrit une approche et une méthodologie permettant de préparer des plans de prévention de la pollution, et décrit et analyse des techniques et technologies de prévention de la pollution adéquates pour des fonderies. Il est conçu pour répondre aux besoins des personnes, ayant divers degrés d'expérience des fonderies, qui doivent préparer un programme de prévention de la pollution pour une installation donnée. Les personnes qui connaissent bien les techniques de fonderie et de prévention de la pollution peuvent passer directement à la Section 5 et aux feuilles de travail fournies en annexe. On encourage les utilisateurs à adapter les feuilles de travail à leurs besoins particuliers et à reproduire toute partie de cette publication dont ils auraient besoin pour préparer leurs programmes de prévention de la pollution

ACKNOWLEDGEMENTS

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The expressed permission of the U.S. Environmental Protection Agency to use and modify portions of their various pollution prevention manuals and worksheets is acknowledged with thanks.

Preparation of this guide was financed by the Fraser Pollution Abatement Office of Environment Canada. The contractor for the study was Kent Engineering Ltd., which thanks Environment Canada's technical work group and representatives of the foundry industry in the Lower Fraser Basin of B.C. for their guidance and assistance.

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DEFINITIONS

Assessment Phase -The phase of a pollution prevention program in which facility data is collected and reviewed; the facility inspected and waste minimization options generated and selected for further study. Follows planning and organization phase.

Cross-Media Transfer - Refers to the transfer of hazardous materials and wastes from one environmental medium to another (e.g., air to water).

Environmental Management Hierarchy - The hierarchy generally recommended by pollution regulatory agencies follows this order: (1) Prevent or reduce pollution at the source wherever feasible; (2) Recycle, in an environmentally acceptable manner, pollution that cannot feasibly be prevented; (3) Treat pollution that cannot feasibly be prevented or recycled; and (4) Dispose of, or otherwise release into the environment, pollution only as a last resort.

Feasibility Analysis Phase - The point in a pollution prevention program at which screened waste reduction options are evaluated technically, economically and environmentally. The results are used to select options to be recommended for implementation. Follows assessment phase.

Hazardous Waste - Simply defined, a waste is hazardous because it contains toxic chemicals, or is ignitable, corrosive, reactive or pathogenic. In British Columbia environmental regulations, hazardous wastes are referred to as "special wastes".

Implementation Phase - The step in a pollution prevention program where procedures, training and equipment changes are put into action to reduce waste. Follows feasibility analysis phase.

Mass Balance - A method of accounting for the quantities of materials produced, consumed, used or accumulated at; released from; or transported to or from a process or facility as a waste, commercial product or byproduct.

Multimedia - Refers to all environmental media (air, land and water) to which a hazardous substance, pollutant or contaminant may be discharged, released or displaced.

Planning and Organization - The first phase of a pollution prevention program in which management commitment is obtained, the program task force organized and overall assessment goals selected.

Pollution/Pollutants - In this report, the terms "pollution" and "pollutants" refer to all non-product outputs, irrespective of any recycling or treatment that may prevent or mitigate releases to the environment.

Pollution Prevention - The use of materials, processes or practices that reduce or eliminate the creation of pollutants or wastes at the source. It includes practices that reduce the use of hazardous materials, energy, water or other resources, and practices that protect natural resources through conservation or more efficient use. In this manual this term is used interchangeably with waste minimization and waste reduction.

Pollution Prevention Assessments - Ongoing, systematic and periodic internal reviews of specific processes and operations designed to identify and provide information about opportunities to reduce the use, production and generation of toxic and hazardous materials and waste. (See Waste.)

Pollution Prevention Assessment Team - A group assembled within a facility to conduct waste reduction assessments. They are selected on the basis of their expertise and knowledge of the process operations. (The assessment team is usually assembled by and works under the direction of the pollution prevention task force.)

Pollution Prevention Task Force - Overall group responsible for instituting a pollution prevention program, for performing a preliminary assessment, and for guiding the program through the development states. (For small facilities with a low diversity of operations, the task force may also function as the pollution prevention assessment team.)

Preliminary Assessment/Pre-assessment - A facility survey performed early in the development of a pollution prevention program for the purpose of determining which areas present opportunities for pollution prevention. The information gathered during the pre-assessment may be used to prioritize sites for detailed assessment later. (However, it is not always useful or necessary to carry out these activities as a step separate from those of pollution prevention assessment.)

Reclamation - Denotes internal reuse of materials/wastes after special treatment or regeneration prior to reuse, recovery of a usable product from the material/waste or processing of the material/waste into a by-product.

NOTE: In much of the literature on foundry sands, recycling denotes internal reuse of material/waste without treatment while reclamation denotes internal reuse of material/waste with special treatment prior to reuse. Green sand foundries have been recycling sand for centuries but have not been practising, until recently, reclamation.

Recycling - Refers to on-site or internal direct reuse without prior reclamation or internal indirect reuse with prior reclamation of materials/waste.

Source Reduction - Source reduction is any practice which 1) reduces the amount of any hazardous substance, pollutant or contaminant entering any waste stream or otherwise released into the environment (including fugitive emissions) prior to recycling, treatment and disposal; and, 2) reduces the hazards to public health and the environment associated with the release of such substances, pollutants or contaminants. The term includes equipment or technology modifications, process or procedure modifications, reformulation or redesign of products, substitution of raw materials, good operating practices and improvements in housekeeping, maintenance, training or inventory control. Source reduction does not entail any form of waste management (e.g., recycling and treatment). The definition of source reduction excludes any practice which alters the physical, chemical or biological characteristics or volume of a hazardous substance, pollutant or contaminant through a process or activity which itself is not integral to and necessary for the production of a product or the providing of a service.

Special Waste - Waste which is generally termed hazardous waste are referred to as Aspecial waste@ in theBritish Columbia Special Waste Regulations. Special wastes include certain Adangerous goods@ as defined in Section 2 of the Transportation of Dangerous Goods Act (Canada) and other wastes specified in the Regulation.

Toxic Chemical Use Substitution - This term describes replacing toxic chemicals with less harmful chemicals, although relative toxicities may not be fully known. Examples would include substituting a toxic solvent in an industrial process with a chemical with lower toxicity and reformulating a product so as to decrease the use of toxic raw materials or the generation of toxic by-products.

In this manual this term also includes measures to reduce or eliminate the use in commerce of chemicals associated with health or environmental risks. Examples include the phase-out of lead in gasoline, the phasing out of the use of asbestos and the elimination of emissions of chlorofluorocarbons and halons. Some of these measures may involve substitution of less hazardous chemicals for comparable uses or the elimination of a particular process or product without direct substitution.

Toxics Use Reduction - This term refers to the activities grouped under "source reduction", where the intent is to reduce, avoid or eliminate the use of toxics in processes and/or products so as to reduce overall risks to the health of workers, consumers and the environment without shifting risks between workers, consumers or parts of the environment.

Treatment - Involves end-of-pipe destruction or detoxification of wastes from various separation/ concentration processes into harmless or less toxic substances.

Waste - In theory, the term "waste" applies to non-product outputs of processes and discarded products, irrespective of the environmental medium affected. It includes wastes that are hazardous as well as non-hazardous. More specifically, a waste includes process streams that are:

- vented to the air
- discharged to the water
- sent to landfill
- sent to an incinerator
- sent to a flare
- sent to a treatment facility

Waste Exchange - A central office in which generators who want to recycle valuable components of their waste can register the waste for off-site transfer to others.

Waste Minimization or Waste Reduction - Includes on-site source reduction and recycling. In this manual the two terms are used interchangeably with pollution prevention.

ACRONYMS

AFS - American Foundrymens Society

BC - British Columbia

BCE - British Columbia Ministry of Environmental Lands and Parks

EC - Emission Concentration

EPTox - (USEPA) Leachate Extraction Procedure Toxicity Test

kg/Mg - Kilograms per one million grams (= kilograms per tonne)

lb./ton - Pounds per ton

RCRA - Resource Conservation and Recovery Act (U.S.)

TCLP - Toxicity Characteristic Leaching Procedure

TLV - Threshold Limit Value

TSDR - Treatment, Storage, Disposal and Recycling

TWA - Time Weighted Average

USEPA - United States Environmental Protection Agency

WM - Waste Minimization

WMOA - Waste Minimization Opportunity Assessment

SUMMARY

Pollution prevention, also termed waste minimization, is the reduction to the extent feasible, of waste that is generated or subsequently treated, stored or disposed of. The highest priorities to pollution prevention are assigned to source reduction and recycling in that order. Each may be attained by a number of techniques or options shown in Figure 1-1, Page 1-3. The methodology and phases of a pollution prevention program are outlined in Figure 5-1, Page 5-2. Worksheets for conducting pollution prevention programs are appended.

Environmental concerns of foundries are air emissions, solid wastes and in the case of foundries using wet scrubbers, having electroplating facilities or in some cases using water for direct cooling or annealing, wastewater discharges. Sources of particulate air emissions in sand casting foundries are molding and core making, melting, casting shake-outs and cleaning of castings. Foundries employing chemical no-bake binders also emit gaseous emissions.

Source reduction options applicable to baghouse dust and scrubber sludge are, reduction of galvanized scrap in the charge and use of induction furnaces: an applicable recyclying option is return to original process after recovery of heavy metals, primarily zinc, lead and calmium if content is high. Source reduction options for hazardous desulphurizing slag include use of low-sulphur feed stock, use different desulphurizing agent; lessen degree of desulphurization if product specifications allow and improvement of process control: applicable recycling techniques involve removal of metal from slag for remelting and recycle of the entire slag mass to the furnace. The primary source control option for casting sands is waste segregation, i.e., not contaminating non-hazardous casting sands with hazardous casting sands. In this way spent sands from iron foundries can often be disposed of as non-hazardous waste while casting sands from the production of brass or other alloy castings may require disposal as hazardous waste. The recycling of casting sand with prior reclamation is an integral operation of the casting process in most foundries. Reclamation processes may involve reclamation of metal (eg. brass) from sand, reclamation of sand by dry scrubbing/attrition and reclamation of sand with thermal systems in the case of chemically or resin bonded sands.

Only foundries employing wet scrubbers or having captive metal finishing operations would be concerned with wastewater treatment. Pollution prevention techniques for these wastewaters may be found in other pollution prevention manuals such as for metal finishing operations. Pollution of stormwater may be prevented by storing wastes, such as spent foundry sands, in containments which prevent contact with precipitation or runoff.

Source control of fugitive emissions within the foundry building with appropriate containments is important in preventing pollution of the indoor plant air and maintaining worker health and comfort. Reduction in energy use through conservation and recovery techniques reduce production process and maintenance wastes within the foundry and air emissions. Waste minimization options are summarized in Sub-Section 4.12.

There are many advantages for minimizing the quantities of wastes by pollution prevention techniques prior to end-of-pipe treatment and discharge to the environment. They include reduced operating costs, regulatory compliance, reduced risk of liabilities associated with wastes, improved public image and employee participation and morale and reduced environmental impact. Thus, in the case of pollution prevention regulatory environmental goals coincide with industry's economic interests.

SECTION 1

INTRODUCTION

This guide is designed to provide foundries with guidance for development of pollution prevention plans for their facilities with the use of their own personnel and other corporate resources. It also provides worksheets for carrying out waste minimization assessments and feasibility analyses. It is envisioned that this guide will be used by foundries, particularly their plant operators and environmental engineers. Others who may find this document useful are regulatory agency representatives, industry suppliers and consultants.

This manual comprises the following sections:

- Introduction (Section 1)
- Foundry processes and wastes generated (Section 2)
- A profile of the foundry industry in the British Columbia Lower Fraser Basin (Section 3)
- Waste minimization options for the foundry industry (Section 4)
- Waste minimization opportunity assessment procedure (Section 5)

Appendices, containing:

- Detailed waste minimization assessment worksheets (Appendix A)
- Weighted sum method for waste minimization option rating (Appendix B)

Sections 2 and 4 are general and therefore may not be wholly relevant to foundries in the B.C. Lower Fraser Basin. The broader coverage is intended to serve the needs of the industry when considering new foundries or processes.

1.1 OVERVIEW OF POLLUTION PREVENTION

Environment Canada’s Fraser Pollution Abatement Office is responsible for delivering the pollution abatement component of the Fraser River Action Plan which has established a goal of reducing disruptive and toxic pollutants discharged to the Fraser River. In pursuit of this goal, the Fraser Pollution Abatement Office has undertaken the preparation of pollution prevention manuals to assist industry in the preparation of pollution prevention programs.

The key to pollution prevention is to undertake an ongoing comprehensive examination of the operation at a facility with the goal of minimizing the creation of all types of waste products. The National Contaminated Sites Remediation Program has indicated a priority element in pollution prevention. Those in control of activities that have the potential to pollute should prepare operational, emergency and contingency plans to prevent or control any conditions that could result in contamination of their sites. A British Columbia Ministry of Environment, Lands and Parks legislative discussion paper (BCE, 1992) recommends that the preferred order for addressing wastes is to reduce, reuse and recycle.

1.2 INCENTIVES FOR POLLUTION PREVENTION

In the case of pollution prevention, national environmental goals coincide with industry's economic interests. Pollution prevention switches the emphasis from waste treatment to waste minimization. An effective pollution prevention program generally will:

- reduce risk of criminal and civil liability;
- reduce operating costs;
- improve employee morale and participation;
- enhance company's image in the community; and
- protect employee and public health and the environment.

The savings associated with many pollution prevention 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 (TSDR) facility fees; fees and taxes on generators; transportation costs; and, permitting, reporting and recordkeeping costs.
- Raw material cost savings. Less waste translates into less 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 workplace 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. For example, installing a magnetic separation system on the shotblast system to recycle metal dust can increase the cost of electricity.

Some 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 require capital investment, but result in major reductions in operating expenses that soon pay back the investment.

1.3 APPROACHES TO WASTE MINIMIZATION

Waste minimization as defined above consists of source reduction and recycling. Of the two approaches,source reduction is usually preferable from an environmental perspective. Source reduction and recycling each are comprised of a number of practices which are illustrated in Figure 1-1. Hence, in exploring waste minimization options, source reduction should be assigned the highest priority, followed by recycling. Waste minimization techniques may not, as is usually the case, completely make waste treatment and disposal unnecessary; therefore, in the overall sense, the environmental management options hierarchy would be:

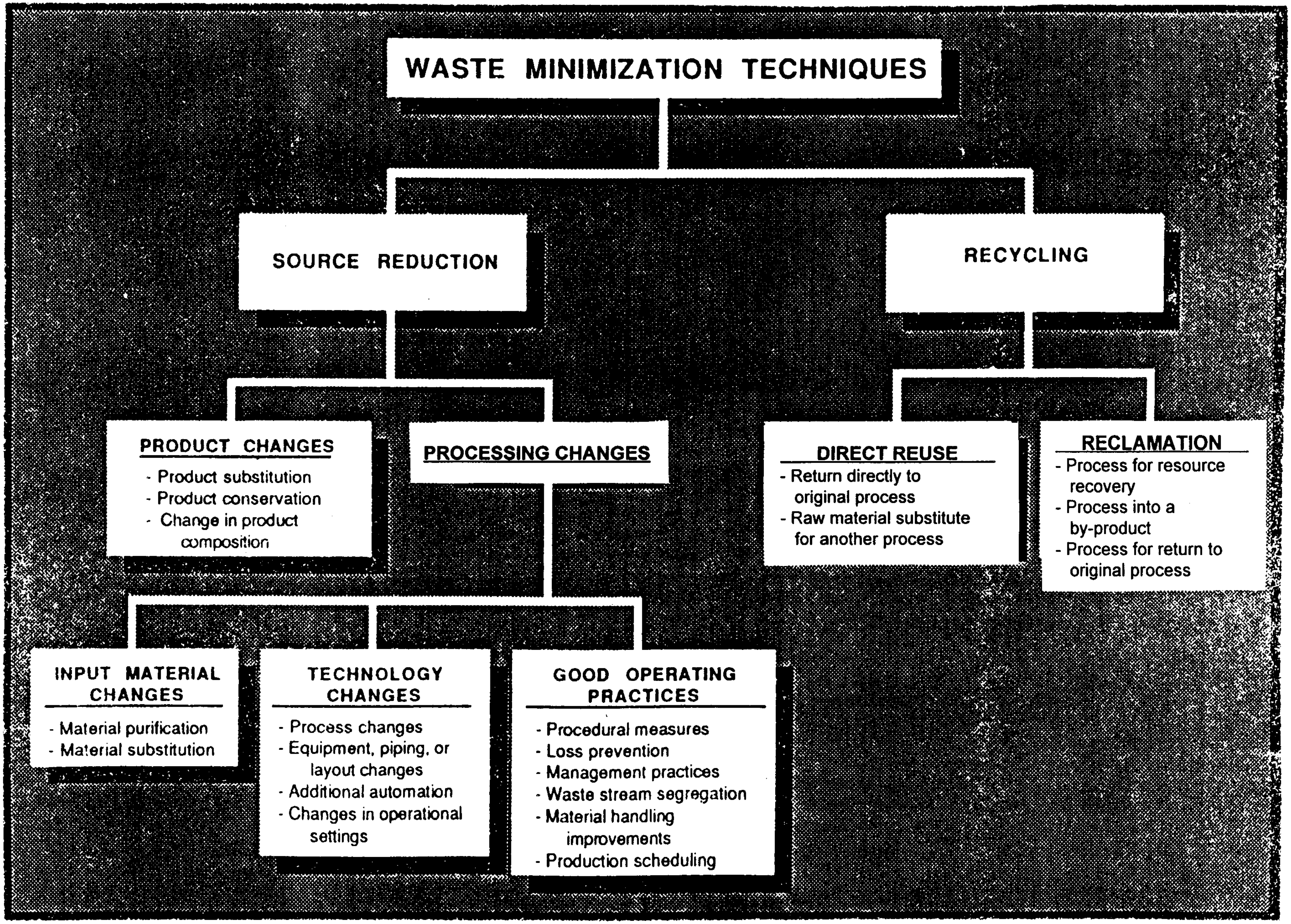


FIGURE 1-1 WASTE MINIMIZATION TECHNIQUES

- Source reduction
- Recycling (on-site)
- Off-site recycling
- Treatment (including disposal)
- Disposal (with or without treatment)

With the increasing level of environmental regulations, initial permitting costs are becoming a significant portion of capital costs for many recycling options (as well as treatment, storage, and disposal options). Many source reduction techniques have the advantage of not requiring environmental permitting in order to be implemented.

REFERENCES

USEPA 1988. *Waste Minimization Opportunity Assessment Manual*. U.S. Environmental Protection Agency. Hazardous Waste Engineering Research Laboratory, EPA/625/7-88/003. Cincinnati, OH.

BCE 1992. *New Approaches to Environmental Protection in British Columbia: A Legislative Discussion Paper*. Victoria, B.C.

SECTION 2

FOUNDRY PROCESSES AND WASTES GENERATED

2.1 INTRODUCTION

The Standard Industrial Classification system categorizes the molding and metal casting industry as foundries. Generally, only limited heat treating (which is in another Standard Industrial Classification) is performed in foundries. This guide treats foundries as distinct from other thermally intensive metal industries such as steel works, blast furnaces, coke ovens and rolling mills; primary/secondary smelting or refining of non-ferrous metals; rolling, drawing, extrusion; and forging and stamping.

Metal casting foundries generally 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. The bulk of wastes generated by foundries is from melting operations, metal pouring and disposal of spent molding materials. 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. Waste generated as a result of metal casting processes are tabled below.

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 (spent shot, grinding wheels, dust)

2.2 PROCESS DESCRIPTION

A generalized block flow diagram of the sand casting process is shown in Figure 2-1: a typical flow diagram specific for gray iron and steel foundries appears later in Figure 2-3. A sand handling system is illustrated in Figure 2-2.

The sand casting process begins with patternmaking. A pattern is a specially made model of a component to be produced. Sand is placed around the pattern in a split container, called a flask, 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.

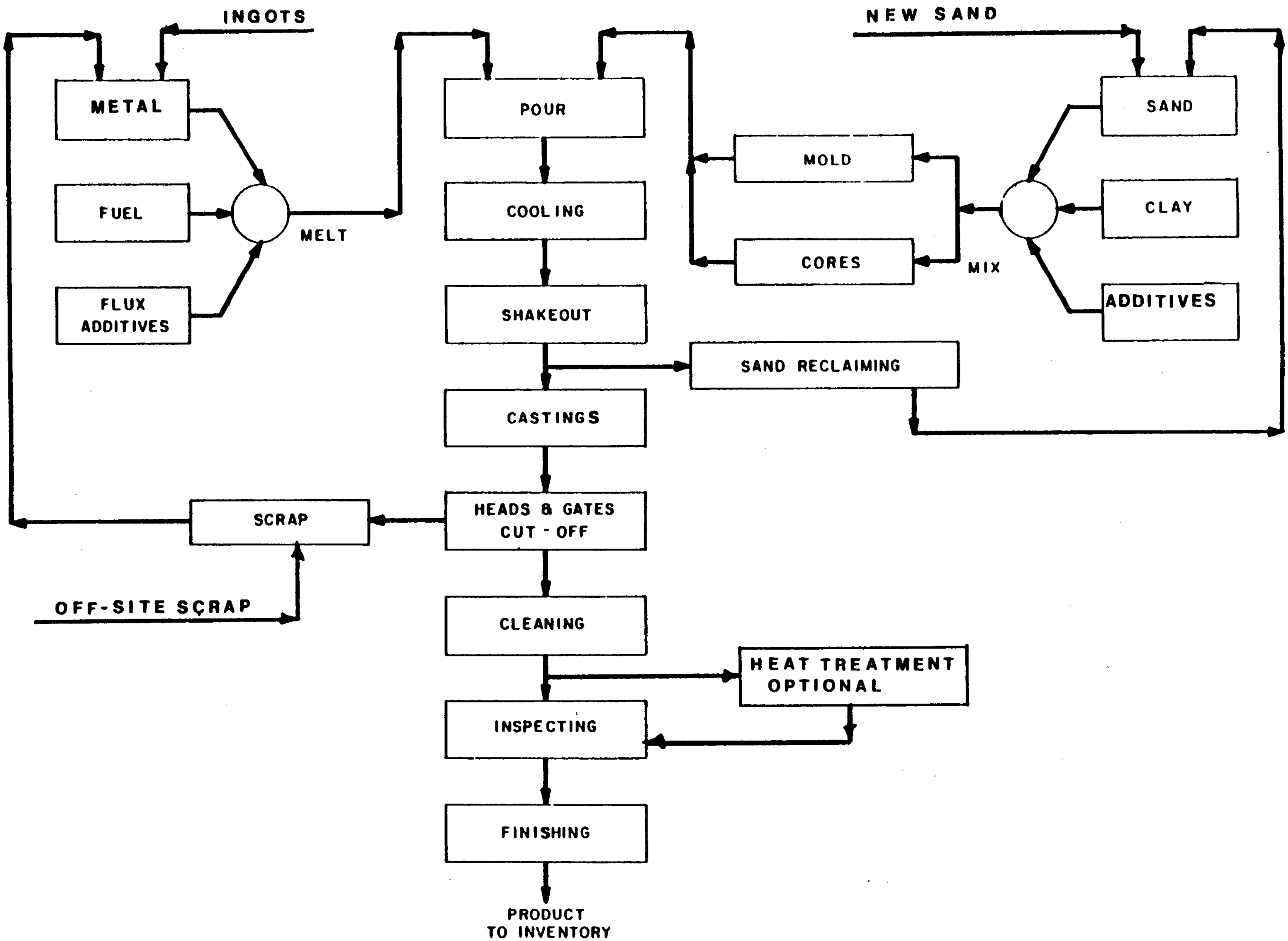


FIGURE 2-1 GENERALIZED FOUNDRY SAND CASTING PROCESS BLOCK FLOW DIAGRAM

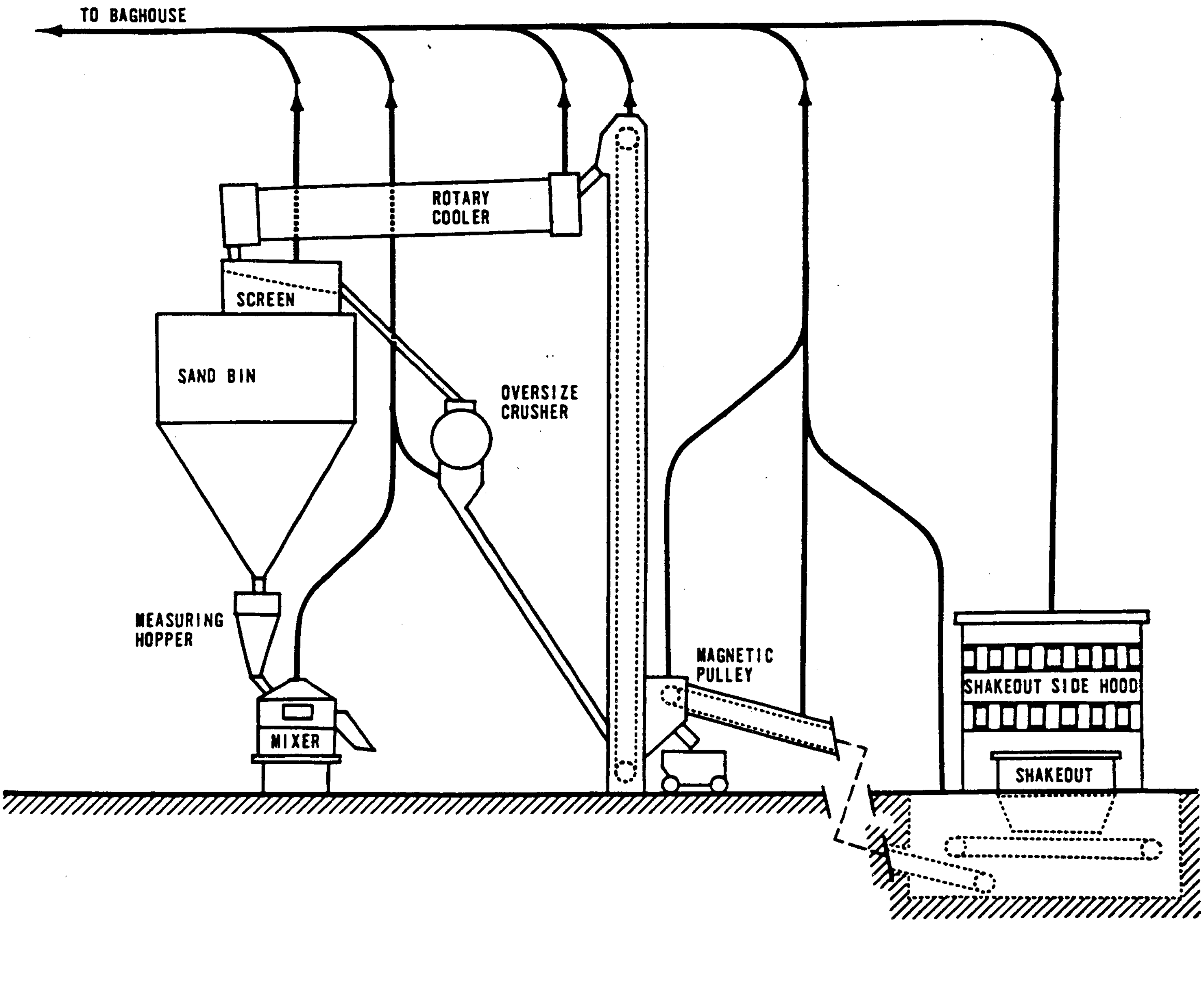


FIGURE 2-2 TYPICAL SAND HANDLING SYSTEM SCHEMATIC

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 core.

2.2.1 *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 (up 2 to 10 percent of the green sand mixture) are added 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), may be added to control sand expansion defects. In green sand molding, water activates the clay binder and is usually added in small percentages (2 to 5 percent).

In dry sand molding, free moisture is completely removed by heating in an oven. Generally a harder, stronger mold results from drying in which less mold gases are present. Thus dry sand molds may produce more dimensionally accurate castings than green sand molds and they are less susceptible to breakage, cracking and gas blows than green sand molds.

Core sands composed of mixtures of sand, with small percentages of binder, are used to produce internal configurations within a casting. Cores must be strong, hard and collapsible. Often the cores must be removed from 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 bind 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 no-bake binders are available, including:

- Furan acid catalyzed 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 percent based on sand weight. Acid catalyst levels vary between 20 to 50 percent based on the weight of binder.

- Phenolic acid catalyzed binders. These are formed in a phenol/formaldehyde condensation reaction. Strong sulfonic acids are used as catalysts.

- Ester-cured alkaline phenolic 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 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 carbon dioxide.

- Oil urethane resins. These resins consist of an alkyd oil type resin, a liquid amine/metallic catalyst and a polymeric methyl di-isocyanate.

- Phenolic urethane (PUN) binder.

- Polyol-isocyanate system (mainly for aluminum, magnesium and other light-alloy foundries). The non-ferrous 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 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 cross-linking agents.

- 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".

2.2.2 *Melting*

The foundry or metal casting process begins with melting of the metal to be poured into foundry molds. During melting, the metal may be alloyed by the addition of other metals, refined when undesirable impurities are present or innoculated to improve their final solidification structure. Cupola, electric arc, induction, hearth (reverberatory), and crucible furnaces are all used to melt metals.

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, vertical shaft furnace, in which alternate layers of metal scrap and ferroalloys, together with foundry coke and limestone or dolomite, are charged at the top. 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. 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. In time the lining must be replaced.

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. Use of the baghouse requires prior cooling of the flue gases, usually by heat exchange with ambient air.

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 non-ferrous 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 ($Si0_2$), which is classified as an acid; alumina (Al_20_3), classified as neutral; and magnesia (Mg0), 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 non-ferrous 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, more commonly, 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.

2.2.3 *Casting*

Once the molten metal has been treated to achieve the desired properties, it is tapped from the furnace and transferred to the pouring area in refractory-lined ladles. Sometimes the molten metal is poured directly from the furnace into a mold or molds without subsequent transfer by ladles. Slag is removed from the molten metal 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.

2.2.4 *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 repaired to eliminate defects by welding, brazing or soldering.

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 workplace.

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, hard-facing, hot dipping, thermal spraying, diffusion, conversion, porcelain enamelling 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 non-mechanical methods, but castings may crack if they are still hot when salt residues are rinsed off with water.

Castings are usually pickled in an acid bath prior to hot dip coating or electroplating. Over-pickling 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 vapour 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, sludge 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 castings 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.

Where coating of castings is performed by outside firms, these same firms are usually responsible for cleaning.

2.2.5 *Heat Treating*

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.

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, austempering) do not generate hazardous waste. Refractory materials (furnace lining) are the only wastes generated, and they are disposed of as non-hazardous waste.

Water is commonly used for carbon steel and gray iron quenching. A water soluble polymer is sometimes used to modify the quenching rate of a water quench. In other applications the quenching fluid may be oil, molten salt, liquid air, brine solution, etc. Quench tanks may be as simple as a vat of water or as elaborate as a well-engineered vessel equipped with means to circulate the fluid, purify the fluid and maintain the fluid at the correct temperature

Heat treating equipment found in foundries generally is confined to conventional furnaces, for operations such as stress-relieving and annealing, and water quenching baths.

2.2.6 *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. These operations are usually contracted out to outside firms.

2.2.7 *Air Emissions and Control*

Discussion of air emissions here is confined mainly to gray iron foundries and steel foundries since they are to a large degree the higher emitters of air pollutants. A typical flow diagram showing fugitive emission sources for gray iron and steel foundries is shown in Figure 2-3. Fugitive emissions are those pollutants which are uncontrolled or escape capture by hoods or canopies at the source. Emission factors for fugitive particulate emissions for gray iron foundries (roughly applicable also to steel foundries) are shown in Table 2-1. The total particulate emissions for each process are broken down to amounts emitted to the work environment and the residual amounts emitted to atmosphere. Note that the major fractions of emissions remain in the work environment.

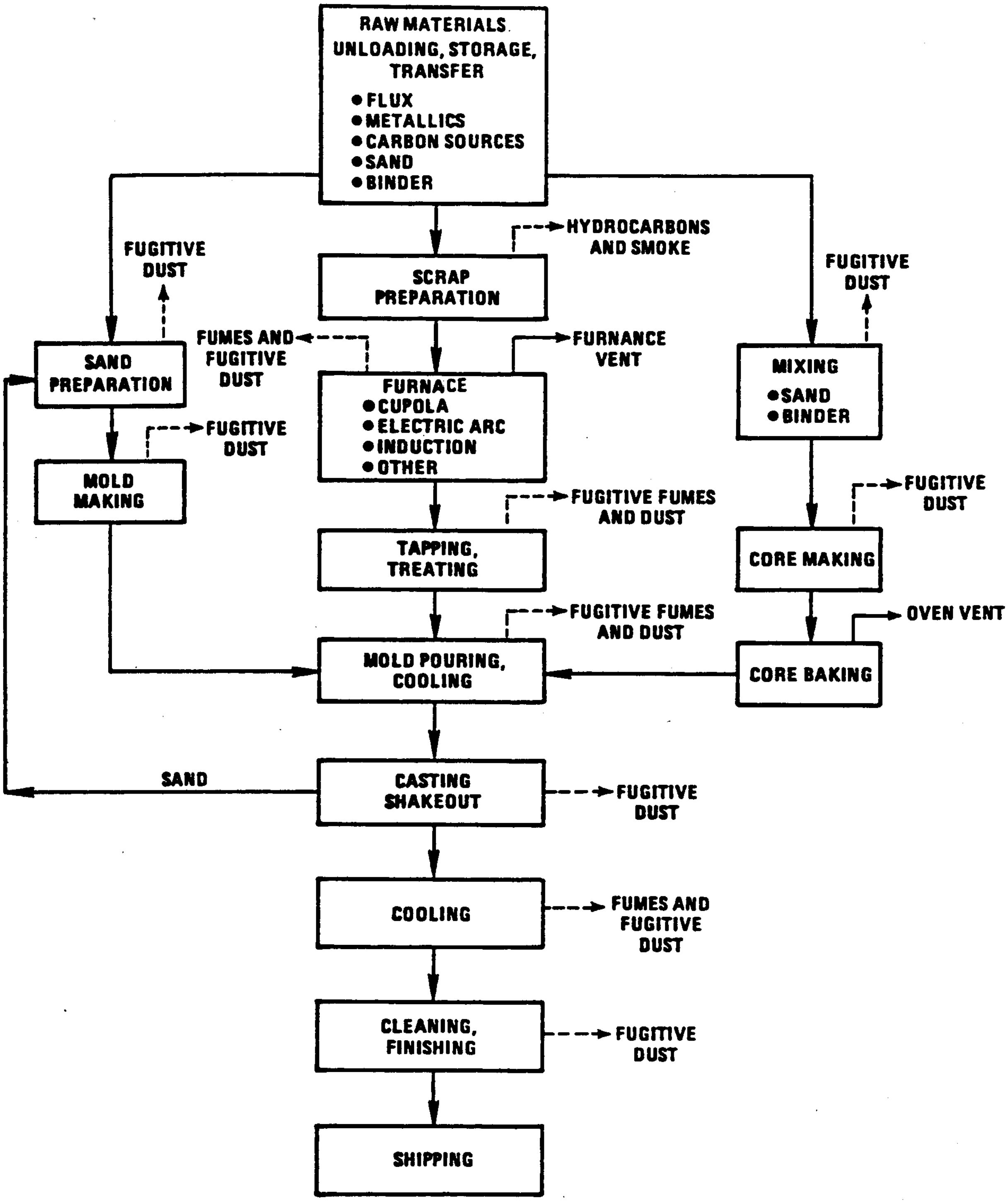
Fugitive emissions from different processes in gray iron and steel foundries and available or generally used methods of control are listed in Table 2-2. A foundry's most concentrated source of emissions is its melting operation. Fugitive emissions from furnaces occur during charging, back-charging, alloying, slag removal, oxygen lancing (in the case of steel melting furnaces), and tapping operatings when the furnace lids and doors are open. Controls for furnace emissions (non-fugitive) during the melting and refining operations when the furnace lids and doors are closed focus on venting the furnace gases and fumes directly to a collection and control system. It should be noted that the foregoing also apply to some aspects of non-ferrous foundries, particularly those using scrap as raw material feed.

Toxic gases may be emitted from the use of heat-cured and no-bake binders and the handling and storage of catalysts in molding and coremaking operations requiring containment and venting from the building. Control of the emissions may be required depending on the nature and concentration of the contaminants and regulatory agency requirements; the available control devices are scrubbers, incinerators and chemical absorption towers.

2.2.8 *Energy Use*

The highest consumption of energy in the form of electricity or natural gas occurs in the melting operation followed by heat treating furnaces. In comparison to other industries, foundries employing electric melting furnaces are very high users of electricity. Therefore, cost of electricity and optimum operation of electrical utility components within the foundry are one of the primary concerns of management.

Processes and applications within the foundry which use natural gas are melting furnaces, heat treating furnaces, ladle heating, scrap preheating or drying, supplement of energy in electrical arc furnaces, sprue and riser removal and non-process type heating applications. Important factors in energy management pertaining to natural gas include fuel-to-air ratios, excess air control, furnace pressure controls, refractories and waste heat recovery.



Note: Cupolas not applicable to steel foundries

FIGURE 2-3 FUGITIVE EMISSION POINTS FOR GRAY IRON AND STEEL FOUNDRIES (USEPA, 1985)

Process	Emissions		Emitted to Work Environment		Emitted to Atmosphere	
	kg/Mg	lb./ton	kg/Mg	lb./ton	kg/Mg	lb./ton
Scrap and Charge Handling, Heating	0.3	0.6	0.25	0.5	0.1	0.2
Magnesium Treatment	2.5	5	2.5	5	0.5	1
Innoculation	1.5 - 2.5	3 - 5	-	-	-	-
Pouring	2.5	5	2.5	5	1	2
Cooling	5	10	4.5	9	0.5	1
Shakeout	16	32	6.5	13	0.5	1
Cleaning, Finishing	8.5	17	0.15	0.3	0.05	0.1
Sand Handling, Preparation, Mulling	20	40	13	26	1.5	3
Core Making, Baking	0.6	1.1	0.6	1.1	0.6	1.1

Emissions are expressed as weight of pollutant per weight of metal melted.
kg/Mg - denotes kilograms per 1 million grams (= kilograms per tonne)

TABLE 2-1 EMISSION FACTORS FOR FUGITIVE PARTICULATES FROM GRAY IRON FOUNDRIES (USEPA, 1985)

PROCESS/SOURCE	EMISSIONS	METHOD OF CONTROL[2]
Raw materials handling	Particulates	Enclosing major emission points and routing to fabric filters or wet collectors.
Scrap preparation	Smoke, organics and CO	Catalytic incinerators and afterburners
Melting Furnaces	Particulates, CO, organics, sulphur dioxide, nitrogen oxides and small quantities of chlorides and fluorides	Roof hoods or special hoods in proximity of furnace doors and tapping ladles to capture emissions and route them to control systems such as bagfilters and venturi scrubbers
Mold and Core Production	Particulates, organics and CO from core baking, organics from mold drying	Baghouses and venturi scrubbers to control particulates. Catalytic incinerators and after-burners to control organics and CO
Casting Operations (Including Shakeout and Cooling)	Particulates, fumes, CO, organics	Baghouses and venturi scrubbers to control particulates
Finishing	Large particulates	Cyclones

(1) Summarized from (USEPA, 1985)
(2) Each method of control includes appropriate hoods or canopies to capture emissions at the source and ducting to convey the emissions to the control device.

TABLE 2-2 FUGITIVE EMISSIONS FROM GRAY IRON AND STEEL FOUNDRIES AND METHODS OF CONTROL[1]

2.3 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 (spent shot, grinding wheels, dust)
- Dust collector and scrubber waste
- Slag
- Miscellaneous waste.

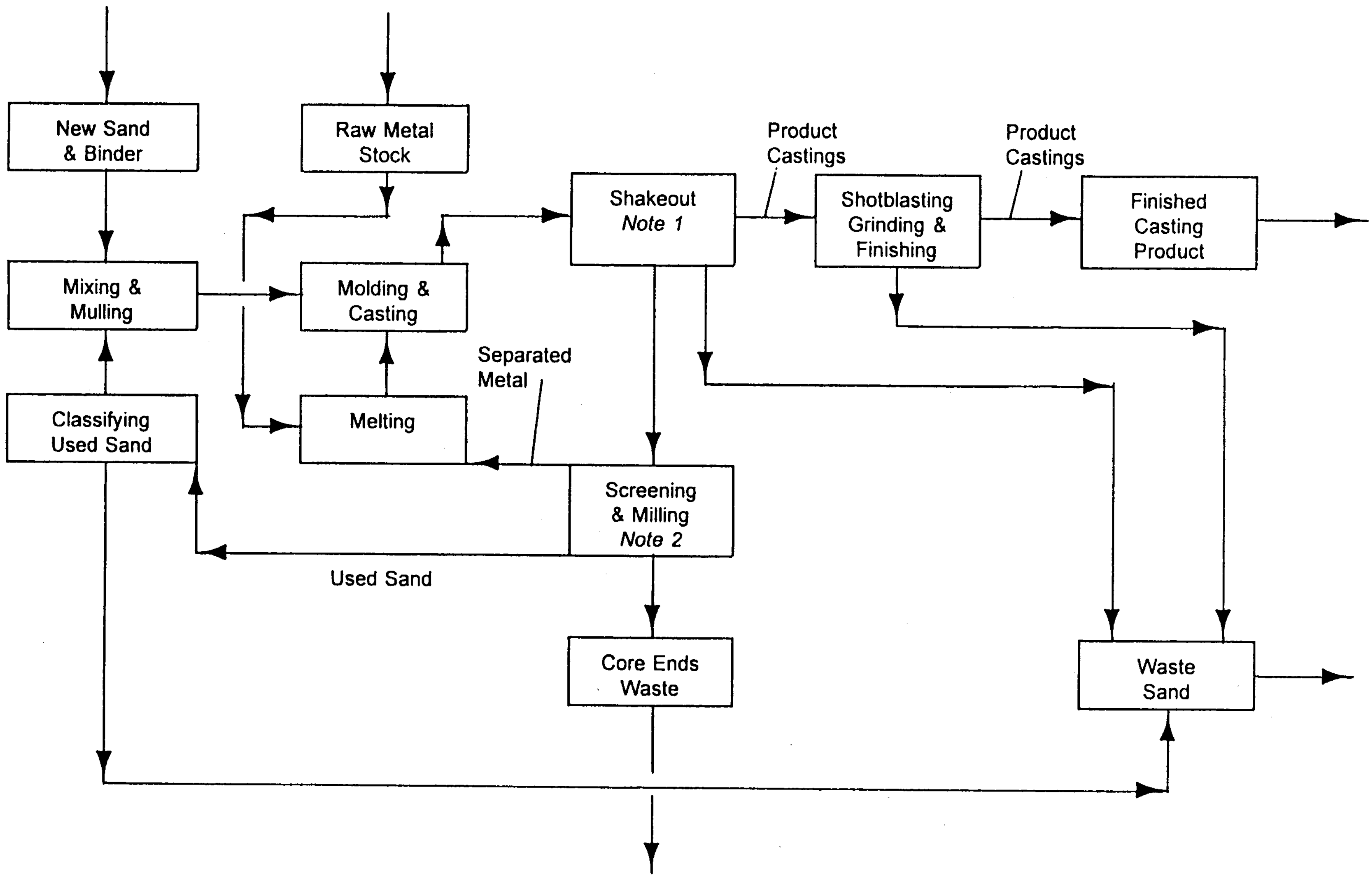
2.3.1 *Spent Foundry Sand*

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 2-4 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 are either partially or completely degraded 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 account 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 off-gases from the core making process. In the free radical cure process, acrylic-epoxy binders are cured using an organic hydroperoxide and sulphur dioxide (SO_2) gas. A wet scrubbing unit is used to absorb 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 sulphite) from precipitating out of solution. Usually, pH-controlled scrubber sludges are discharged to the sewer system as non-hazardous waste. If not properly treated, the waste may be classified as hazardous corrosive waste.



Note 1: Removal of molding sand from castings
Note 2: Break-up of large mold chunks and separation of metal pieces

FIGURE 2-4 PRIMARY SOURCES OF WASTE SAND

2.3.2 *Investment Casting Waste*

Investment casting shells can be used only once and are disposed of in landfills as a non-hazardous 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.

2.3.3 *Cleaning Room Waste*

Cleaning room waste that is ultimately disposed of 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.

2.3.4 *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 may contain 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 non-ferrous metal production may contain copper, aluminum, lead, tin and zinc. Steel dust may be encapsulated and disposed of in a permitted landfill, while non-ferrous dust is often sent to a recycler for recovery of metal.

2.3.5 *Slag Waste*

Slag is a 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 also 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 sulphur content of iron, some foundries use calcium carbide desulphurization in the production of ductile iron. The calcium carbide desulphurization slag generated by this process may be classified as a reactive waste.

2.3.6 *Wastewaters*

Cooling water, such as that from cooling of induction furnaces, is usually discharged to a storm sewer system without treatment. Most foundries generate little or no process wastewater. Water quenching baths, if employed, when purged or discarded, may require treatment depending on the nature of contaminants and regulations governing discharges. Stormwater, if uncontaminated by contact with waste materials, such as spent foundry sand, usually can be discharged directly to municipal storm sewers.

2.3.7 *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.

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USEPA 1992. *Guides to Pollution Prevention: Metal Casting and Heat Treating Industry*. Office of Research and Development, Washington, DC 20460, EPA/625/R-92/009.

SECTION 3

PROFILE OF THE FOUNDRY INDUSTRY IN THE LOWER FRASER BASIN OF BRITISH COLUMBIA

3.1 BACKGROUND

In the early development of B.C.'s industrial history, centred on the logging, fishing, mining and marine industries, foundry castings were imported from the U.S., Britain and Eastern Canada. Because of the long shipping distances and long delivery times, it was not long before the first rudiments of a foundry industry began as all of the industries needed some metal product(s) cast in a foundry. The first foundry was probably started in 1858 in Victoria which, at that time, became a supply centre and jumping-off point for the Fraser River and Cariboo gold rushes. By 1882-1883, the B.C. Directory for the period listed a number of foundries operating in the Victoria area. The growth of Vancouver after the arrival of the trans-continental railway in 1886 and the development of the required municipal infrastructure created a large demand for foundry castings. Vancouver's first foundries were started just prior to that time as part of firms manufacturing machinery for the fish canning, sawmilling, mining and other industries. By 1892 the growth of the mining industry saw the establishment of foundries at Nelson and Trail. The mechanization of the forest industry and start of the pulping industry around 1910, followed by World War I, gave great impetus to the growth of the foundry and machinery manufacturing industries in B.C. After a severe downturn during the Great Depression, World War II returned prosperity to the industry along with diversification and technological advances. A time of mergers, collapses and new beginnings followed the end of World War II and the number of foundries dwindled during the 1960s and beyond. With strong competition from newly industrialized countries with low-paid workforces and more stringent pollution standards in B.C., the number of foundries decreased. During 1995 about 500 people were employed in the foundry industry in B.C. (Bromley, 1995).

3.2 FOUNDRY TYPES AND DISTRIBUTION

There were nine non-ferrous foundries and nine ferrous foundries for the Lower Fraser Basin listed in the yellow pages of the 1995-96 Vancouver Telephone Directory. In addition, about five foundries, primarily small non-ferrous foundries in manufacturing and vocational training, were identified. Most of the non-ferrous foundries, with the exception of two being located in Langley and Surrey, are located in the Greater Vancouver area. All ferrous foundries, with the exception of one located in Vancouver and one located in Port Coquitlam, are located in Surrey.

Looking at the whole of B.C., there is one iron foundry in Penticton, and a non-ferrous foundry in Roberts Creek. Closely allied to non-ferrous foundry operations is a secondary smelter located in Surrey.

3.3 RAW MATERIALS AND PRODUCTS CAST

3.3.1 *Non-Ferrous Foundries*

Non-ferrous foundries cast a variety of metals and alloys, including brass, bronze, aluminum, magnesium and a variety of alloys. Raw metal is primarily in the form of metal and alloy ingots with any further treating or alloying occurring in the melting furnace. The use of ingots, as opposed to scrap, as feed, keeps emissions from the melting furnace at a low level.

The majority of non-ferrous foundries are jobbing shops producing a range of product castings such as fire-fighting equipment fittings, propellers, marine and fishing equipment, bushings, valves, ornaments, plaques and artwork. Some shops have contracts for ongoing production of the same products for a production baseline. The size of castings for the industry ranges from a few kilograms to 5 tonnes.

3.3.2 *Ferrous Foundries*

Ferrous foundries in the Lower Fraser Basin cast gray, ductile and cast irons and carbon and alloyed steels, including stainless steels. Raw metal feed comprises pig iron ingots, steel ingots, ingots of different alloying metals, and iron, steel and other metal scrap. The majority of iron and steel scrap is not of the clean variety which can give rise to dust and hydrocarbon emissions during handling of the scrap and charging of the furnace.

While the majority of steel and iron foundries engage in general jobbing, three foundries are known to have a base product line primarily in waterworks fittings, alloyed steel products for the mining industry, wire rope fittings, manhole frames and covers, and pipe fittings. One large foundry engages mainly in the production of alloyed steel castings for the mining, pulp and paper and forestry industries and for items of equipment such as pumps. Within the industry, castings of up to 9 tonnes in weight can be made.

3.4 FOUNDRY OPERATIONS AND EQUIPMENT

Operations and equipment found in the Lower Fraser Basin foundries include most of those described in Section 2.

Natural gas fired crucible and electric induction melting furnaces predominate in non-ferrous foundries although some foundries also employ gas-fired reverberatory furnaces. Electric induction furnaces are found in most ferrous foundries: two foundries employ electric arc furnaces and one foundry employs a cupola for melting operations. Pouring, cooling and shakeout of molds are, in most cases, batch operations because of the variety or size of the articles cast. A few foundries, casting a large number of small articles, employ a conveyor system enabling more or less continuous pouring, cooling and shakeout operations.

Silica, olivine and zircon sands are used for molding and core making. The most common type of molding process found in nearly all foundries is green sand molding which uses clay as a binder. The sand binders in cores are oil binders or, more commonly, synthetic binders of the no-bake type. In the green sand molding process the sand is reused after screening for removal of clay and fine sand.

Coremaking sands are either discarded or routed to the green sand molding process. More recently the recycling of core sands is being considered by at least two of the ferrous foundries.

Mechanical cleaning methods, such as blast cleaning employing steel shot or grit, are found in most foundries. Any further or special cleaning for application of coatings, including electroplating, is usually done off-site by coating applicators. Coal tar epoxy coating of municipal waterworks and sewerage fittings by dipping and painting occurs on-site within the foundry.

The general condition of foundries in the Lower Fraser Basin ranges from ferrous foundries that in outward appearances are not much different from a foundry of 50 years vintage, to non-ferrous foundries that resemble modern manufacturing plants. This contrast arises from the nature and scale of operations and not management policies. Ferrous foundries melt higher tonnages of metal (much of which comes from scrap), cast heavier articles, use larger volumes of sand and the plant floor is subjected to use by heavy mobile equipment for handling the castings. Consequently, improvements in housekeeping and modernization are more difficult to accomplish in ferrous foundries than in non-ferrous foundries.

Heat treating is done in natural gas fired ovens without recuperation of waste heat for possible uses such as preheating of combustion air, space heating or heating of make-up air for exhaust systems. Possible reasons may be economics, indoor space not being heated or the availability of recovered heat not being coincident with possible use.

3.5 WASTE MANAGEMENT

3.5.1 *Air Emissions*

Control of air emissions is generally the major environmental problem associated with foundries, followed by solid wastes such as spent sands, slag, baghouse dusts and cleaning room wastes. Baghouses, often preceded by cylones, are used by foundries throughout the Lower Fraser Basin for collection of dusts and fumes. Each operation usually has a dedicated collection and control system for segregation of dusts of different characteristics thus avoiding any cross-contamination and increasing the volume of contaminated waste. The management of baghouse wastes is discussed in the following sub-section.

The permitting of air emissions is under the jurisdiction of the Greater Vancouver Regional District. An examination of air emissions permits issued indicates that the foundries are generally in compliance with standards set out in their permits for particulate and gaseous emissions. Thus far, gaseous emissions, primarily from coremaking and, in some instances from molding operations, are within the standard limitations and are being met without controls which for the application would be scrubbers or absorption towers.

Dedicated air emission control systems are usually employed for furnaces, shakeouts and cleaning operations. In the case of furnaces, they are effective when the furnace lids are closed. However, when the furnace lids are open during charging, backcharging, alloying, slagging and tapping, when the highest concentrations of furnace emissions occur, these largely escape into the building atmosphere. Complete capture of particulate emissions at shakeouts is difficult due to operational constraints on hood design. Fugitive emissions from the above and other sources, such as handling of raw materials, cooling of castings and handling and mixing of chemical and resin binders (see Figure 2-3), result in high levels of air contamination in the vicinity of the source and sometimes all of the foundry building space. Since the mission of pollution prevention is to reduce wastes at the source and to protect both the environment and human health, effective capture of air pollutants at their source and, more generally, building ventilation should receive due attention in the foundry's pollution prevention program. The task is a difficult one calling for both expertise and ingenuity and therefore improvement targets should not, at the offset at least, be set too high.

Of interest to foundries should be the U.S. Foundry of the Future Project sponsored by the Casting Emission Reduction Program (CERP) designed to help foundries find more cost-effective and practical ways to comply with environmental regulations (Holic and Philbin, 1995). It is also designed to improve and/or develop materials and processes in foundry technology to allow the metal casting industry to be competitive while working to achieve a zero effect on the environment. The motivation behind this project is the 1990 Clean Air Act Amendments (CAAA) which may force foundries in the U.S. to close or move offshore by 2000 due to the high cost of regulatory compliance. A pilot foundry is being built at McClellan Air Force Base to study foundry air emissions. The foundry will model foundry air emissions and carry out a wide range of emission measurements and evaluations. The pilot foundry will use green sand molding to produce cast iron engine blocks as a test part. The foundry will also have aluminum and ductile iron capability and full process control and source monitoring. The CERP initiative includes the characterization, validation and analysis of existing foundry emission data; the identification of data gaps and collection of that data at foundries; correlation of hazardous air pollutants to sources; construction of an emissions database; and the ranking and prioritization of emissions sources for process modification. The processes to be tested include melting, post-melting treatment, metal transfer, pouring, cooling, shakeout, cleaning and finishing, sand preparation, mold making, mold coating, coremaking/coating/drying, core storage and material storage and handling. This should be a most interesting and timely project to watch. The foundry of the future will undoubtedly focus on pollution prevention of both indoor and outdoor atmospheres.

3.5.2 *Solid Wastes*

Green sand fines and spent sand from ferrous foundries are stored on foundry sites for periodic disposal or awaiting disposal. The storage areas on the whole do not have any provisions for preventing contact with precipitation or for the containment of runoff. Small users of sand, particularly non-ferrous foundries, dispose of waste sand through contract disposal firms.

Solid waste management practices by Lower Fraser Basin foundries are listed below:

Waste and Source	Waste Management Practices
Spent molding green sand	Off-site reuse by concrete mix manufacturer On-site landfill On-site storage Contract disposal
Spent coremaking sand	Recycle to green sand molding and ultimately dispose as spent green sand Contract disposal
Baghouse dust (from melting furnace)	Recycle to original or other melting furnace Contract disposal
Baghouse dust (from molding and coremaking)	Recycle to original process Dispose of as spent molding green sand Contract disposal
Melting furnace slag	Off-site reuse by concrete mix manufacturer Recycle metal values On-site storage Contract disposal
Machining wastes	Reuse in melting furnace Sell to scrap dealer Contract disposal
Shot blast grit from cleaning	Off-site reuse by concrete mix manufacturer Contract disposal
Cleaning room and miscellaneous wastes	Municipal landfill if uncontaminated by heavy metals, otherwise contract disposal

A group of foundries in the Lower Fraser Basin had a consultant carry out a study in 1995 on available alternate means of managing solid wastes, particularly spent foundry sand. As a result, some foundries are evaluating results and recommendations of the study particularly with regard to the management of the large volumes of spent green sand from ferrous foundries. Non-ferrous foundries do not have all of the above listed waste management alternatives available to them when the wastes are contaminated with heavy metals and must be treated as special wastes. A discussion of possible reuses for spent foundry sands is found in Section 4.

3.5.3 *Wastewaters*

Uncontaminated cooling water is usually discharged to municipal storm sewers or ditches. Some foundries employ static water quench tanks. The frequency of static quench tank dumps, quench water characteristics when dumped, and receiving facility or medium are unknown. One foundry has a permit for the discharge of process wastewater to a ditch after clarification and oil separation.

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SECTION 4

WASTE MINIMIZATION OPTIONS FOR FOUNDRIES

4.1 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; and
- ! 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 from both 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 may find the use of mass balances around their facilities and processes helpful in identifying areas where waste is occurring, perhaps unknowingly. The use of good process control procedures often leads to increased process efficiency.

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.

The pollution prevention options presented below for the foundry industry include source reduction and recycling. The options presented are for foundries in general and hence all may not necessarily be relevant or applicable to foundries in the Lower Fraser Basin (e.g., options for scrubbers).

4.2 SOURCE REDUCTION OPTIONS FOR BAGHOUSE DUST AND SCRUBBER WASTE

4.2.1 *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 should be identified and charge material containing lower concentrations of the contaminants acquired. A charge modification program at a large foundry can successfully reduce the lead and cadmium levels in dust collector waste to below EPTox values (Stephens et al.,1988). Foundries should work closely with steel scrap suppliers to develop reliable sources of high-grade scrap.

4.2.2 *Install Induction Furnaces*

Electric 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, energy use efficiency 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).

Emission factors for uncontrolled furnaces for gray iron and steel foundries are tabled below (USEPA, 1985):

Furnace Type	**Gray Iron Foundry**		**Steel Foundry**	
	kg/Mg	lb./ton	kg/Mg	lb./ton
Cupola	8.5	17		
Electric Arc	5	10	6.5	13
Electric Induction	0.75	1.5	0.05	0.1
Reverberatory	1	2		
kg/Mg - denotes kilograms per 1 million grams (= kg/tonne)				

4.3 RECYCLING OPTIONS FOR BAGHOUSE DUST AND SCRUBBER WASTE

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

4.3.1 *Recycle to the Original Process*

Electric arc furnaces generate 1 to 2 percent of their charge into dust or fumes (Chaubal et al.,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 if a high percentage galvanized metal scrap is used as the recovered dust tends to be high in zinc.

Many methods have been proposed for flue-dust recycling, including direct zinc recovery (Morris et al.,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.

4.3.2 *Off-Site Recycle by Reclamation of Metals*

Although this route is not considered as being a pollution prevention measure, it is mentioned here as it is a preferred route to treatment and/or disposal in a secure landfill.

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 might be useful in the non-ferrous foundry industry (e.g., brass foundries), its application within gray iron foundries is not practical. Some foundries market furnace dust as input to brick manufacturing and other consumer product applications, but product liability limits this option. Promising processes for zinc recovery are examined in (Morris et al.,1985).

4.3.3 *Off-Site Recycle to Cement Manufacturer*

Silica-based baghouse dust from sand systems and cupola furnaces may be used as a raw material by cement companies (Kelley, 1989; AFS, 1989). The dust is sent into a primary crusher and then pre-blended with other com-ponents 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.

4.4 SOURCE REDUCTION OPTIONS FOR HAZARDOUS DESULPHURIZING SLAG

In the production of ductile iron, it is sometimes necessary to add a desulphurizing agent in the melt to produce the desired casting microstructure. One desulphurization agent commonly used is solid calcium carbide (CaC_2). Calcium carbide is thought to decompose to calcium and graphite. The calcium carbide desulphurization slag is generally removed from the molten iron in the ladle and placed into a hopper. For adequate sulphur 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 sulphur, 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 et al.,1985). Problems with this method include handling a potentially explosive waste material; generating a waste stream that contains sulphides (due to calcium sulphide in the slag) and many other toxic compounds; and liberating arsine, phosphine and other toxic materials in the off-gas.

4.4.1 *Alter Feed Stock*

Once way to reduce the need for calcium carbide is to reduce the amount of high sulphur 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 favour a different solution (Stephens et al., 1988).

4.4.2 *Alter Desulphurization Agent*

To eliminate the use of calcium carbide, several major foundries have investigated the use of alternative desulphurization agents (Stephens et al.,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 desulphurization.

4.4.3 *Alter Product Requirements*

Often, the specifications for a product are based not on the requirements of that product but on what is achievable in practice. When total sulphur 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 desulphurized only to the extent actually needed, much of this waste could be reduced or eliminated (Stephens et al.,1988).

4.4.4 *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 et al.,1988). Very fine granules, coated granules, and solid rods of calcium carbide have been investigated as ways of controlling the reaction more closely.

4.5 RECYCLING OPTIONS FOR HAZARDOUS DESULPHURIZING SLAG

4.5.1 *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 et al.,1988). Inside the furnace, calcium hydroxide forms in the slag as the recycled calcium carbide either removes additional sulphur 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 sulphide stays with the slag or how much sulphur is carried in the flue gas to the scrubber system. Initial tests indicate that the sulphur does not concentrate in the metal, so that product quality is not affected.

4.5.2 *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 in a gray iron production. The cupola furnace slag scavenges trace metals from the induction furnace slag. The resulting cupola slag may be rendered a non-hazardous waste due to lower toxic metal concentrations.

4.6 SOURCE REDUCTION OPTIONS FOR SPENT FOUNDRY SAND

In most foundries, casting sands are recycled internally until they can no longer be used. Then, many of the sands, such as those from iron foundries, usually can be landfilled as non-hazardous 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.

4.6.1 *Waste Segregation*

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

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

- Modifying 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 shot blast 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.

4.7 RECYCLING OPTIONS FOR SPENT FOUNDRY SAND

4.7.1 *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 on 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.

One red brass foundry reports that the material separated from the sand in the screening system is recycled in a ball mill (AFS, 1989). 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.

4.7.2 *Reclaim Metal and Sand*

A process for reclaiming metal and sand in brass foundries is shown in Figure 4-1 (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 Pittsburgh Mineral Environmental Technology, the chemical treatment step decreases the EPTox 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 non-hazardous and may have saleable value.

4.7.3 *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, illustrated in Figure 4-2, 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.

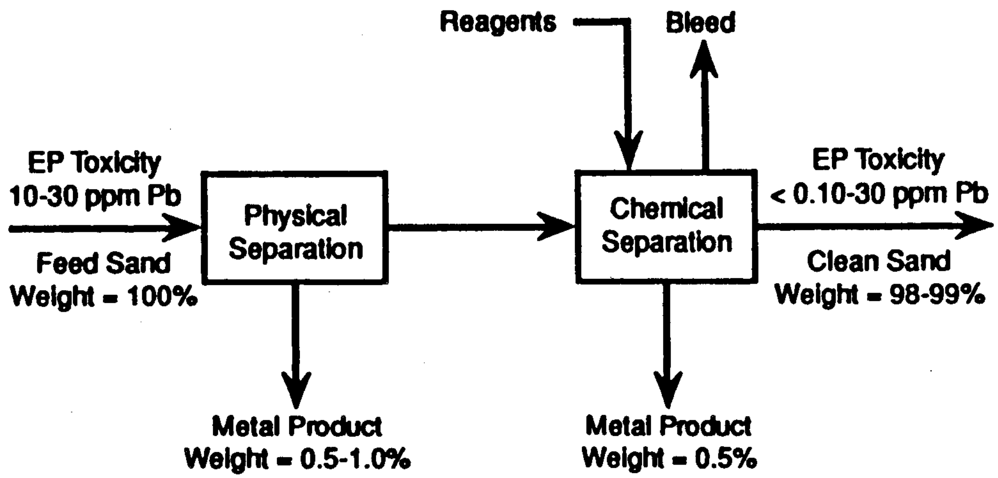
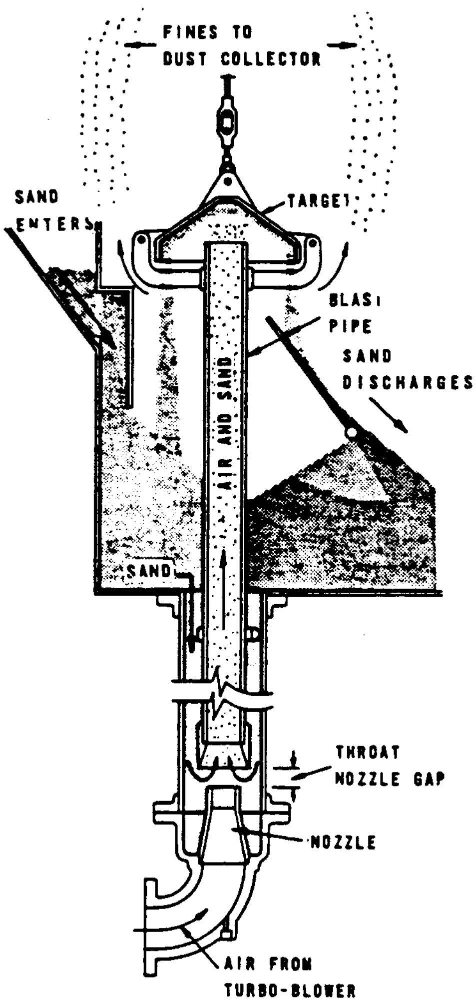


FIGURE 4-1 SIMPLIFIED PROCESS FLOW DIAGRAM FOR SAND TREATMENT IN BRASS FOUNDRIES (from AFS, 1989)



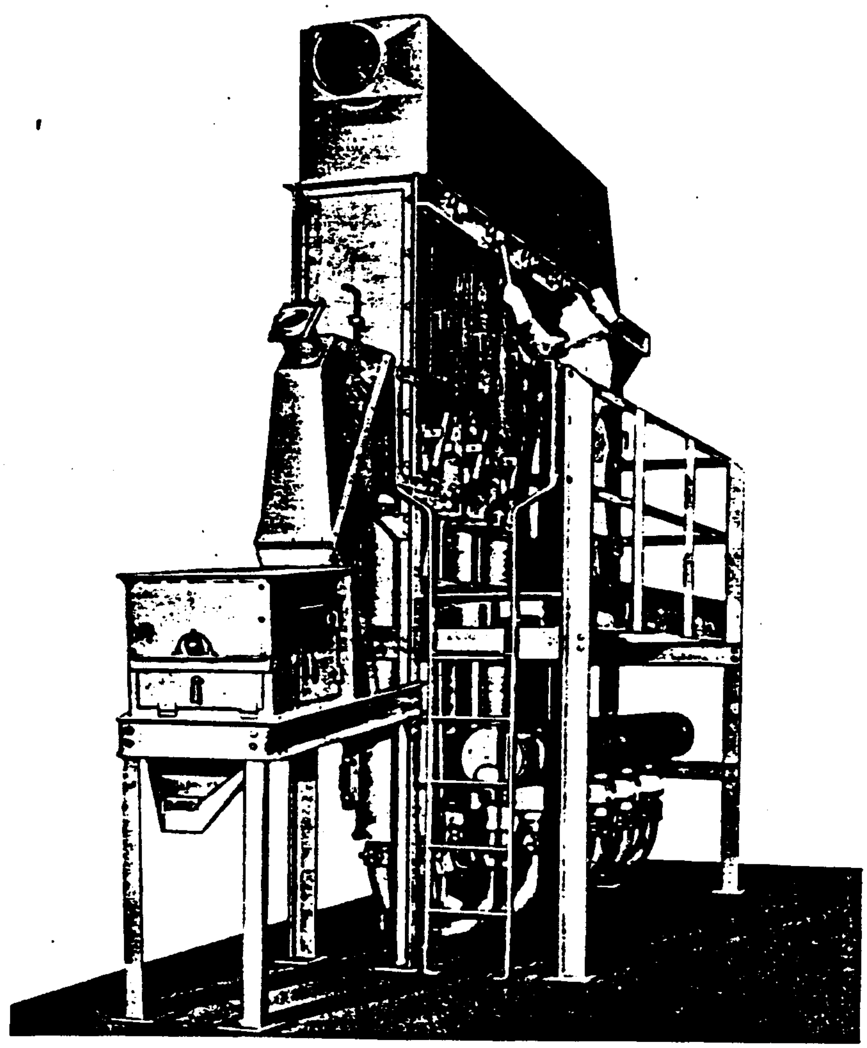


FIGURE 4-2 PNEUMATIAC SAND SCRUBBER
(National Engineering Co., Chicago, Ill.)

4.7.4 *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 practised on a limited basis in Japan for the past 20 years and was being re-evaluated 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).

1. 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 (renders powdery) 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.

2. 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; combustion gas 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.

3. Multiple-Hearth Vertical Shaft Furnace. In this system the 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 centre 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 centre 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 are continuing to evolve, and foundries must evaluate each system carefully with regard to the suitability for a particular foundry operation.

4.7.5 *Off-site Recycle by Re-use as a Construction Material*

Although this route is not considered as being a pollution prevention measure, it is mentioned here as it is a preferred route to disposal in a municipal waste landfill.

Non-hazardous foundry waste has been used in municipal waste landfills as a supplement for daily earth cover (Smith et al., 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 et al.,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, provincial and local regulations regarding its handling, storage and disposal. 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 and Martin, 1986; Traeger, 1987; and Wellander, 1988). Toxicity characteristic leaching procedure (TCLP) and AFS leaching potentials for inorganics and non-volatile 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 the U.S. 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 these 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 in the U.S. are re-examining their existing solid waste regulations to create special waste categories that will allow non-hazardous materials such as spent foundry sand to be reused beneficially for landfill construction, daily landfill 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 and 1984) has yielded similar findings. The Ministry of Transport for the province of Ontario has been using spent foundry sand in asphalt mixes since the early 1980s with no deleterious effects, other than a slightly altered surface appearance (OMEE & CFA, 1993).

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 and 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 plant in Davenport, Iowa, where a local foundry sends over 100 cubic yards of waste daily (AFS, 1989) and in Ontario (OMEE & CFA, 1993).

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.

4.8 SOURCE REDUCTION OPTIONS FOR FUGITIVE EMISSIONS

A control system for air emissions comprises a hood or canopy enclosing the emission source or other means of capturing fugitive emissions, ducting to convey the emissions to the control device, and the control device itself. As described in sub-section 2.2.7, fugitive emissions arise from controlled and uncontrolled sources. Figure 2-3 shows fugitive emission points for gray iron and steel foundries: Table 2-2 lists the emissions and methods of control. Since these fugitive emissions occur within the confines of the foundry building (which is usually vented to the atmosphere) within which the major fraction of particulate pollutants are held with a lesser fraction escaping to the atmosphere (see Table 2-1), such emissions have the potential to impact adversely on worker health and the environment. Although venting the building space via a control device may eliminate any adverse effects on the environment, the question of potential adverse effects on worker health would remain. Venting and controlling emission from the total building space to maintain a healthy and comfortable atmosphere within the building is both impractical and ineffective due to the size and cost of the control system needed to handle and remove pollutants from the large volumes of air. The point being made here is that no matter how fugitive emissions are vented to the atmosphere, unless fugitive emissions are effectively captured at the source, adverse impacts on the building work space environment will remain. For the above reasons, source control of fugitive emissions with appropriate containments is an important aspect of air pollution prevention in foundries. Each foundry should assess the fugitive emission situation at a particular site and arrive at the best suited means of effective control. Helpful references for designof source capture systems for fugitive emissions are:

USEPA. 1973. Air Pollution Engineering Manual 2nd Edition. EPA Research Triangle Park, North Carolina. Publication No. AP-40.

American Conference of Governmental Hygienists. 1995. Industrial Ventilation, A Manual of Recommended Practice. 1995. Lansing, Michigan.

AFS. 1985. Foundry Ventilation Manual. AFS Publication Sales, Des Plaines, Illinois.

AFS. 1993. Health and Safety Guides. AFS Publication Sales, Des Plaines, Illinois.

4.9 ENERGY USE REDUCTION OPTIONS

An AFS publication (AFS, 1982) provides a detailed treatment of foundry energy management. This section provides only a brief outline of some energy use reduction options.

1. Electrical Energy - Energy conservation in arc melting furnaces, the highest consumer of electrical energy in the foundry, is closely tied to power distribution, power demand regulation, power factor correction and, most important, operating practice itself.

Conventional induction furnace designs call for a copper-tube induction coil that can be filled with water for cooling while conducting electric current. Due to the high heat loss through the top and bottom of the melt, most of the energy transmitted through these parts of the coil is wasted. However, the coil is still needed at the top and bottom for cooling because the risk of penetration is greatest in these parts of the crucible. To solve this problem, Ajax Magnethermic Europe Ltd. of Oxted, U.K., developed a three-part induction coil consisting of a power coil in the middle along with top and bottom cooling coils (Figure 4-3). The Ajax coil only transmits energy through the power coil, made of copper, while the top and bottom cooling coils, made of non-magnetic austenitic nickel-bearing stainless steel, protect the crucible. The stainless steel coils, apart from their corrosion resistance, improve melting efficiency in terms of kilowatt-hours per tonne of molten metal by up to 5 percent (Rohrig, 1996).

2. Natural Gas - The efficiency of use of natural gas in a foundry is typically about 20 percent. Natural gas use efficiency can be improved by the following:

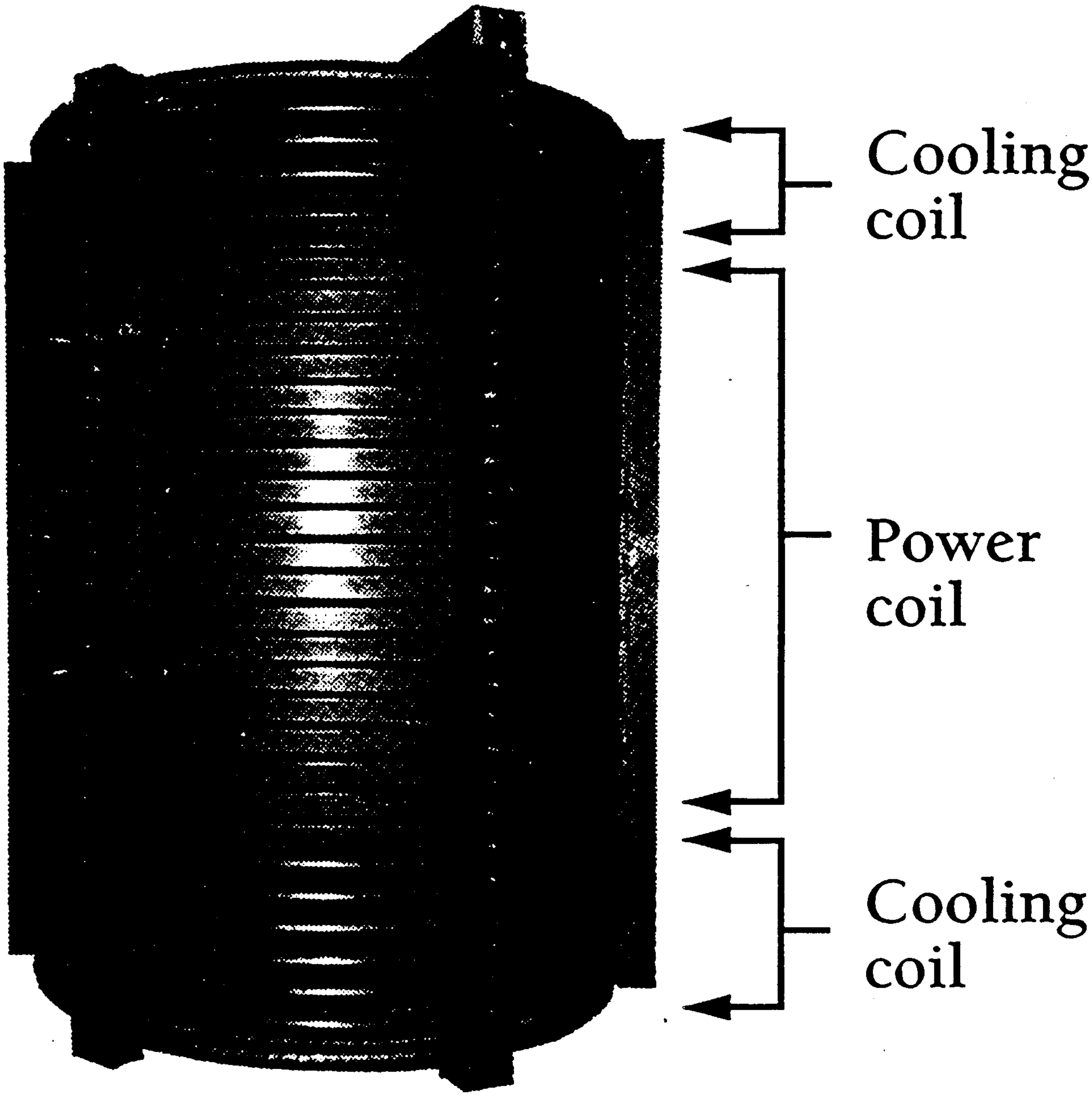


FIGURE 4-3 A THREE-PART INDUCTION FURNACE COIL

1) *Distribution* - Eliminate the leaks which may exist in the natural gas distribution system.

2) *Combustion* - Ensure that all burners operate at the correct air-to-fuel ratio across the complete range of firing rates.

3) *Excess Air* - Eliminate air infiltration to the furnace and provide combustion air through the burner such that excess air approaches 0 percent.

4) *Radiation Losses* - Put covers of refractory or ceramic fibre blankets over all surfaces which are at elevated temperatures and generate radiation losses, such as molten metal in ladles and launders.

5) *Conduction Losses* - Minimize the heat flow between the hot surface of the refractory to the cold surface by inserting ceramic fibre or fibre-type sleeves between the working refractory and the furnace wall.

6) *Heat Sink Losses* - Replace refractories of high density and high heat content, such that significant thermal energy is not expended just to bring the refractory up to working temperatures.

7) *Waste Heat* - Potential uses of waste heat include: preheat combustion air in foundry processes, heating of building make-up air, heating of foundry building.

4.10 POLLUTION PREVENTION OF STORMWATER

Most spent foundry sands, including waste green sand, dry sand, shell sand, alkyd oil urethane sand, phenolic methane sand, furan no-bake sand and organic-modified sodium silicates, are likely to contain traces of phenols. Even spent sands from processes involving non-phenolic binders and additives can contain appreciable concentrations of leachable phenols formed through high-temperature thermal decomposition and rearrangement of organic binders during the pouring process whose quantity is difficult to predetermine (Johnson, 1981). During the molding and casting processes the foundry sands become contaminated with tramp metals, residual partially degraded binder, and mold additives. Therefore, sands from different foundries should be characterized (with respect to leachable phenols concentration and heavy metals) for disposal or reuse purposes. In order to achieve consistency in spent sand material characteristics by blending, stockpiles of sufficient size must be developed. Precipitation percolating through stockpiles will mobilize leachable phenols which may have to be removed from the runoff before it discharges into surface or groundwater supplies. Containment of runoff can be achieved by the construction of a storage pad having impermeable base and sides to prevent leakage of any leachate. Leachate may need treatment prior to discharge. Applicable regulatory requirements should be followed. Alternatively, the storage facility may be provided with a roof to prevent contact with precipitation.

4.11 GOOD OPERATING PRACTICES

Good operating practices are procedural, administrative or institutional measures that a company can use to minimize waste. Good operating practices apply to the human aspect of manufacturing operations. Many of these measures are used in industry largely as efficiency improvements and good management practices. Good operating practices can often be implemented with little cost and, therefore, have a high return on investment. These practices can be implemented in all areas of a plant, including production, maintenance operations and in raw material and product storage. Good operating practices include the following:

- Waste minimization programs.

- Management and personnel practices that include employee training, incentives and bonuses and other programs that encourage employees to conscientiously strive to reduce waste.

- Material handling and inventory practices that include programs to reduce loss of input materials due to mishandling, expired shelf life of time-sensitive materials, and proper storage conditions.

- Loss prevention practices to minimize wastes by avoiding leaks from equipment and spills.

- Waste segregation practices to reduce the volumes of hazardous wastes by preventing the mixing of hazardous and non-hazardous wastes.

- Containment of stored wastes (e.g., spent foundry sand).

- Cost accounting practices that include programs to allocate waste treatment and disposal costs directly to the departments or groups that generate wastes rather than charging these costs to general company overhead accounts.

- Judicious production scheduling of batch production runs may reduce the frequency of equipment cleaning and the resulting wastes.

4.12 SUMMARY OF WASTE MINIMIZATION OPTIONS

Waste minimization options for foundries are summarized below:

Waste Origin/Type	Source Control and Recycling Methods
Baghouse dust and scrubber waste/Dust contaminated with lead, zinc and cadmium	Control the quality of scrap metal to reduce the contaminant input such as zinc.
	Install induction melting furnaces to reduce dust production.
	Recycle dust to original process or to another process.
	Recover contaminants with pyrometallurgical treatment, rotary kiln, or other processes.
	Recycle to cement manufacturer.
Production of ductile iron/Hazardous slag	Reduce the amount of sulphur in the feedstock.
	Use calcium oxide or calcium

	fluoride to replace calcium carbide as the desulphurization agent.
	Improve process control.
	Recycle calcium carbide slag.
Casting/Spent casting sand	Material substitution, e.g., olivine sand is more difficult to detoxify than silica sand.
	Separate sand and shot blast dust.
	Improve metal recovery from sand.
	Reclaim sand and mix old and new sand for mold making.
	Reclaim foundry mold and core sand by washing, air scrubbing or thermal treatment.
	Avoid contamination of stormwater by outdoor storage piles of spent casting sand.
	Reuse sand for construction purposes if possible.
Various Sources/Fugitive emissions	Capture at source before disbursing in foundry building.
Melting and Heat Treating Furnaces/ Energy	Power factor correction and load management for electrical energy.
	Increase natural gas use efficiency combustion improvements, heat loss prevention and waste heat recovery.

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SECTION 5

WASTE MINIMIZATION OPPORTUNITY ASSESSMENT PROCEDURE

5.1 INTRODUCTION

A Waste Minimization Opportunity Assessment (WMOA), sometimes called a waste minimization or reduction 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
- implementation.

The steps involved in conducting a waste minimization assessment are outlined in Figure 5-1 and described in more detail below. Briefly, after planning and organization, the assessment consists of a careful review of a plant's operations and waste streams and the selection of specific areas to assess. After particular waste streams or areas are 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. This section describes these steps in more detail with reference to worksheets in Appendix A.

5.2 PLANNING AND ORGANIZATION PHASE

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

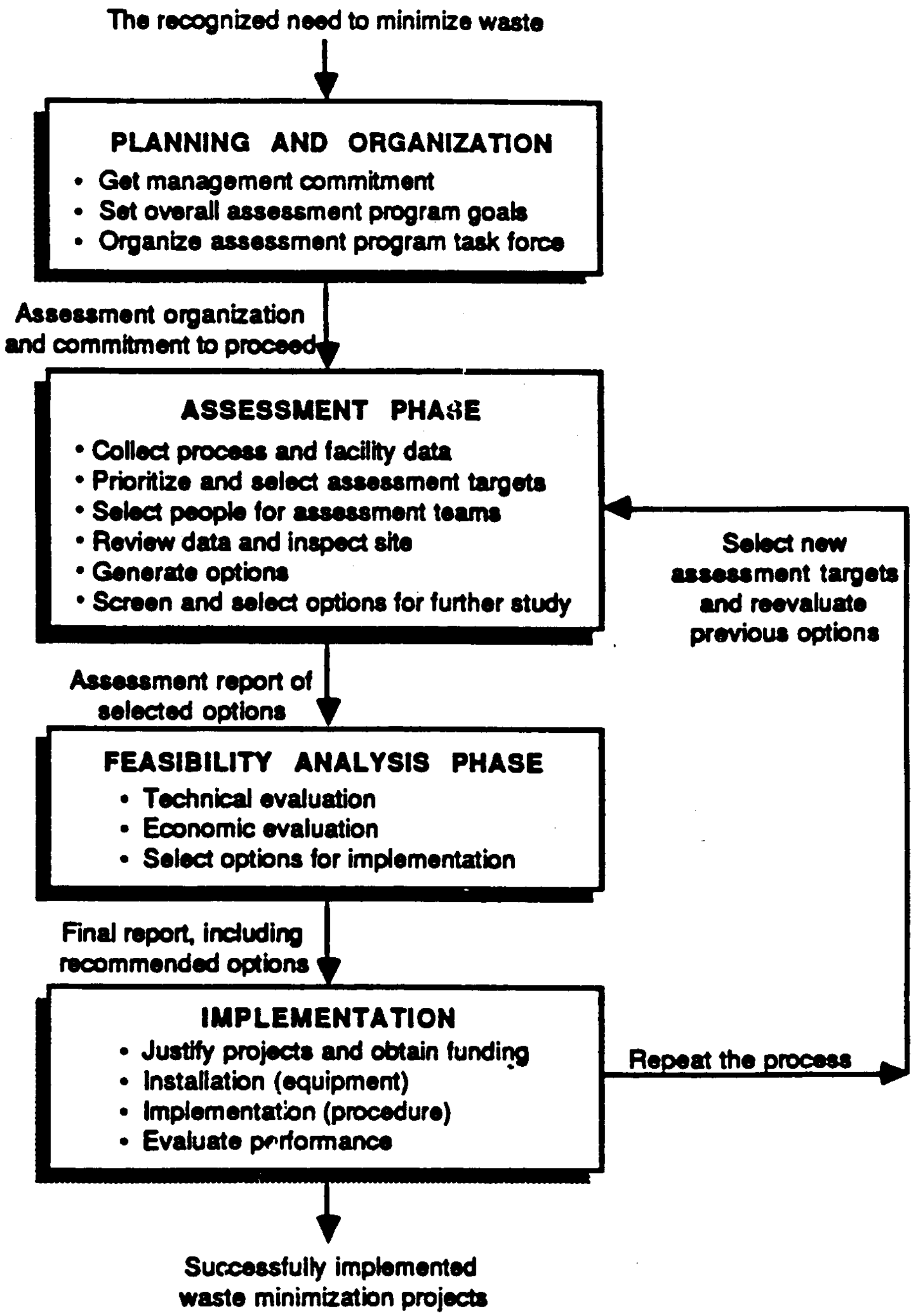

FIGURE 5-1 THE WASTE MINIMIZATION ASSESSMENT PROCEDURE (USEPA 1988 AND 1992)

5.2.1 *Getting Management Commitment*

The advantages and objectives of a WM program are best conveyed to a company's employees through a formal policy statement or management directive. A company's upper management is responsible for establishing a formal commitment throughout all divisions of the organization. The person in charge of the company's environmental affairs is responsible to advise management of the importance of WM and the need for this formal commitment.

Although management commitment and direction are fundamental to the success of a WM program, commitment throughout an organization is necessary in order to resolve conflicts and to remove barriers to the WM program. Employees often cause the generation of waste, and they can contribute to the overall success of the program.

Any WM program needs a program manager to help overcome the inertia present when changes to an existing operation are proposed and to lead the WM program, either formally or informally. An environmental engineer, production manager or plant process engineer may be a good candidate for this role. Regardless of who takes the lead, he or she must be given enough authority to effectively carry out the program.

A statement of management commitment to WM may be as simple as that shown in Table 5-1.

5.2.2 *Organizing The Program Task Force*

In a large foundry the task force should include members of any group or department in the company that have a significant interest in the outcome of the program. In the case of small foundries it could be comprised only of the program manager. While the formality or informality of the WM program will depend on the nature of the company, typical responsibilities of the WM program task force are:

- Get commitment and a statement of policy from management.
- Establish overall WM program goals.
- Establish a waste tracking system.
- Prioritize the waste streams or facility areas for assessment.
- Select assessment teams or act as assessment team.
- Conduct (or supervise) assessments.
- Conduct (or monitor) technical/economic feasibility analyses of favourable options.
- Select and justify feasible options for implementation.
- Obtain funding and establish schedule for implementation.
- Monitor (and/or direct) implementation progress.
- Monitor performance of the option, once it is operating.

WASTE MINIMIZATION POLICY ANNOUCEMENT

Company: ________________________ Date: __________

At ________________________,

we believe the reduction of toxic substances and wastes is everybody's business.

Meet our Waste Minimization Team:

Team Leader: ________________________________

Phone: _____________

Members: Phone:

Responsibilities of our Waste Minimization Team:

1. **Inspecting our facilities to assess how toxic substances are used and to identify evidence of waste, including hazardous waste.**
2. **Involving co-workers in identifying problems and suggesting possible solutions.**
3. **Helping to set and meet our reduction objectives.**
4. **Helping to spread the word.**

At ____________________, we are committed to reducing our use of toxic substances and our generation of all kinds of wastes.

If you have ideas that could help, please contact anyone on the team.

TABLE 5-1 EXAMPLE OF A SIMPLE COMPANY POLICY STATEMENT FOR A WASTE MINIMIZATION PROGRAM

In a small company, a single person may be all that will be required to implement a WM program. However, even at a small facility, at least two people should be involved to get a variety of viewpoints and perspectives. The involvement of an outside environmental consultant may also be advantageous.

5.2.3 *Setting Goals*

The first priority of the WM program task force is to establish goals that are consistent with the policy adopted by management. Waste minimization goals can be qualitative, for example, "a significant reduction of toxic substance emissions into the environment", or quantitative. Although quantitative goals establish a clear guide as to the degree of success expected of the program they are more difficult to realistically define.

The qualities that goals should possess are:

- ACCEPTABLE to those who will work to achieve them.
- FLEXIBLE and adaptable to changing requirements.
- MEASURABLE over time.
- MOTIVATIONAL.
- SUITABLE to the overall corporate goals and mission.
- UNDERSTANDABLE.
- ACHIEVABLE with a practical level of effort.

5.3 ASSESSMENT PHASE

The purpose of the assessment phase is to develop a comprehensive set of waste minimization options, and to identify the attractive options that deserve additional, more detailed analysis. The assessment phase involves a number of steps as shown in Figure 5-1.

5.3.1 *Collecting and Compiling Data*

Information that can be useful in conducting the assessment is listed below. A review of this information and development of a facility profile will provide important background for understanding the plant's production and maintenance processes and will allow assessment priorities to be determined.

Design Information
- Process flow diagrams
- Material and heat balances (both design balances and actual balances) for:
  - production processes
  - pollution control processes

- Operating manuals and process descriptions
- Equipment lists
- Equipment specifications and data sheets
- Piping and instrument diagrams
- Plot and elevation plans
- Equipment layouts and work flow diagrams.

Environmental Information
- Hazardous waste manifests
- Emission inventories
- Biennial hazardous waste reports
- Waste analyses
- Environmental audit reports
- Permits and/or permit applications.

Raw Material/Production Information
- Product composition and batch sheets
- Material application diagrams
- Material safety data sheets
- Product and raw material inventory records
- Operator data logs
- Operating procedures
- Production schedules

Economic Information
- Waste treatment and disposal costs
- Product, utility and raw material costs
- Operating and maintenance costs
- Departmental cost accounting reports

Other Information
- Company environmental policy statements
- Standard procedures
- Organization charts

5.3.2 *Prioritizing Waste Streams and/or Operations to Assess*

Ideally, all waste streams and plant operations should be assessed. However, prioritizing the waste streams and/or operations to assess is necessary when available funds and/or personnel are limited. The WM assessments should concentrate on the most important waste problems first, and then move on to the lower priority problems as the time, personnel and budget permit. Typical considerations for prioritizing waste streams to assess are:

- Compliance with current and future regulations.

- Costs of waste management (treatment and disposal).

- Potential environmental and safety liability.

- Quantity of waste.

- Hazardous properties of the waste (including toxicity, flammability, corrosivity and reactivity).

- Other safety hazards to employees.

- Potential for (or ease of) minimization.

- Potential for removing bottlenecks in production or waste treatment.

- Potential recovery of valuable by-products.

- Available budget for the waste minimization assessment program and projects.

Worksheet 1 and 2 in Appendix A provide a framework for evaluating operating practices and waste stream priorities for the remainder of the assessment.

Small foundries, or large foundries with only a few waste generating operations may, assess their entire facility as one operation. It is also beneficial to look at an entire facility as one operation when there are a large number of similar operations.

5.3.3 *Selecting the Assessment Teams*

The WM task force is concerned with the whole plant and directing the overall program. There may be one or more assessment teams each concentrating on a particular waste stream or particular area of the plant. Each team should include people with direct knowledge of the particular waste stream or area of the plant.

The WM program task force, supplemented by additional personnel if needed, can also function as the assessment team - particularly in smaller plants with a limited number of operations or where the whole facility is to be assessed as one operation. Outside consultants can bring a wide variety of experience and expertise to a waste minimization assessment. Consultants may be especially useful to companies who may not have in-house expertise in the relevant waste minimization techniques and technologies.

5.3.4 *Site Inspection*

With specific areas or waste streams selected, and with the assessment team(s) in place, the assessment continues with a visit to the site. Guidelines for the site inspection for each assessment team are:

- Prepare an agenda in advance that covers all points that still require clarification. Provide staff contacts in the area being assessed with the agenda several days before the inspection.

- Schedule the inspection to coincide with the particular operation that is of interest.

- Monitor the operation at different times during the shift, and if needed, during all three shifts, especially when waste generation is highly dependent on human involvement (e.g., parts cleaning operations).

- Interview the operators, shift supervisors and foremen in the assessed area. Do not hesitate to question more than one person if an answer is not forthcoming. Assess the operators' and their supervisors' awareness of the waste generation aspects of the operation. Note their familiarity (or lack thereof) with the impacts their operation may have on other operations.

- Photograph the area of interest, if warranted. Photographs are valuable in the absence of plant layout drawings. Many details can be captured in photographs that otherwise could be forgotten or inaccurately recalled at a later date.

- Observe the "housekeeping" aspects of the operation. Check for signs of spills or leaks. Visit the maintenance shop and ask about any problems in keeping the equipment leak-free. Assess the overall cleanliness of the site. Pay attention to odours and fumes.

- Assess the organization structure and level of coordination of environmental activities between various departments.

- Assess administrative controls, such as cost accounting procedures, material purchasing procedures, and waste collection procedures.

In performing the site inspection the assessment team should follow the process from the point where raw materials enter the area to the point where the products and the wastes leave the area. The team should identify the suspected sources of waste. This may include the production process, maintenance operations and storage areas for raw materials, finished product and work in process.

Information collected during the site inspection may be entered on *Worksheets 3, 5, 9 and 11.*

5.3.5 *Generating WM Options*

Once the origins and causes of waste generation are understood, the assessment process enters the creative phase. The objective of this step is to generate a comprehensive set of WM options for further consideration. The process for identifying options should follow a hierarchy in which source reduction options, the preferred means of minimizing waste, are explored first, followed by recycling options. Treatment options (which are outside the subject scope of this guide) should be considered only after acceptable waste minimization techniques have been found to be not feasible.

Source reduction techniques are characterized as good operating practices, technology changes, material changes or product changes. Recycling techniques are characterized as direct reuse techniques and reclamation techniques. These techniques, summarized in Figure 1-1, are described below:

1. Source Reduction: Good Operating Practices

   Good operating practices are procedural, administrative or institutional measures, described earlier in Sub-Section 4.11, that a company can use to minimize waste.

2. Source Reduction: Technology Changes

   Technology changes are oriented toward process and equipment modifications to reduce waste. Technology changes can range from minor changes that can be implemented in a matter of days at low cost, to the replacement of processes involving large capital costs. These changes include the following:

   - Changes in the production process
   - Equipment, layout, or piping changes
   - Use of automation
   - Changes in process operating conditions, such as

- Flow rates
- Temperatures
- Pressures
- Residence times

3. Source Reduction: Input Material Changes

   Input material changes accomplish waste minimization by reducing or eliminating the hazardous materials that enter the production process. Also, changes in input materials can be made to avoid the generation of hazardous wastes within the production processes. Input material changes include:

   - Material purification
   - Material substitution

4. Source Reduction: Product Changes

   Product changes are performed by the manufacturer of a product with the intent of reducing waste resulting from a product's use. Product changes include:

   - Product substitution
   - Product conservation
   - Changes in product composition

5. Recycling: Direct Reuse

   Recycling via direct use involves the return of a waste material either to the originating process as a substitute for an input material, or to another process as an input material.

6. Recycling: Reclamation

   Reclamation is the recovery of a valuable material from a hazardous waste. Reclamation techniques differ from direct reuse techniques in that the recovered material is processed before return to the originating process, processed for resource recovery or processed into a by-product.

The process by which waste minimization options are identified should occur in an environment that encourages creativity and independent thinking by the members of the assessment team. While the individual team members will suggest many potential options on their own, the process can be enhanced by using some of the common group decision techniques. These techniques allow the assessment team to identify options that the individual members might not have come up with on their own. Brainstorming sessions with the team members are an effective way of development WM options.

Worksheets 4, 6, 8, 10 and 12 (each following inspection information sheets *3, 5, 7, 9 and 11* in that order for continuity) in Appendix A may be used for listing options that are proposed during an option generation session. All of the options then may be listed on *Worksheet 13*. Each option may be described in detail on *Worksheet 14*, any number of which may be reproduced.

5.3.6 *Screening and Selecting Options for Further Study*

Many waste minimization options might be identified in a successful assessment. At this point, it is necessary to identify those options that offer real potential to minimize waste and reduce costs. The screening procedure serves to eliminate suggested options that appear marginal, impractical or inferior without a detailed and more costly feasibility study.

The screening procedures can range from an informal review and a decision made by the program manager or a vote of the team members, to quantitative decision-making tools. The informal evaluation is an unstructured procedure by which the assessment team or WM program task force selects the options that appear to be the best. This method is especially useful in small facilities, with small management groups, or in situations where only a few options have been generated. This method consists of a discussion and examination of each option.

The weighted sum method is a means of quantifying the important factors that affect waste management at a particular facility, and how each option will perform with respect to these factors. This method is recommended when there are a large number of options to consider. Appendix B presents the weighted sum method in greater detail, along with an example. *Worksheet 15* in Appendix A is designed to screen and rank options using this method.

5.4 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.

5.4.1 *Technical Evaluation*

The technical evaluation determines whether a proposed WM option will work in a specific application. The technical evaluation of an option also must consider facility constraints and product requirements, such as those described below.

- Is the system safe for workers?
- Will product quality be maintained?
- Is space available?
- Is the new equipment, materials or procedures compatible with production operating procedures, work flow and production rates?
- Is additional labour required?
- Are utilities available? Or must they be installed, thereby raising capital costs?
- How long will production be stopped in order to install the system?
- Is special expertise required to operate or maintain the new system?
- Does the vendor provide acceptable service?
- Does the system create other environmental problems?

Although an inability to meet these constraints may not present insurmountable problems, correcting them will likely add to the capital and/or operating costs. If after the technical evaluation, the project appears infeasible or impractical, it should be dropped. *Worksheet 16* in Appendix A is a checklist of important items to consider when evaluating the technical feasibility of a WM option.

5.4.2 *Economic Evaluation*

An economic evaluation is carried out using standard measures of profitability, such as payback period, return on investment and net present value. Each organization has its own economic criteria for selecting projects for implementation. In performing the economic evaluation, various costs and savings must be considred. As in any projects, the cost elements of a WM project can be broken down into capital costs and operating costs. The economic analysis described in this section and in the associated worksheets represents a preliminary, rather than detailed, analysis. For more detailed economic evaluations refer to Perry, Chemical Engineers Handbook (1985) and Peters and Timmerhaus, Plant Design and Economics for Chemical Engineers (1980).

For smaller facilities with only a few processes, the entire WM assessment procedure will tend to be much less formal. In this situation, several obvious WM options, such as installation of flow controls and good operating practices may be implemented with little or no economic evaluation. In these instances, no complicated analyses are necessary to demonstrate the advantages of adopting the selected WM options.

1. Capital Costs

Capital cost items associated with a plant upgrading project include not only the fixed capital costs for designing, purchasing and installing equipment, but also, especially in the case of large plant upgrades, costs for working capital, permitting, training, start-up and financing charges. For most projects, the use of outside assistance will be needed.

2. Operating Costs and Savings

The basic economic goal of any waste minimization project is to reduce (or eliminate) waste disposal costs and to reduce input material costs. However, a variety of other operating costs (and savings) should also be considered. In making the economic evaluation, it is convenient to use incremental operating costs in comparing the existing system with the new system that incorporates the waste minimization option. ("Incremental operating costs" represent the difference between the estimated operating costs associated with the WM option, and the actual operating costs of the existing system, without the option.) Incremental operating costs and savings, and incremental revenues (or savings) typically associated with waste minimization projects are listed below.

- Reduced waste management costs.
  This includes reductions in costs for:
  - Off-site treatment, storage and disposal fees
  - Fees and taxes on hazardous waste generators
  - Transportation costs
  - On-site treatment, storage and handling costs
  - Permitting, reporting and recordkeeping costs.

- Input material cost savings.
  An option that reduces waste usually decreases the demand for input materials.

- Insurance and liability savings.
  A WM option may be significant enough to reduce a company's insurance payments. It may also lower a company's potential liability associated with remedial clean-up of treatment, storage and disposal facilities and workplace safety. (The magnitude of liability savings is difficult to determine.)

- Changes in costs associated with quality.
  A WM option may have a positive or negative effect on product quality. This could result in higher (or lower) costs for rework, scrap or quality control functions.

- Changes in utilities costs.
  Utilities costs may increase or decrease. This includes steam, electricity, process and cooling water, plant air, refrigeration or inert gas.

- Changes in operating and maintenance labour, burden and benefits.
  An option may either increase or decrease labour requirements. This may be reflected in changes in overtime hours or in changes in the number of employees. When direct labour costs change, then the burden and benefit costs will also change. In large projects, supervision costs will also change.

- Changes in operating and maintenance (O & M) supplies.
  An option may increase or decrease the use of O & M supplies.

- Changes in overhead costs.
  Large WM projects may affect a facility's overhead costs.

- Changes in revenues from increased (or decreased) production.
  An option may result in an increase in the productivity of a unit. This will result in a change in revenues. (Note that operating costs may also change accordingly.)

- Increased revenues from by-products.
  A WM option may produce a by-product that can be sold to a recycler or sold to another company as a raw material. This will increase the company's revenues.

Reducing or avoiding present and future operating costs associated with waste treatment, storage and disposal are major elements of the WM project economic evaluation because the costs of waste management increase with increasingly stringent environmental regulations.

For the purpose of evaluating a project to reduce waste quantities, some types of costs are larger and more easily estimated. These include:

- disposal fees

- transportation costs

- predisposal treatment costs

- raw materials costs

- operating and maintenance costs.

It is suggested that savings in these costs be taken into consideration first, because they have a greater effect on project economics and involve less effort to estimate reliably. The remaining elements are usually secondary in their direct impact and should be included on an as-needed basis in fine-tuning the analysis.

Capital and operating cost informat may be entered on *Worksheet 17* found in Appendix A.

3. Profitabilty Analysis

If the project has no siignificant capital costs, the project's profitability can be judged by whether an operating cost savings occurs or not. If such a project reduces overall operating costs, it should be implemented as soon as practical.

For projects with significant capital costs, a more detailed profitability analysis is necessary. The three standard profitability measures are:

- Payback period
- Internal rate of return (IRR)
- Net present value.

The payback period for a project is the amount of time it takes to recover the initial cash outlay on the project. The formula for calculating the payback period on a pre-tax basis is the following:

$$\text{Payback period (in years)} = \frac{\text{Capital investment}}{\text{Annual operating cost savings}}$$

For example, suppose a waste generator installs a piece of equipment at a total cost of $120,000. If the piece of equipment is expected to save $48,000 per year, then the payback period is 2.5 years.

Payback periods are typically measured in years. However, a particularly attractive project may have a payback period measured in months. Payback periods in the range of three to four years are usually considered acceptable for low-risk investments. This method is recommended for quick assessments of profitability. *Worksheet 18* is used to find a simple payback period for an option that requires capital investment. If large capital expenditures are involved, it is usually followed by more detailed analysis.

The internal rate of return (IRR) and the net present value (NPV) are both discounted cash flow techniques for determining profitability. Many companies use these methods for ranking capital projects that are competing for funds. Capital funding for a project may well hinge on the ability of the project to generate positive cash flows beyond the payback period to realize acceptable return on investment. Both the NPV and IRR recognize the time value of money by discounting the projected future net cash flows to the present. For investments with a low level of risk, an after-tax IRR of 12 to 15 percent is typically acceptable.

Most of the popular spreadsheet programs for personal computers will automatically calculate IRR and NPV for a series of cash flows. Refer to any financial management, cost accounting or engineering economics text for more information on determining the IRR or NPV.

Worksheet 19 is used to find the net present value and internal rate of return for an option that requires capital investment.

5.4.3 *Selecting Options for Implementation.*

Options selected for implementation should be those that pass both technical and economic evaluations.

5.5 FINAL REPORT

The product of a waste minimization assessment is a report that presents the results of the assessment and the technical and economic feasibility analyses and recommendations to implement the feasible options.

A good final report can be an important tool for getting a project implemented. It is particularly valuable in obtaining funding for the project. In presenting the feasibility analyses, it is often useful to evaluate the project under different scenarios. For example, comparing a project's profitability under optimistic and pessimistic assumptions (such as increasing waste disposal costs) can be beneficial. Sensitivity analyses that indicate the effect of key variables on profitability are also useful.

The report should include not only how much the project will cost and its expected performance, but also how it will be done. It is important to discuss:

- whether the technology is established, with mention of successful applications
- the required resources and how they will be obtained
- estimated construction period
- estimated production downtime
- how the performance of the project can be evaluated after it is implemented.

In summarizing the results, a qualitative evaluation of intangible costs and benefits to the company should be included. Reduced liabilities and improved image in the eyes of the employees and the community should be discussed.

5.6 IMPLEMENTATION

The WM assessment program team members should be flexible enough to develop alternatives or modifications. They should also be committed to the point of doing background and support work, and should anticipate potential problems in implementing the options. Above all, they should keep in mind that an idea will not sell if the sponsors are not sold on it themselves.

5.6.1 *Obtaining Funding*

The WM assessment final report provides the basis for obtaining company funding of WM projects. Because projects are not always sold on their technical and economic merits alone, a clear description of both tangible and intangible benefits can help edge a proposed project past competing projects for funding.

Since most established businesses have different sources of funding to which they can turn, funding sources are not discussed.

5.6.2 *Installation*

Waste minimization options that involve operational procedural, or materials changes (without additions or modifications to equipment), should be implemented as soon as the potential cost savings have been determined. For projects involving equipment modifications or new equipment, the installation of a waste minimization project is essentially no different from any other capital improvement project. The phases of the project include planning, design, procurement, and construction.

Worksheet 20 is a form of documenting the progress of a WM project through the implementation phase.

5.6.3 *Demonstration and Follow-up*

After the waste minimization option has been implemented, it remains to be seen how effective the option actually turns out to be. Options that don't measure up to their original performance expectations may require rework or modifications. It is important to get warranties from vendors prior to installation of the equipment.

The documentation provided through a follow-up evaluation represents an important source of information for future uses of the option in other facilities. *Worksheet 21* is a form for evaluating the performance of an implemented WM option.

5.6.4 *Measuring Waste Reduction*

The easiest way to measure waste reduction is by recording the quantities of waste generated before and after a WM project has been implemented. The difference, divided by the original waste generation rate, represents the percentage reduction in waste quantity. However, this simple measurement ignores other factors that also affect the quantity of waste generated.

In general, waste generation is directly dependent on the production rate. Therefore, the ratio of waste generation rate to production rate is a convenient way of measuring waste reduction. However, in doing so, a distinction should be made between production-related wastes and maintenance-related wastes and clean-up wastes.

Also, a few waste streams may be inversely proportional to production rate. For example, a waste resulting from outdated input materials is likely to increase if the production rate decreases. This is because the age-dated materials in inventory are more likely to expire when their use in production decreases.

In measuring waste reduction, the total quantity of an individual waste stream should be measured, as well as the individual waste components or characteristics. Many companies have reported substantial reduction in the quantities of waste disposed. Often, much of the reduction can be traced to good housekeeping and steps taken to concentrate a dilute aqueous waste. Although concentration, as such, does not fall within the definition of waste minimization, there are practical benefits that result from concentrating wastewater streams, including decreased disposal costs. Concentration may render a waste stream easier to recycle, and is also desirable if a facility's current wastewater treatment system is hydraulicaly overloaded.

Measuring waste minimization by using a ratio of waste quantity to material throughput or product output is generally more meaningful for specific units or operations, rather than for an entire facility, except in instances when the entire facility is considered as one operation. For those operations not involving chemical reactions, it may be helpful to measure WM progress by using the ratio of input material quantity to material throughput or production rate.

5.6.5 *Ongoing Waste Minimization Program*

The WM program is a continuing, rather than a one-time effort. Once the highest priority waste streams and facility areas have been assessed and those projects have been implemented, the assessment program should look to areas and waste streams with lower priorities. The ultimate goal of the WM program should be to reduce the generation of waste to the maximum extent practically and economically achievable. Companies that have eliminated the generation of hazardous waste should continue to look at reducing industrial wastewater discharges, air emissions and solid wastes.

The frequency with which assessments are done will depend on the program's budget, the company's budgeting cycle (annual cycle in most companies), and special circumstances. These special circumstances might be:

- a change in raw material or product requirements
- higher waste management costs
- new regulations
- new technology
- a major event with undesirable environmental consequences (such as a major spill).

To be truly effective, a philosophy of waste minimization must be developed in the organization. This means that waste minimization must be an integral part of the company's operations.

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APPENDIX A

WASTE MINIMIZATION ASSESSMENT WORKSHEETS FOR FOUNDRIES

The worksheets in this appendix are intended to assist foundries in systematically evaluating a pollution prevention program. The table below lists the worksheets according to the particular phase of the program and briefly describes the purpose of the worksheets in a WMOA procedure. Worksheets 1 to 15 cover a range of possible foundry operations, some which may not be found in any one particular foundry, and hence, may be passed over.

Number	Title	Purpose/Remarks
Assessment Phase (Sub-Section 5.3)		
1.	Good Operating Practices	Form for listing good operating practices
2.	Waste Sources	Checklist of waste streams generated
3.	Waste Minimization: Casting Operations	Form for listing steps in the casting process
4.	Option Generation: Casting Operations	Options for minimizing casting operations waste
5.	Waste Minimization: Heat Treating Operations	Form for listing steps in the heat treating process
6.	Option Generation: Heat Treating Operations	Options for minimizing heat treatment waste
7.	Waste Minimization: Metal Parts Cleaning and Stripping	Form for listing steps in the cleaning and stripping process
8.	Option Generation: Metal Parts Cleaning and Stripping	Options for minimizing cleaning and stripping waste
9.	Waste Minimization: Metal Surface Treating and Plating	Form for listing steps in the surface treating and plating process
10.	Option Generation: Metal Surface Treating and Plating	Options for minimizing surface treating and plating waste
11.	Waste Minimization: Other Processes	Form for listing steps in other processes that generate waste
12.	Option Generation: Other Processes	Options for minimizing other waste
13.	Option Generation Record	Form for recording options proposed during brainstorming or nominal group technique sessions. Includes the rationale for proposing each option.

Number	Title	Purpose/Remarks
14.	Option Description	Form for describing and summarizing information about proposed options. Also notes approval of promising options.
15.	Options Evaluation by Weighted Sum Method	Form for screening options using the weighted sum method.
<u>Feasibility Analysis Phase (Sub-Section 5.4)</u>		
16.	Technical Feasibility	Detailed checklist for performing a technical evaluation of a WM option. This worksheet is divided into sections for equipment-related options, personnel/procedural-related options, and materials-related options.
17.	Cost information	Detailed list of capital and operating cost information for use in the economic evaluation of an option.
18.	Profitability Worksheet #1 Payback Period	Based on the capital and operating cost information developed from Worksheet 17, this worksheet is used to calculate the payback period.
19.	Profitability Worksheet #2 Cash Flow for NPV and IRR	This worksheet is used to develop cash flows for calculating NPV or IRR.
<u>Implementation (Sub-Section 5.6)</u>		
20.	Project Summary	Form for summarizing important tasks to be performed during the implementation of an option. This includes deliverable, responsible person, budget and schedule.
21.	Option Performance	Form for recording material balance information for evaluating the performance of an implemented option.

Plant ____________	Waste Minimization Assessment	Prepared by ____________
		Checked By ____________
Date ____________	Proj. No. ____________	Sheet ____ of ____ Page ____ of ____

WORKSHEET
1

GOOD OPERATING PRACTICES

Suggested Waste Minimization Options	Currently Done Y/N?	Rationale/Remarks on Option
Good Operating Practices		
Material Handling Improvements		
Waste Stream Segregation		
Loss Prevention Practices		
Preventive and Corrective Maintenance		
Personnel Practices and Training		
Management Initiatives		
Employee Training		
Employee Incentives		
Procedural Measures		
Documentation and Tracking		
Storage		
Mass Balance Calculations Around Facilities, Processes		
Use of Process Control for Increased Process Efficiency		

Plant ____	Waste Minimization Assessment	Prepared by ____
		Checked By ____
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WORKSHEET
2

WASTE SOURCES

Waste Source: Casting	Significance		
	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			

Plant ____________ Date ____________	Waste Minimization Assessment Proj. No. ____________	Prepared by ____________ Checked By ____________ Sheet ___ of ___ Page ___ of ___

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? ____________

Plant ____________	Waste Minimization Assessment	Prepared by ____________
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		Sheet ___ of ___ Page ___ of ___

WORKSHEET
4

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		

Plant ____________	Waste Minimization Assessment	Prepared by ____________
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		Sheet ___ of ___ Page ___ of ___

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: ____________

Plant ____________	Waste Minimization Assessment	Prepared by ____________
Date ____________	Proj. No. ____________	Checked By ____________ Sheet ___ of ___ Page ___ of ___

WORKSHEET
6

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		

Plant ____________ Date ____________	Waste Minimization Assessment Proj. No. ____________	Prepared by ____________ Checked By ____________ Sheet ___ of ___ Page ___ of ___

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	

Plant ____________ Date ____________	Waste Minimization Assessment Proj. No. ____________	Prepared by ____________ Checked By ____________ Sheet ___ of ___ Page ___ of ___

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: ____________

Plant ______ Date ______	Waste Minimization Assessment Proj. No. ______	Prepared by ______ Checked By ______ Sheet ___ of ___ Page ___ of ___

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: ______

Plant ____________ Date ____________	Waste Minimization Assessment Proj. No. ____________	Prepared by ____________ Checked By ____________ Sheet ____ of ____ Page ____ of ____

WORKSHEET
8

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		

Plant ______________	Waste Minimization Assessment	Prepared by ______________
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Date ______________	Proj. No. ______________	Sheet ___ of ___ Page ___ of ___

WORKSHEET
9

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? ______________

Plant ____________	Waste Minimization Assessment	Prepared by ____________
		Checked By ____________
Date ____________	Proj. No. ____________	Sheet ____ of ____ Page ____ of ____

WORKSHEET
10

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		

Plant ____________	Waste Minimization Assessment	Prepared by ____________
Date ____________	Proj. No. ____________	Checked By ____________
		Sheet ___ of ___ Page ___ of ___

WORKSHEET
11

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: ____________

Plant ____________ Date ____________	Waste Minimization Assessment Proj. No. ____________	Prepared by ____________ Checked By ____________ Sheet ___ of ___ Page ___ of ___

WORKSHEET
12

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		

Firm ______	**Waste Minimization Assessment**	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 1 Page ___ of ___

WORKSHEET 13

OPTION GENERATION

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

Meeting Coordinator ______

Meeting Participants ______

List Suggested Options	Rationale/Remarks on Option

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 1 Page ___ of ___

WORKSHEET 14

OPTION DESCRIPTION

Option Name: ______

Briefly describe the option ______

______

______

______

______

______

______

______

Waste Stream(s) Affected: ______

______

Input Material(s) Affected: ______

______

Product(s) Affected: ______

______

Indicate Type:

☐ **Source Reduction**

- ___ **Equipment-Related Change**
- ___ **Personnel/Procedure-Related Change**
- ___ **Materials-Related Change**

☐ **Recycling/Reuse**

- ___ **Onsite** ___ **Material reused for original purpose**
- ___ **Offsite** ___ **Material used for a lower-quality purpose**
- ___ **Material sold**
- ___ **Material burned for heat recovery**

Originally proposed by: ______ **Date:** ______

Reviewed by: ______ **Date:** ______

Approved for study? ______ **yes** ______ **no, by:** ______

Reason for Acceptance or Rejection ______

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 1 Page 1 of 1

WORKSHEET 15

OPTIONS EVALUATION BY WEIGHTED SUM METHOD

Criteria	Weight (W)	Options Rating (R)									
		#1 Option ______		#2 Option ______		#3 Option ______		#4 Option ______		#5 Option ______	
		R	R x W	R	R x W	R	R x W	R	R x W	R	R x W
Reduction in waste's hazard											
Reduction of treatment/disposal costs											
Reduction of safety hazards											
Reduction of input material costs											
Extent of current use in industry											
Effect on product quality (no effect = 10)											
Low capital cost											
Low O & M cost											
Short implementation period											
Ease of implementation											

Final Evaluation		#1	#2	#3	#4	#5
Final Evaluation	Sum of Weighted Ratings Σ (W x R)					
	Option Ranking					
Feasibility Analysis Scheduled for (Date)						

Firm ______ Site ______ Date ______	Waste Minimization Assessment Proc. Unit/Oper. ______ Proj. No. ______	Prepared By ______ Checked By ______ Sheet 1 of 6 Page ___ of ___

WORKSHEET
16a

TECHNICAL FEASIBILITY

WM Option Description ______

1. **Nature of WM Option**
   - ☐ **Equipment-Related**
   - ☐ **Personnel/Procedure-Related**
   - ☐ **Materials-Related**

2. **If the option appears technically feasible, state your rationale for this.** ______

Is further analysis required? ☐ **Yes** ☐ **No. If yes, continue with this worksheet. If not, skip to worksheet 15.**

3. **Equipment - Related Option**

	YES	NO	
Equipment available commercially?	☐	☐	______
Demonstrated commercially?	☐	☐	______
In similar application?	☐	☐	______
Successfully?	☐	☐	______

Describe closest industrial analog ______

Describe status of development ______

Prospective Vendor	Working Installation(s)	Contact Person(s)	Date Contacted [1]

1. **Also attach filled out phone conversation notes, installation visit report, etc.**

Firm ______	Waste Minimization Assessment	Prepared By ______
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WORKSHEET **16b**

TECHNICAL FEASIBILITY

(continued)

WM Option Description ______

3. Equipment-Related Option (continued)

Performance information required (describe parameters): ______

Scaleup information required (describe): ______

Testing Required: ☐ yes ☐ no

Scale: ☐ bench ☐ pilot ☐ ______

Test unit available? ☐ yes ☐ no ______

Test Parameters (list) ______

Number of test runs: ______

Amount of material(s) required: ______

Testing to be conducted: ☐ in-plant ☐ ______

Facility/Product Constraints:

Space Requirements ______

Possible locations within facility ______

Firm ______	Waste Minimization Assessment	Prepared By ______
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WORKSHEET **16c**

TECHNICAL FEASIBILITY

(continued)

WM Option Description ______

2. Equipment-Related Option (continued)

Utility Requirements:

Electric Power Volts (AC or DC) ______ kW ______

Process Water Flow ______ Pressure ______

Quality (tap, demin, etc.) ______

Cooling Water Flow ______ Pressure ______

Temp. In ______ Temp. Out ______

Coolant/Heat Transfer Fluid ______

Temp. In ______ Temp. Out ______

Duty ______

Steam Pressure ______ Temp. ______

Duty ______ Flow ______

Fuel Type ______ Flow ______

Duty ______

Plant Air ______ Flow ______

Inert Gas ______ Flow ______

Estimated delivery time (after award of contract) ______

Estimated installation time ______

Installation dates ______

Estimated production downtime ______

Will production be otherwise affected? Explain the effect and impact on production. ______

______

______

______

Will product quality be affected? Explain the effect on quality. ______

______

______

______

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 4 of 6 Page ___ of ___

WORKSHEET **16d**

TECHNICAL FEASIBILITY

(continued)

WM Option Description ______

3. Equipment-Related Option (continued)

Will modifications to work flow or production procedures be required? Explain. ______

Operator and maintenance training requirements

Number of people to be trained ______ ☐ **Onsite** ☐ **Offsite**

Duration of training ______

Describe catalyst, chemicals, replacement parts, or other supplies required.

Item	Rate or Frequency of Replacement	Supplier, Address

Does the option meet government and company safety and health requirements?

☐ **Yes** ☐ **No** **Explain** ______

How is service handled (maintenance and technical assistance)? Explain ______

What warranties are offered? ______

WORKSHEET **16e**

TECHNICAL FEASIBILITY

(continued)

WM Option Description ______

3. Equipment-Related Option (continued)

Describe any additional storage or material handling requirements. ______

Describe any additional laboratory or analytical requirements. ______

4. Personnel/Procedure-Related Changes

Affected Departments/Areas ______

Training Requirements ______

Operating Instruction Changes. Describe responsible departments. ______

5. Materials-Related Changes (Note: If substantial changes in equipment are required, then handle the option as an equipment-related one.)

	Yes	No
Has the new material been demonstrated commercially?	☐	☐
In a similar application?	☐	☐
Successfully?	☐	☐

Describe closest application. ______

Firm ____	Waste Minimization Assessment	Prepared By ____
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Date ____	Proj. No. ____	Sheet 6 of 6 Page ___ of ___

WORKSHEET
16f

TECHNICAL FEASIBILITY
(continued)

WM Option Description ____________________

4. Materials-Related Changes (continued)

Affected Departments/Areas ____________________

Will production be affected? Explain the effect and impact on production.

Will product quality be affected? Explain the effect and the impact on product quality.

Will additional storage, handling or other ancillary equipment be required? Explain.

Describe any training or procedure changes that are required.

Decribe any material testing program that will be required.

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 1 of 6 Page __ of __

WORKSHEET
17a

COST INFORMATION

WM Option Description ______

CAPITAL COSTS - Include all costs as appropriate. **TOTALS**

☐ **Purchased Process Equipment**
- Price (fob factory) ______
- Taxes, freight, insurance ______
- Delivered equipment cost ______
- Price for Initial Spare Parts Inventory ______ ______

☐ **Estimated Materials Cost**
- Piping ______
- Electrical ______
- Instruments ______
- Structural ______
- Insulation/Piping ______ ______

☐ **Estimated Costs for Utility Connections and New Utility Systems**
- Electricity ______
- Steam ______
- Cooling Water ______
- Process Water ______
- Refrigeration ______
- Fuel (Gas or Oil) ______
- Plant Air ______
- Inert Gas ______ ______

☐ **Estimated Costs for Additional Equipment**
- Storage & Material Handling ______
- Laboratory/Analytical ______
- Other ______ ______

☐ **Site Preparation** ______
(Demolition, site clearing, etc.) ______

☐ **Estimated Installation Costs**
- Vendor ______
- Contractor ______
- In-house Staff ______ ______

WORKSHEET
17b

COST INFORMATION
(continued)

CAPITAL COSTS (Cont.) **TOTALS**

☐ **Engineering and Procurement Costs (In-house & outside)**

Planning	____	
Engineering	____	
Procurement	____	
Consultants	____	____

☐ **Start-up Costs**

Vendor	____	
Contractor	____	
In-house	____	____

☐ **Training Costs** ____ ____

☐ **Permitting Costs**

Fees	____	
In-house Staff Costs	____	____

☐ **Initial Charge of Catalysts and Chemicals**

Item #1	____	
Item #2	____	____

☐ **Working Capital** [Raw Materials, Product, Inventory, Materials and Supplies (not elsewhere specified)].

Item #1	____	
Item #2	____	
Item #3	____	
Item #4	____	____

☐ **Estimated Salvage Value (If any)** ____

Firm ____	Waste Minimization Assessment	Prepared By ____
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Date ____	Proj. No. ____	Sheet 3 of 6 Page ___ of ___

WORKSHEET 17c

COST INFORMATION

(continued)

CAPITAL COST SUMMARY

Cost Item	Cost
Purchased Process Equipment	
Materials	
Utility Connections	
Additional Equipment	
Site Preparation	
Installation	
Engineering and Procurement	
Start-up Cost	
Training Costs	
Permitting Costs	
Initial Charge of Catalysts and Chemicals	
Fixed Capital Investment	
Working Capital	
Total Capital Investment	
Salvage Value	

Firm ______	Waste Minimization Assessment	Prepared By ______
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Date ______	Proj. No. ______	Sheet 4 of 6 Page ___ of ___

WORKSHEET 17d

COST INFORMATION

(continued)

☐ **Estimated Decrease (or Increase) in Utilities**

Utility	Unit Cost $ per unit	Decrease (or Increase) in Quantity Unit per time	Total Decrease (or Increase) $ per time
Electricity			
Steam			
Cooling Process			
Process Water			
Refrigeration			
Fuel (Gas or Oil)			
Plant Air			
Inert Air			

INCREMENTAL OPERATING COSTS - Include all relevant operating savings. Estimate these costs on an incremental basis (i.e., as decreases or increases over existing costs).

☐ **BASIS FOR COSTS** Annual ______ Quarterly ______ Monthly ______ Daily ______ Other______

☐ **Estimated Disposal Cost Saving**

Decrease in TSDR Fees ______

Decrease in State Fees and Taxes ______

Decrease in Transportation Costs ______

Decrease in Onsite Treatment and Handling ______

Decrease in Permitting, Reporting and Recordkeeping ______

Total Decrease in Disposal Costs ______

☐ **Estimated Decrease in Raw Materials Consumption**

Materials	Unit Cost $ per unit	Reduction in Quantity Units per time	Decrease in Cost $ per time

Firm ______	Waste Minimization Assessment	Prepared By ______
Site ______	Proc. Unit/Oper. ______	Checked By ______
Date ______	Proj. No. ______	Sheet 5 of 6 Page __ of __

WORKSHEET 17e

COST INFORMATION

(continued)

☐ **Estimated Decrease (or Increase) in Ancillary Catalysts and Chemicals**

Catalyst/Chemical	Unit Cost $ per unit	Decrease (or Increase) in Quantity Unit per time	Total Decrease (or Increase) $ per time

☐ **Estimated Decrease (or Increase) in Operating Costs and Maintenance Labor Costs (include cost of supervision, benefits and burden).**

______

______

______

☐ **Estimated Decrease (or Increase) in Operating and Maintenance Supplies and Costs.**

______

______

______

☐ **Estimated Decrease (or Increase) in Insurance and Liability Costs (explain).** ______

______

______

☐ **Estimated Decrease (or Increase) in Other Operating Costs (explain).**

______

______

INCREMENTAL REVENUES

☐ **Estimated Incremental Revenues from an Increase (or Decrease) in Production or Marketable By-products (explain).**

______

______

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WORKSHEET **17f**

COST INFORMATION

(continued)

INCREMENTAL OPERATING COST AND REVENUE SUMMARY (ANNUAL BASIS)

Decreases in Operating Cost or Increases in Revenue are Positive.
Increases in Operating Cost or Decrease in Revenue are Negative.

Operating Cost/Revenue Item	$ per year
Decrease in Disposal Cost	
Decrease in Raw Materials Cost	
Decrease (or Increase) in Utilities Cost	
Decrease (or Increase) in Catalysts and Chemicals	
Decrease (or Increase) in O & M Labor Costs	
Decrease (or Increase) in O & M Supplies Costs	
Decrease (or Increase) in Insurance/Liabilities Costs	
Decrease (or Increase) in Other Operating Costs	
Incremental Revenues from Increased (Decreased) Production	
Incremental Revenues from Marketable By-products	
Net Operating Cost Savings	

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WORKSHEET
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PROFITABILITY WORKSHEET # 1
PAYBACK PERIOD

Total Capital Investment ($) (from Worksheet 17c) ______

Annual Net Operating Cost Savings ($ per year) (from Worksheet 17f) ______

Payback Period (in years) $= \dfrac{\text{Total Capital Investment}}{\text{Annual Net Operating Cost Savings}} =$ ______

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WORKSHEET
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PROFITABILITY WORKSHEET #2
CASH FLOW FOR NPV, IRR

Cash incomes (such as net operating cost savings and salvage value) are shown as positive.
Cash outlays (such as capital investments and increased operating costs) are shown as negative.

Line		Constr. Year	Operating[1] Year							
		0	1	2	3	4	5	6	7	8
A	Fixed Capital Investment									
B	+ Working Capital									
C	Total Capital Investment									
D	Salvage Value[2]									
E	Net Operating Costs Savings									
F	- Interest on Loans									
G	- Depreciation									
H	Taxable Income									
I	- Income Tax[3]									
J	Aftertax Profit[3]									
K	+ Depreciation									
L	- Repayment of Loan Principal									
M	- Capital Investment (line C)									
N	+ Salvage Value (line D)									
O	Cash Flow									
P	Present Value of Cash Flow[4]									
Q	Net Present Value (NPV)[5]									
	Present Worth[6] (5% discount)	1.0000	0.9524	0.9070	0.8638	0.8227	0.7835	0.7462	0.7107	0.6768
	(10% discount)	1.0000	0.9091	0.8264	0.7513	0.6830	0.6209	0.5645	0.5132	0.4665
	(15% discount)	1.0000	0.8696	0.7561	0.6575	0.5718	0.4972	0.4323	0.3759	0.3269
	(20% discount)	1.0000	0.8333	0.6944	0.5787	0.4823	0.4019	0.3349	0.2791	0.2326
	(25% discount)	1.0000	0.8000	0.6400	0.5120	0.4096	0.3277	0.2621	0.2097	0.1678

1 Adjust table as necessary if the anticipated project life is less than or more than 8 years.
2 Salvage value includes scrap value of equipment plus sale of working capital minus demolition costs.
3. The worksheet is used for calculating an aftertax cash flow. For pretax cash flow, use an income tax rate of 0%.
4 The present value of the cash flow is equal to the cash flow multiplied by the present worth factor.
5 The net present value is the sum of the present value of the cash flow for that year and all of the preceeding years.
6 The formula for the present worth factor is $\frac{1}{(1+r)^n}$ where n is years and r is the discount rate.
7 The internal rate of return (IRR) is the discount rate (r) that results in a net present value of zero over the life of the project.

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WORKSHEET 20

PROJECT SUMMARY

Goals/Objectives ______

Task	Deliverable	Task Leader	Manhours	Budget	Duration			Reference
					Wks	Start	Finish	
1.								
2.								
3.								
4.								
5.								
6.								
7.								
8.								
9.								
10.								
11.								
12.								
13.								
14.								
15.								
16.								
17.								
18.								
19.								
20.								
21.								
22.								
23.								
		TOTALS						

Approval By ______ Date ______

Authorization By ______ Date ______

Project Started (Date) ______

Firm ______	Waste Minimization Assessment	Prepared By ______
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WORKSHEET
21

OPTION PERFORMANCE

WM Option Description ______

☐ Baseline (without option) ☐ Projected ☐ Actual

(a) Period Duration ______ From ______ To ______

(b) Production per Period ______ Units (______)

(c) Input Materials Consumption per Period

Material	Pounds	Pounds/Unit Product

(d) Waste Generation per Period

Waste Stream	Pounds	Pounds/Unit Product

(e) Substance(s) of Concern - Generation Rate per Period

Waste Stream	Substance	Pounds	Pounds/Unit Product

APPENDIX B

OPTION RATING
WEIGHTED SUM METHOD

The Weighted Sum Method is a quantitative method for screening and ranking waste minimization options. This method provides a means of quantifying the important criteria that affect waste management in a particular facility. This method involves three steps.

1. Determine what the important criteria are in terms of the WM assessment program goals a constraints, and the overall corporate goals an constraints. Examples of criteria are the following:

   - Reduction in waste quantity
   - Reduction in waste hazard (e.g., toxicity, flammability, reactivity, corrosivity, etc.)
   - Reduction in waste treatment/disposal costs
   - Reduction in raw material costs
   - Reduction in liability and insurance costs
   - Previous successful use within the company
   - Previous successful use in industry
   - Not detrimental to product quality
   - Low capital cost
   - Low operating and maintenance costs
   - Short implementation period (and minimal disruption of plant operations)
   - Ease of implementation

   The weights (on a scale of 0 to 10, for example) are determined for each of the criteria in relation to their importance.For example, if reduction in waste treatment and disposal costs are very important, while previous successful use within the company is of minor importance, then the reduction in waste costs is given a weight of 10 and the previous use within the company is given a weight of 1 or 2. Criteria that are not important are not included (or given a weight of 0).

2. Each option is then rated on each of the criteria. Again, a scale of 0 to 10 can be used (0 for low and 10 for high).

3. Finally, the rating of each option from particular criteria is multiplied by the weight of the criteria. An option's overall rating is the sum of the products of rating times the weight of the criteria.

The options with the best overall ratings are then selected for the technical and economic feasibility analyses. Worksheet 13 in Appendix A is used to rate options using the Weighted Sum method. Table G-1 presents an example using the Weighted Sum Method for screening and ranking options.

Table G-1. Sample Calculation using the Weighted Sum Method

ABC Corporation has determined that reduction in waste treatment costs is the most important criterion, with a weight factor of 10. Other significant criteria include reduction in safety hazard (weight of 8), reduction in liability (weight of 7), and ease of implementation (weight of 5). Options X, Y, and Z are then each assigned effectiveness factors. For example, option X is expected to reduce waste by nearly 80%, and is given an rating of 8. It is given a rating of 6 for reducing safety hazards, 4 for reducing liability, and because it is somewhat difficult to implement, 2 for ease of implementation. The table below shows how the options are rated overall, with effectiveness factors estimated for options Y and Z.

	Ratings for each option			
Rating Criteria	Weight	X	Y	Z
Reduce treatment costs	10	8	6	3
Reduce safety hazards	8	6	3	8
Reduce liability	7	4	4	5
Ease of implementation	5	2	2	8
Sum of weight times ratings		166	122	169

From this screening, option Z rates the highest with a score of 169. Option X's score is 166 and option Y's score is 122. In this case, option Z and option X should both be selected for further evaluation because both of their scores are high and relatively close to each other.