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BASEL CONVENTION

TECHNICAL GUIDELINES

Technical guidelines on the environmentally sound recycling/reclamation of metals and metal compounds (R4)

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I. Introduction

1. The present technical guidelines are principally intended to provide guidance, to countries which are building their capacity to manage waste in an environmentally sound and efficient manner, in their development of procedures or strategies for recycling metals and metal compounds, and to encourage further recycling of metals in an environmentally sound manner. Some waste will contain metals and metal compounds in forms and amounts sufficient for recycling and reclamation to be considered in preference to disposal, and in that case such recycling and reclamation is to be preferred.

A. Scope of the guidelines: metals

2. These guidelines focus mainly on the recycling and reclamation of metals and metal compounds that are listed in Annex I to the Basel Convention as categories of wastes to be controlled. Those categories include the following metals and their compounds: antimony (Sb), arsenic (As), beryllium (Be), cadmium (Cd), lead (Pb), mercury (Hg), selenium (Se), tellurium (Te) and thallium (Tl). They also include compounds of copper, zinc and hexavalent chromium, but not the metals themselves. These metals and metal compounds may be referred to as Annex I metals and metal compounds or, more simply, as Annex I metals. Materials that contain them are controlled under the Basel Convention if they fall within the Convention's definition of waste, unless they do not possess any of the hazardous characteristics listed in Annex III to the Convention.

3. Because the majority of metal-bearing hazardous wastes listed in Annex VIII of the Basel Convention are non-ferrous, and in order to keep them to a manageable size, these guidelines do not focus directly on ferrous metals, such as iron and steel, nor on precious metals, such as gold and silver.

4. Much of what is discussed below regarding recovery, recycling, and reclamation applies to all common non-ferrous metals whether listed in Annex I to the Basel Convention or not. However, special attention is paid to Annex I, or Y-list, metals. It will be pointed out that the prime substances for recycling and reclamation are metals, metal alloys and some metal compounds. Metal compounds are, depending on their physical or chemical form, either raw materials or (intermediate) products and are not materials destined for waste streams. The compounds which are commonly reused by recycling or are extracted/produced by reclamation arise from metal uses such as galvanizing or from metal products within pollution-control dusts or sludges.

5. Other possible relevant Y-List entries include Y5 wastes from the manufacture, formulation and use of wood-preserving chemicals (e.g., cupric arsenates or similar metallic formulations with arsenic); Y7 wastes from heat treatment and tempering operations containing cyanides, Y14 waste chemical substances arising from research and development or teaching activities which are not identified and/or are new and whose effects on man and/or the environment are not known; and Y17 wastes resulting from the surface treatment of metals and plastics (e.g., from electroplating). Note that Y16 wastes, from production, formulation and use of photographic chemicals and processing materials, are included in these guidelines only if the materials do not contain silver. Such wastes often contain silver, which is not regulated under the Basel Convention, and are commonly reclaimed for silver, but this is achieved by chemical processes which differ from most other recovery processes.

6. In general, the Basel Convention seeks to regulate substances with significant potential to give rise to adverse environmental or health effects if improperly disposed of; it excludes other less potentially hazardous metals and some forms of the listed metals that have a low potential for environmental effects, such as scrap metallic lead in non-dispersible form. For example, copper and zinc scrap metal is not regulated under the Convention; copper and zinc compounds are if they exhibit an Annex III characteristic. An example is given below in which zinc by-products are discussed.

B. Scope of the guidelines: processes

7. The guidelines are intended to provide information on the management options available for recycling and reclamation of non-ferrous metals and metal compounds and the practices that should be considered to avoid adverse environmental effects associated with that recycling. Some guidance is given on the final disposal of wastes that may arise from those operations.

8. Many technical terms and terms of art are used in discussing non-ferrous metals. For a glossary see http://www.amm.com/ref/glossary.htm.

9. The guidelines distinguish between different segments in the industrial structure, *recovery, recycling* and *reclamation*. Recovery can be viewed as taking metallic or metal-containing items and metallic pieces before they reach the waste stream or taking them out of the waste stream. Recycling then follows as the preparation of those items and pieces so that they may be used directly (e.g., in direct remelt) or sent for reclamation. Reclamation generally refers to a metallurgical process, usually pyrometallurgical, but hydrometallurgical for some metals and processes, whereby the recovered or recycled metal is purified and remelted or refined into a form that can be used in the same was as virgin metal. It should be noted that recovery, recycling and reclamation are not always included within the waste regimes in all countries. However, recycling and reclamation of hazardous wastes do fall under the Basel management regime under the definitions of waste (Article 1, subparagraph 1 (a) and Annex IV, section B).

10. Recovery and recycling of Annex I metals do not have to be highly expensive or technically complex processes, although management and workers must be properly trained and equipped to deal with hazards to human health and the environment. As discussed in this document, recovery is possible by identifying, accumulating, sorting to specification and selling Annex I metals on the domestic or world markets. Recovered metals may be sent to a remelt shop, such as a foundry, or to a refiner, or to a reclamation facility. Reclamation takes place in a primary or dedicated secondary smelters or, in some cases, by hydrometallurgy.

11. Few countries can afford to build or operate complex smelters and their associated infrastructure. There are economies of scale for smelters, especially primary (ore-based) smelters, so that larger is generally better. Primary smelters are often located near ore bodies. Secondary smelters are specially designed for the reclamation of metals. Secondary metals, materials which contain metals and some of their residues can be sent to and reclaimed within primary or secondary smelter plants. Additional environmental controls may be necessary to manage and process some secondary materials safely; such secondary materials represent a growing proportion of the feedstock at some smelters.

12. Smelting of secondary materials usually results in a main product and several by-products. For example, a typical copper smelter uses a three-stage process to produce pure copper. By-products are zinc oxide, tin-lead alloys, nickel sulphate, selenium and precious metals, which need other smelters to refine them, and also arsenic. It may be possible to use the slag as a construction material or for sandblasting, but such uses of copper slag have, historically, resulted in arsenic and lead contamination. Entry B2040 in Annex IX of the Basel Convention includes slag from copper production, mainly for construction and abrasive applications, provided that it is chemically stabilized, has a high iron content (above 20%), and is processed to industrial specifications such as DIN 4301 and DIN 8201. Some copper slags have a high and recoverable metal content and entry B1100 in Annex IX of the Basel Convention includes slags from copper processing destined for further processing or refining, provided they do not contain arsenic, lead or cadmium in hazardous concentrations.

13. These guidelines are intended for managers or regulators, not design engineers or other highly technical personnel. Those readers are referred to the metals recycling technical literature. For example, a comprehensive book by Henstock details much of the chemistry of non-ferrous metals recovery and reclamation, although some of the processes described are not commercial for technical or economic reasons. The comprehensive, encyclopaedic volume of the European Commission Joint Research Centre[1] details modern engineering solutions for the production and reclamation of non-ferrous metals.

14. This text is not intended to provide design or process information that can be used to undertake recycling or reclamation of metals or metal compounds. Rather, the guidelines provide a review of some available options with commentary on their application. If recovery, recycling - or especially reclamation - of metals or metal compounds is proposed, then a detailed economic, market, engineering and design process must be undertaken to protect the capital investment, together with an assessment and evaluation of environmental impacts and control strategies. Metals are commodities and are traded and recycled in a global market; the preparatory steps listed below must be taken with that in mind.

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[1] European Commission Joint Research Centre, *Integrated Pollution Prevention and Control (IPPC): Reference Document on Best Available Techniques in the Non-Ferrous Metals Industries* (2000). http://www.jrc.org/.

15. These guidelines are not intended to replace or provide guidance as to the domestic regulation of metals or metal compounds. It is expected that the local regulatory bodies, such as the relevant environmental protection authority, will set the regulatory controls that should apply in each instance. Reclamation, whether through smelting or hydrometallurgy, requires a sophisticated regulatory infrastructure. Recycling, such as through collection, sorting and preparation to specification, requires a much simpler regulatory regime so is well suited to new installations, especially in developing countries. Nor are these guidelines intended to explore the differences between wastes and secondary resources or secondary raw materials. International Standards Organization standard ISO 14040:1997, which defines raw materials as "material of primary or secondary sources that is used to produce a product (intermediate or final)" should be consulted in this connection.[2]

16. These guidelines are not intended to provide a definitive listing of all forms of metals and metal compounds that may be regulated under the Basel Convention. The text of the Convention, its annexes and supporting documentation produced in member countries should be referred to for that purpose. Also, the reader is reminded of the differences between Basel Convention hazardous wastes (Article 1, subparagraph 1 (a)) and wastes which are considered hazardous under domestic legislation (Article 1, subparagraph (b)), as they may not always be the same.

- **Caution: Metals in finely divided form, i.e. fine powders, can be dangerous.**

17. These guidelines stress the recovery and sale of materials to specifications. It is impossible for materials to be sold otherwise. Specifications often include limits on cleanliness, which promote cleaner production and environmental protection. However, some specifications apply merely to origin, that is, that the material must arise from an established process.

18. Specifications are either supplied by or negotiated between buyers and sellers. Both may rely on internationally established, published specifications. The international specifications may be obtained from the Bureau for International Recycling (BIR), www.bir.org, or the Institute of Scrap Recycling Industries (ISRI), www.isri.org.

19. Metals can be recovered, recycled or reclaimed over and over again without losing their properties. In final form, recycled metals are indistinguishable from virgin metals.

20. The recovery, recycling and reclamation of metals are industrial processes that require environmental controls. Recovery and recycling (as described in the present text) generally require a very different level of control than does reclamation because these more rudimentary operations are often must less likely to disperse pollutants into the environment or workplace.

C. Scope of the guidelines: topics

21. These guidelines encompass a number of broad areas in various chapters:

- Sources and use of secondary Annex I metals
- Suitability of waste metals for recovery and reclamation
- Establishing a recycling or recovery facility
- Environmentally sound reclamation facilities
- Environmental and health considerations
- Assessment of predicted environmental impacts
- Waste prevention and cleaner production
- Potential environmental hazards and their control
- Shut-down of metals reclamation facilities
- Glossary of terms

[2] See http://www.iso.ch/.

II. Sources and use of secondary Annex I metals

22. Secondary metals can be recovered from scrap metals or from metal-bearing ash, residues, slag, slugs, dross, skimming, scaling, dust, powder, sludge, cake and catalysts. Scrap metals arise predominantly from three sources: home, plant or runaround scraps; prompt or manufacturing scrap (or trim); and obsolete scrap from dismantled or discarded items.

23. What are called home, plant or runaround scraps are the waste arisings of metals production. For example, they may be the ends of rollings or the removed build-up from molten metal ladles, or the trim from a foundry, such as sprues and gates. A variety of intermediate impure metals or metal compounds are produced in a non-ferrous smelter. These are not wastes but valuable intermediates and in-process materials for the next step, often the next metal, in refining and reclamation, which may take place on or off site.

24. Prompt or manufacturing scrap (or trim) arises from the production of intermediate products (e.g., rods, bars, sheets, strips, tubes, profiles, plates, ingots) or from the machining or forming of intermediate products and final products. The scrap has the form of turnings, borings, clips, punch, trim or rejected (off-specification) parts. This scrap is clean, in that it has in a sense never been used, and is of known composition, i.e. the same as the material sold to the plant. This is valuable material and is sometimes sought by the provider of the metal. It is valuable also to scrap processors. Recycling takes place by direct reuse, as by remelting.

25. Obsolete scrap is the type of scrap on which waste managers must focus their attention. It arises from obsolete items, such as demolished buildings and end-of-life automobiles, appliances and electronic devices. The obsolete item often must be dismantled, whether by a vehicle shredder, shears or by workers with hand tools. The non-ferrous metals contained must be identified, prepared and sorted to buyers' specifications in order to be sold for recycling. The buyers will use this prepared scrap for the production of such products as billets, cathodes, granules or plates. Sometimes these new raw material forms may fall under the controls of the Basel Convention (Annex VIII) or under national control.

26. Processors of obsolete scrap can also handle prompt scrap. Turnings, borings, clippings and other forms, if necessary properly prepared by scrap processors, are directly used as raw materials to produce products, for example by direct remelting.

27. Most of the non-ferrous metals collected, sorted and graded for recycling are not hazardous, i.e., not in Annex VIII. The large volume of intermediate or final products produced from scrap non-ferrous metals prepared from secondary resources consist commonly of aluminium, copper, lead or alloys of base metals copper, aluminium and zinc. Nonetheless, the following discussion is offered as a guide to some of the sources of obsolete scrap of metals, their alloys and their compounds mentioned in Annex VIII.

A. Antimony

28. Antimony is not used in pure form but as a minor, albeit important, alloying additive. The most important use of antimony is as a hardener in lead for storage batteries. The metal also finds applications in solders and other alloys, such as printers' type. Antimony in small quantities is used as an alloying element in bearings and in tin alloys such as pewter and costume jewellery alloys. Antimony compounds are used as catalysts, pigments, in matches and fireworks, and as veterinary parasiticides. Antimony trioxide is the most important of the antimony compounds and is primarily used in flame-retardant formulations such as those used in children's clothing, toys, aircraft, and automobile seat covers. All are unlikely sources of recyclable antimony.

29. When antimony-containing alloys are reclaimed, the minor amounts of antimony are likely to remain with the base metal in the alloy. For example, if an antimony-lead alloy is melted, the air pollution control equipment is much more likely to capture lead than antimony. Lead melts at 327°C and antimony at 630°C.

30. A possible exception is that antimony trichloride solution is sometimes used to "bronze" iron, colour zinc black and dye woods. Any of these uses may give rise to residues of questionable recyclability but which need special management.

31. It is highly unlikely that waste antimony will ever be encountered by itself.

B. Arsenic

32. Arsenic is generated as a by-product in the non-ferrous metals industry. Also, small percentages are added to lead alloys for battery grids and cable sheathing to improve hardness. In amounts up to three percent, arsenic improves the properties of lead-based bearing alloys. Smaller quantities are used in a few copper alloys. Arsenic has been used in the manufacture of specialty low-melting-point glasses, in which it is completely sequestered, and it is a minor component of a class of semiconductors. None of these applications will giver rise to arsenic for recycling.

- **Caution: Metallic arsenic quickly develops a whitish coating of the oxide. If, by rare chance, you encounter metallic arsenic, do not attempt to recycle it without expert guidance. The coating, like many arsenic compounds, is highly toxic. The metal should not be melted except by specialized technicians.**

33. Arsenic, in minute quantities, serves a variety of functions in the electronics industry. It is used in the processing of gallium arsenide crystals (used in mobile phones, lasers and so on), as a dopant in silicon wafers, and to manufacture arsine gas (H3As), which is used to make superlattice materials and high-performance integrated circuits. Arsenic metal also increases the corrosion resistance and tensile strength of copper alloys and strengthens posts and grids in lead-acid batteries. Waste containing arsenic require careful handling because the metal leaches and has a relatively low boiling point of 614°C.

34. Arsenic compounds have been used as insecticides, wood preservatives, pigments in glasses and ceramics and in veterinary therapies. Most of the arsenic is consumed as the trioxide, mainly in the manufacture of preservatives for pressure-treated wood. These are unlikely sources of recyclable materials.

35. It is highly unlikely that waste arsenic will ever be encountered by itself.

C. Beryllium

36. Beryllium is used as an alloying additive to copper and nickel (up to a maximum of 2%) for springs, electrical contacts, aircraft landing gear bearings, plastic moulding tools, oil field exploration and drilling equipment, spot-welding electrode support arms and safety tools. Unalloyed beryllium is used in nuclear weapons, spacecraft, nuclear reactor radiation reflectors, X-ray windows, inertial guidance systems and other precision instrumentation. The oxide, beryllia (BeO), is used in some electronic equipment as a heat sink. Sources for recycling are the prompt scrap generated in processing beryllium-copper alloys and quantities of obsolete military equipment containing metallic beryllium. Some small amounts of the oxide may be encountered in the recycling of electronic goods and should be recovered or otherwise isolated from the environment. It is highly unlikely that beryllium metal will be encountered, except by specialists dealing with this metal.

- **Caution: Beryllium in massive form, pure or alloyed, is not dangerous to handle. Danger, including the risk of the disease berylliosis, arises when beryllium or beryllia is in the form of very small, airborne particles capable of being inhaled. Only specialized technicians and facilities should saw, machine, heat, melt or incinerate the material. Sufficient quantities of alloy or metal waste arisings can be sold in the form you find them. They can be handled with gloved hands with no problems. See also the section on copper.**

37. Beryllium compounds, with the exception of beryllium oxide (beryllia), are often laboratory curiosities and are not at all likely to be encountered. However, because beryllium is present at very small concentrations in almost all electronic scrap (and in higher concentrations in a very small number of electronic devices), it needs attention, because such scrap is commonly recycled for copper and precious metal reclamation. At the low beryllium levels normally encountered in scrap equipment (< 0.1%) no special precautions are generally required, and the traces of beryllium and its intermediate compounds become part of the copper scrap stream for recovery. Where the beryllium content of the scrap is higher, however, melting may result in an inhalation risk from beryllia in slag, and air extraction and filtration should be used to control that risk.

D. Cadmium

38. Cadmium metal is now mainly used in nickel-cadmium batteries. The use of cadmium as an anticorrosive plating and in pigments and stabilizers is now banned in northern European countries, although there is still some use of cadmium for these purposes in other countries. Cadmium is also used in electronic components, such as semiconductors, and in the control rods of nuclear reactors. Fertilizers produced from phosphate ores may constitute a major source of diffuse cadmium pollution. In Australia, for example, phosphate fertilizers have been a major source of cadmium additions to agricultural soil. The Australian fertilizer industry has made significant reductions in the cadmium content of fertilizers over the past 10 years and now uses rock phosphate with lower cadmium concentrations for local manufacture (http://www.cadmium-management.org.au/). In the United States of America, the Environmental Protection Agency (USEPA) has set a maximum permitted concentration for cadmium of 1.4 mg/kg (ppm) per unit (1%) zinc content in zinc micronutrient fertilizers produced from recycled zinc wastes (http://www.epa.gov/epaoswer/hazwaste/recycle/fertiliz/index.htm)

39. About three quarters of cadmium consumption is used in nickel-cadmium batteries, and because such batteries are easy to collect for recycling, most of the secondary cadmium comes from these spent batteries. Cadmium is also produced as a by-product in the zinc production process and some secondary cadmium comes from the flue dust generated during the melting of recycled galvanized steel scrap in electric arc furnaces. Recovery of cadmium from batteries and flue dust is complex and hazardous and must only be carried out in a specialized facility. Cadmium can also be reclaimed from the pollution control sludges from electroplating facilities. These sludges arise from treating the wastewater.

- **Caution: If pure cadmium metal is found, do not create dust or fumes, for example by machining or melting. Only specialized technicians may be allowed to melt cadmium metal.**

E. Hexavalent chromium compounds

40. Chromium is an alloying agent used in steel and various nickel based and cobalt based superalloys, aluminium base alloys, electrical resistance alloys, hard facing grains and powders, and for electroplating. No special precautions are necessary in handling chromium metal or its alloys.

41. Chromium alloys such as stainless steels and superalloys are highly desirable for recycling. Most chromium is recycled as a component of stainless steel back into stainless steel. Little chromium metal as such is found or recycled.

42. Hexavalent chromium (Cr^{6+} or Cr(VI)) compounds are hazardous. This form of chromium is found in plating solutions and may be removed by chemical additives. However, some may be carried over and not be removed by the rinse water. If the Cr^{6+} in plating solutions is reduced (“killed”), the chromium can be recovered from the subsequent wastewater treatment sludge. While there are generally difficulties in achieving the purity of product and concentrations required at an attractive economic cost, under the right circumstances, Cr^{6+} can be recycled. Most larger plating shops recycle their rinse water to some extent. Also, there may well be many situations where the best practical environmental option is to recycle waste containing hexavalent chromium without first chemically reducing it (either within an operation, or, if the waste in question is chemically and physically suitable, at a chromium chemicals manufacturing facility). Cr^{6+} compounds are usually identified in minute quantities when present, except in treating wood, where the presence of trivalent chromium in the treated wood product predominates (>99.9%) and, because of natural reducing agents in the wood, hexavalent chromium is hardly present even in trace quantities.

43. Hexavalent chromium is used for its preservative properties and as a soluble salt in electroplating with chromium metal. In tanning, the trivalent form (as chrome alum ($KCr(SO_4)_2$) is usually used. In wood treatment it is not the hexavalent chromium that is the preservative (if chromium really functions as a preservative at all). Chromium serves as a fixative agent and in properly fixed wood is present in the trivalent form. The chemically complexed trivalent chromium in the treated wood is very different from the chromic acid or other hexavalent chromium compound used in the original treatment.

44. Chromium can be reclaimed from the pollution control sludges from electroplating facilities. These sludges arise from treating the wastewater. Chromium can also be reclaimed from a number of different spent catalysts and metallic dusts.

F. Copper compounds

45. Most copper compounds are not hazardous and are therefore listed in Annex IX to the Convention. Annex VIII identifies just a few. Copper metal and its alloys (e.g., brasses and bronzes) are highly desirable for recovery, recycling or reclamation. Like zinc (paragraph 63 below), copper is an essential element.

46. The copper compounds listed in Annex VIII are not likely to be encountered for recycling. A few are intermediary products or process chemicals at smelters; many never leave the smelter, where they are usually reclaimed. An exception is spent etching solutions containing copper from circuit board manufacturing. These solutions can be restored to useable form, hence recycled. The chemical reactions to do this, or otherwise to recover the copper, must be carried out by experienced processors, who are sometimes the suppliers of the etching solutions.

- **Caution: Special consideration is necessary for electrical and electronic assemblies or scrap containing hazardous components. Incineration of electrical and electronic scrap, as well as cable incineration, produces hazardous fumes and needs environmental controls. Electrical wire must be stripped and not incinerated. Once stripped, electrical wire is not hazardous for melting because it is very high-quality copper.**

47. Copper can also be reclaimed from various slags, ashes, drosses, catalysts and dusts, and also from sludges, e.g., from treatment of the wastewater from electroplating facilities. Copper is one of the most widely used and highly recovered, recycled and reclaimed metals, in part because it is easily to recover thanks to the distinctive appearance of the metal and its alloys.

- **Caution: Copper smelting requires modern pollution control equipment. Copper from electronic scrap may contain beryllium, which because of its health hazard must be captured in the air pollution control equipment.**

- **Caution: If copper-containing electronic scrap is ground for recovery, the dust must be controlled and captured. Grinding can release beryllium-containing dusts.**

G. Lead

48. Lead is ubiquitous in the earth's crust, with rich deposits of ores in many countries. Also, the relatively low melting point and malleability of lead have led to its use in many applications since early historical times. Today, the major use for lead is in automotive batteries. As a result, lead consumption increases with growth in a country's economy and vehicle population.

49. By the mid-1980s, a significant shift in lead use had taken place because of concerns for health and the environment. The use of lead in non-battery products continues to decline. In the United States of America, as an example, 88% of lead used goes into batteries. About 1 million tonnes (equivalent to 61% of United States consumption) was recovered from used batteries alone. Total use of secondary lead amounted to 76% of the lead produced in 1999 in the United States. In 1999, recovery from lead-acid batteries just in the United States amounted to 18% of world production of lead. This illustrates the importance and ease of recycling lead.

50. Worldwide, the principal sources of secondary lead for recycling are spent lead-acid batteries (automotive, truck, marine and stationary), smelter dusts and slags, and cable sheathing (a massive form, Annex IX). Lead recovery from spent batteries needs special management, such as avoiding manual disassembly (as by splitting with an axe) or open burning, and in its decision VI/22 the Conference of the Parties to the Basel Convention adopted the Technical Guidelines for the Environmentally Sound Management of Waste Lead-acid Batteries. Other information may be found at

www.ilmc.org, and the United Nations Conference on Trade and Development has presented some papers on its experiences in assisting developing countries in upgrading battery collection and smelters (both technical and environmental performance) and increasing recycling (see www.unctad.org). The smelters also accept the lead sulphate in the spent batteries so that it does not have to be removed before reclamation.

51. Recycling of lead-acid batteries is important for another reason: it keeps them out of the waste stream destined for final disposal. Lead in lead-acid batteries in unlined landfills can find its way into groundwater if it is not chemically complexed and fixed in the particular soil it encounters.

52. Lead can be reclaimed from the pollution control sludges arising from treatment of the wastewater from electroplating facilities. Lead can also be reclaimed from solder wastes, but recycling lead/tin solders can be extremely dangerous because emissions of dioxins, beryllium, arsenic, isocyanates and lead itself are likely.

53. Lead can be reclaimed from cathode-ray tubes such as used in personal computer monitors. The glass of the tube can be broken up and sent to a facility for the reclamation of glass or lead, but care must be taken to manage hazards such as exposure to toxic phosphors and the risk of silicosis. Alternatively, the glass can be used in a lead smelter as a flux. In either case, the facility recovering the leaded glass from cathode ray tubes should cut it from the other components of the tube with care not to crush the glass to fine particles that can be breathed by workers.

54. Small quantities of lead compounds are used in some plastics, although this use is phasing out. Some few compounds are used in veterinary medicine. Lead oxides and chromates may be used in specialized paints for structures, such as bridges, because of the excellent corrosion resistance imparted by the paints. Tetraethyl lead is used in fuel as an anti-knock agent, although its use for this is decreasing. Most of the world (by population) has phased out this use of lead (http://www.ilmc.org/). Lead is still used extensively in PVC-coated wires (2% – 5%) and this use of lead is not being phased out as yet. This lead is not recycled but is released if the wires or insulation are burned.

- **Caution: Recovered lead, and especially batteries, should not be melted in the open air but only in specially equipped smelters. Workers must wear personal protection equipment such as approved facemasks. They should also change clothes and shower at the end of the workday so that no lead dust is carried home.**

55. Brass may include as much as 3% lead to increase machineability. Lead is almost insoluble in brass, but is dispersed in the form of fine globules. Moreover, its low melting point allows it to act as a lubricant, reducing the friction coefficient between tools and product. Thus wear on tools is reduced and surface finish of products is improved. In Europe, about two thirds of the tonnage produced is made up of recycled leaded brass which has been remelted; one half of the total is machining scrap taken back by the provider. During brass furnace operations, precautions to be taken by the operators are similar to those for lead production, although the constraints are less stringent since the lead concentration is far lower. Lead is also used as an alloying element with other metals, such as aluminium, generally to facilitate machining.

H. Mercury

56. Mercury is an oddity of nature, the only metal which is liquid at room temperature. As a result of this unique property, including its uniform volumetric thermal expansion and good electric conductivity, mercury finds specialty uses, including in laboratory equipment. Some is used in lighting and in chemical manufacture; use in dry-cell batteries or as an electrode in electrolytic cells is being phased out. Most mercury is used for the manufacture of industrial chemicals and for electrical and electronic applications, including a new use in flat-screen computers and televisions. It is found in fluorescent light tubes. It is rare to find mercury in a typical non-ferrous metal recovery/recycling operation. Mercury is still used by some artisanal miners to amalgamate gold from ore, but this practice is not environmentally sound. Methyl mercury can form in nature from elemental mercury and is one of the most serious toxic threats known. It presents a serious liability and risk for mercury waste disposers/recyclers.

- **Caution: Mercury vapours are a health hazard. Containers should be securely covered and all operations involving mercury metal should be carried out in a well-ventilated area or in a closed system to prevent accumulation of mercury vapour in the workplace. This is of utmost importance if the operation involves heating mercury above room temperature. There are also broader hazards to public health.**

57. Mercury is used in dentistry for obtrusion. Mercury compounds are used sparingly in veterinary medicine, explosives, fireworks and specialty antibacterials. Mercury compounds are found which are destined for recycling, such as dental amalgams and calomel (mercuric chloride), which are recycled in pharmaceutical formulations. Mercury is a trace metal naturally present in some ores and is captured from gas scrubbers installed at zinc, copper and lead smelters.

58. Mercury metal may be recycled in special facilities by vacuum distillation. However, mercury recycling is potentially hazardous and there have been tragedies such as the deaths of three workers and the illness of at least 20 others from mercury exposure in South Africa in the early 1990s. Recycling is an important source of mercury, representing most domestic mercury produced in the United States of America. As mercury is still used in products and processes, recycling may remain an important source of mercury to minimize production of primary mercury. In order to stop recirculation of mercury in society, some countries are considering methods for final disposal, such as aboveground, monitored and retrievable secure storage, together with policies for production, marketing and use. More and more uses of mercury are being phased out in developed countries but are increasing in developing countries, where there is usually very limited capacity to deal with mercury wastes.

I. Selenium

59. Selenium wastes are generated in the copper-refining industry (anode slimes) and in gas scrubbers at nickel smelters, alloy plants and so on. Selenium is used as an alloying agent, particularly to replace lead in free-machining brasses for plumbing. The metal is also used in electrical rectifiers, although this use is rapidly giving way to silicon, as an alloying agent, in the toner cartridges of xerographic copiers, although this use is rapidly giving way to organic compounds, in pigments and as a colorant in glass. A major use is as a feed additive for livestock and for some human dietary supplements as an anticancer agent, because selenium is an essential nutrient. A few selenium compounds are used in veterinary medicine. The quantities of selenium or its compounds destined for recycling range from extremely small to negligible.

J. Tellurium

60. Tellurium is a relatively rare element, and is also a by-product from copper production. It is used as an alloying agent in iron and steel (the dominant use, up to 0.1%), in thermoelectric alloys, in fuse wire for explosives, in catalysts, in vulcanization and as a colorant in glasses and ceramics. Highly pure tellurium is used in semiconductors. Tellurium compounds may substitute for the element itself as colorant agents. The quantities of tellurium or its compounds destined for recycling range from extremely small to negligible.

K. Thallium

61. Thallium and its compounds are highly toxic materials and are strictly controlled to prevent threats to human health and the environment. Thallium has limited uses, such as an alloying agent for mercury for electric switches in spacecraft and in hi-tech electronic devices. A few radioactive thallium compounds are used in medical diagnostic procedures. There is almost no probability of seeing thallium or its compounds for recycling.

- **Caution: If for any reason you come across thallium metal or its compounds, do not handle because of the high toxicity. Contact the appropriate authorities.**

62. Thallium sulphide is used as rat poison and thallium sulphate is used as insecticide and pesticide. A few radioactive thallium compounds are used in medical diagnostic procedures. There is almost no probability of seeing thallium or its compounds for recycling. However, thallium-based high temperature superconductors for advanced superconducting electronic devices are currently being deployed.

L. Zinc compounds

63. About one third of zinc production is from recycling. Zinc is necessary to modern living and health; in tonnages produced, it stands fourth among all metals in the world, exceeded only by iron, aluminium and copper. About three quarters of the total is consumed as metal, mainly as a coating to protect iron and steel from corrosion (galvanized metal), as an alloying metal to make bronze and brass, as zinc-based die-casting alloy and as rolled zinc. The remaining quarter is consumed in the form of zinc compounds, mainly by the rubber, chemical, paint and agricultural industries, principally as zinc oxide. Zinc is a necessary element for the proper growth and development of humans, animals and plants; it is the second most common trace metal, after iron, naturally found in the human body. Zinc oxide is used as a medicament.[3]

64. Because of wide differences in the character and zinc content of scrap, recycling processes for zinc-bearing scrap vary widely. The recycling of clean, new scrap, as brass, rolled zinc clippings and rejected die castings, usually requires only remelting. In the case of mixed non-ferrous shredded metal scrap, zinc is segregated from other materials by hand or by magnetic separation. Zinc has a relatively low melting point and may be separated from some other metals in a sweat furnace.[4] Most of the zinc recovered from electric arc furnace dust is recovered in rotary kilns by the Waelz process.

65. Zinc compounds, not the metal, are listed in Annex VIII to the Basel Convention. Very few zinc compounds are hazardous.[5] Zinc ashes and drosses are commonly recycled and there have been a few reports of drosses containing sufficient lead to exhibit an Annex III characteristic. However, lead and cadmium levels in ashes or drosses depend on the levels in the zinc, which are generally minor or trace, with much of the zinc used in continuous galvanizing processes producing ashes and drosses passing any Annex III test.

66. “Ashes” and “drosses” are terms commonly used in metallurgy. For example, in the zinc smelting process, an “ash“ is not created by burning any material per se, but rather it is the top layer of molten zinc that has oxidized in air. When it is skimmed, the ash is a clean mixture of zinc oxide and zinc metal, hence a good material for recycling. Drosses are skims and the leftovers from the molten zinc container, also an excellent source of metal for recovery and reuse. Drosses from continuous galvanizing processes where aluminium is the alloying agent do not contain lead. However, ashes, skims and leftovers from hot-dip galvanizing processes will typically contain lead in hazardous concentrations if Prime Western grade zinc is used, or if lead is used on the bottom of the bath.

67. Another source of zinc is from the air pollution control dusts from electric arc steelmaking. Much of the steel used in these furnaces is from shredded end-of-life automobiles. The sheet steel used in modern vehicles is coated with zinc (galvanized). The zinc is vaporized in the electric arc furnace and is captured in the air pollution control equipment; it is suitable for recycling only in specialized plants. Major regulatory authorities identify these fine dusts as hazardous because of their cadmium and lead contents, but they can be recycled into zinc micronutrient fertilizers. For example, in the United States of America about half of all zinc fertilizers are made from hazardous industrial wastes which can include emission control dusts from electric arc steel furnaces and brass foundries as well as ash from energy recovery facilities that burn tyres. USEPA regulates the conversion of zinc wastes into fertilizers, most of which are applied sparingly to farmlands (typically, a few pounds per acre per year), and are used to fertilize crops such as maize, potatoes and fruit trees. The regulations limit hazardous metals in recycled zinc fertilizers by setting standards based on demonstrated good manufacturing practices, and by setting a standard for dioxins based on background levels in soils.

[3] Of the zinc compounds produced, most is zinc oxide, which in its commercial form is very pure.

[4] Sweat furnaces (otherwise known as dry hearth furnaces) separate metals by melting depending on their various melting points.

[5] Some references properly list triethyl zinc as hazardous . This compound is used in military explosives and is a laboratory curiosity. It will not arise for recycling.

III. Suitability of waste metals for recovery and reclamation

68. In general, waste metals for recovery and reclamation are materials that comprise pure metals or metal compounds or can be readily reduced to those forms. Mixing with other materials can introduce impurities that can make purification more expensive, or, if they are not removed, can adversely affect the intended production processes or end use of the metal or metal compound. Some metallurgical processes are designed, however, to process mixed metals and materials. Examples of separation processes that will often yield a pure metal from mixtures are electrolysis (particularly applicable to copper and zinc); vaporization/sublimation/volatilization (particularly applicable to cadmium and mercury); and drossing (particularly applicable to lead).

69. The recovery of metal will usually be determined by a commercial evaluation as to whether it can be returned to use at a profit. The users of metal will always be able to purchase it from primary sources, and metal which is produced from secondary sources must compete in the same markets. The factors that determine whether recycling and reclamation is viable include:[6]

- The initial purity of the metals to be recovered
- The market for the products of recycling and reclamation processes
- The monetary value of the metal
- The cost of collection and transport
- The cost of sorting and transformation into reusable metal
- The cost of special or additional worker and environmental protections associated with the material
- The cost of compliance with any additional environmental regulation associated with the material
- The final disposal cost avoided by recycling
- The cost of disposing of any residual material after the recycling and reclamation processes are completed

Other determining factors are lower energy consumption compared to primary production and also the long-term availability of sources to recycle, which is associated with the decision to invest in specific recycling facilities of a certain capacity which must be utilized to maintain competitiveness.

70. Non-ferrous metals are extensively recovered, recycled and reclaimed in world society.[7] Table 1 gives some idea of the extent of recovery of some non-ferrous metals. Smelters can be major point-source polluters if they are not operated cleanly, and typical emissions from smelters in an Organisation for Economic Co-operation and Development (OECD) country may be found at http://www.ec.gc.ca/pdb/npri/npri_home_e.cfm.

71. Some of the data in table 1 are for the United States of America alone because the data are available; although some are old, they are still the most recent available. Nevertheless, recycling rates are generally high for non-ferrous metals, which gives an idea of the value of recycling. World production figures and a few Annex IX metals are also included to provide perspective.[8]

72. Recycling rates must be viewed with caution for several reasons. Most of the metals recycled were produced years or decades before (coming from obsolete scrap). Recycling rates are often compared to present consumption, which could be much higher than when the obsolete items were first manufactured. Arithmetically, as production of a metal rises, recycling as a percentage of production could go down even if the tonnage recycled goes up. In fact, a recycling rate should be calculated from

6 See M. C. Campbell, *Non-ferrous Metals Recycling* (International Council on Metals and the Environment, Ottawa 1996).

7 These metals were recycled as far back as the Bronze Age (4500 B.C. in the Middle East) because they were too valuable to discard. This situation has not changed.

8 Data are from M. C. Campbell, *Non-ferrous Metals Recycling* (International Council on Metals and the Environment, Ottawa,1996), http://www.icmm.com/html/pubs_intro.php; H. Alter, "Industrial Recycling and the Basel Convention" (*Resources Conservation and Recycling*, Vol. 19, pp. 29-53, 1997), which quotes figures from the United States of America Bureau of Mines; United States of America Geologic Survey, *Minerals Yearbook* (United States of America Department of Commerce, Government Printing Office, Washington D.C., 2000).

the total volume of metal which is coming out of the application after the end of life and what is really recycled. This is the comparison between metal which is available for recycling and metal which is not following the closed loop due to several reasons (difficult to recycle because of its physical form or simply disposed in landfill).

73. There are few limitations to the extensive recycling of non-ferrous metals and their commonly occurring residues (a metal-bearing residue is often a compound of the metal, such as the oxide or a complex silicate making up a slag).

74. There must be sufficient quantity and value of the material to make recovery worthwhile. This should take into account the cost of replacement with new material and the cost of disposal of waste material. It may be worthwhile to accumulate larger quantities over longer periods of time or from larger geographical areas. Transport costs can be a significant factor, particularly if the metal content is only a small fraction of the total. Often a simple cost analysis will be sufficient to indicate whether recovery will be practical. For the metals considered in these guidelines, the quantities of metals and metal compounds varies greatly from metal to metal, and can vary from thousands of tonnes to only hundreds of kilograms per year globally.

75. In determining the suitability of metals and metal compounds for recovery, it is essential to consult with the end user of the material, i.e. the metal recycler or reclamation facility. It is essential to determine limitations and specifications with regard to quantity, physical form, acceptable constituents and unacceptable constituents, and requirements for quality assurance. Indeed, refineries will often specify the maximum levels of impurities associated with a required metal waste before acceptance, and the price (economic viability) will also vary according to impurity levels. For example:

- A nickel refiner may take nickel waste containing copper as a constituent and will vary the price according to the copper content, but may place stringent limits on zinc.
- A copper smelter may accept a copper waste with a small percentage of nickel as well as zinc, tin and lead but is likely to place a stringent specification on the maximum concentration of mercury, beryllium, bismuth, chromium or sodium.
- Makers of stainless steel may accept waste materials combining iron, nickel and chromium, where the composition is defined.
- Certain forms of metals, such as the halides or cyanides, may need to be converted into other compounds such as the hydroxide before they will be acceptable to a smelter.

76. Materials comprising just metals (or just some metal compounds, which is an unlikely situation), or which are readily reducible are the most suitable for recovery and reclamation. The buyers' specifications will detail which contaminants must be controlled. It is always better to have sorted (or otherwise prepared) single metals and alloys or permitted scrap mixtures for recycling. For example, a mixture of copper and zinc scrap will suit a brass foundry.

77. Some processes have been designed to accept and efficiently process mixtures. For example, some copper smelters have added specialized pollution control systems so that they can use printed circuit boards as feedstocks to recover precious metals, copper and other metals.

78. Specifications also deal with prompt scrap, which is important in controlling cleaner production if the manufacturer wants to be able to sell the prompt scrap.

79. Some metals can be recovered from rather crude mixtures. For example, plumbing scrap consisting of copper, brass and some lead (from solder) can be sold to special brass foundries. Secondary copper smelters accept plumbing scrap without any restriction, because they produce lead or lead-containing by-products.

80. Complex mixtures of metals (and metal compounds) are rarely encountered outside of the primary non-ferrous metals industries. These mixtures are a result of the refining and smelting processes. They are processed and separated by these very same processes (non-ferrous metal ores, except for aluminium, contain more than one recoverable metal and are processed in a sequence of steps whereby the residue from one recovery is the feed for the next).

81. Several non-ferrous metals are recovered from electroplating wastewater treatment sludges. The sludges can be sold based on their metal content and subsequently reclaimed.

82. Environmentally sound electroplating facilities will treat their spent plating and rinse baths before discharge. The small amounts of metal compounds in these potential discharges (e.g., copper, chromium, lead, zinc, cadmium or nickel) can be removed from their dilute solutions by a variety of means. The simplest is to increase the alkalinity (addition of caustic) to precipitate the metal hydroxides, which have value based on their metal assay. The value is increased if certain precautions are taken beforehand. For assistance, see http://www.namf.org/.

83. The metal hydroxide (or other) wastewater treatment sludges are like many other non-ferrous metal wastes (or ores) in that their value depends on their assay (metal content). The buyers will provide specifications. For assistance, see http://www.namf.org/.

84. Some slags and other residues from pyrometallurgical processes have a market value (their metal assays are high) to other pyrometallurgical facilities. However, a well-operated smelter (or foundry) will have low-assay slags as they do not waste valuable metals. Some air pollution control dusts and sludges will, by necessity, have high assay values. These are best recovered in the same smelter provided this does not cause impurity build-up. Properly skilled and experienced technicians and facilities are the best qualified to handle such pollution control dusts and sludges, many of which are hazardous.

Table 1. Extent of metals production and recovery
(thousands of tonnes per year for selected metals, data for 1989, recycled as percentage of consumption)

Metal	Production 1999		Recycled		Recycled as % of production		NOTES
	Western world	USA	Western world	USA	Western world	USA	
Antimony	122	0.5	20			49 (1989)	Production from ore only
Beryllium	6.2	5.1					Production from ore only
Cadmium	19.1	1.2	19			10	Amount recycled increased with more battery recycling
Chromium	14,000			118		21(1989)	Recovery as stainless steel, ferroalloy; production from ore
Cobalt	31.2			0.3		22 (1989)	Residues for recycling limited
Copper	11,582	2,132	5,582	1,257	34	31	
Lead	4,944	1,447	2,953	1,097	60	76	Recovery higher with higher lead-acid battery recycling
Mercury	3				62		Decline in demand for mercury
Nickel	1,050			71		33	High recovery as stainless steel
Selenium	0.15						
Tellurium	0.01						
Tin	269	16	17	16		30	
Zinc	5,831	371	555	140	30	>25	Recovery higher with available arc furnace dusts

IV. Establishing a recycling or recovery facility

85. The present chapter describes how a recovery facility may be established for collecting, storing, sorting, grading (to meet specifications), packaging and selling non-ferrous metals. Some of these facilities may be described as low-tech; no great, complicated equipment is needed. Their purpose is to receive, sort and grade metals for sale to smelters, remelters and refiners. These facilities, or scrapyards, are an integral part of the infrastructure of global recycling of non-ferrous metals.[1] A typical processing plant for the recovery of metals is shown diagrammatically below.

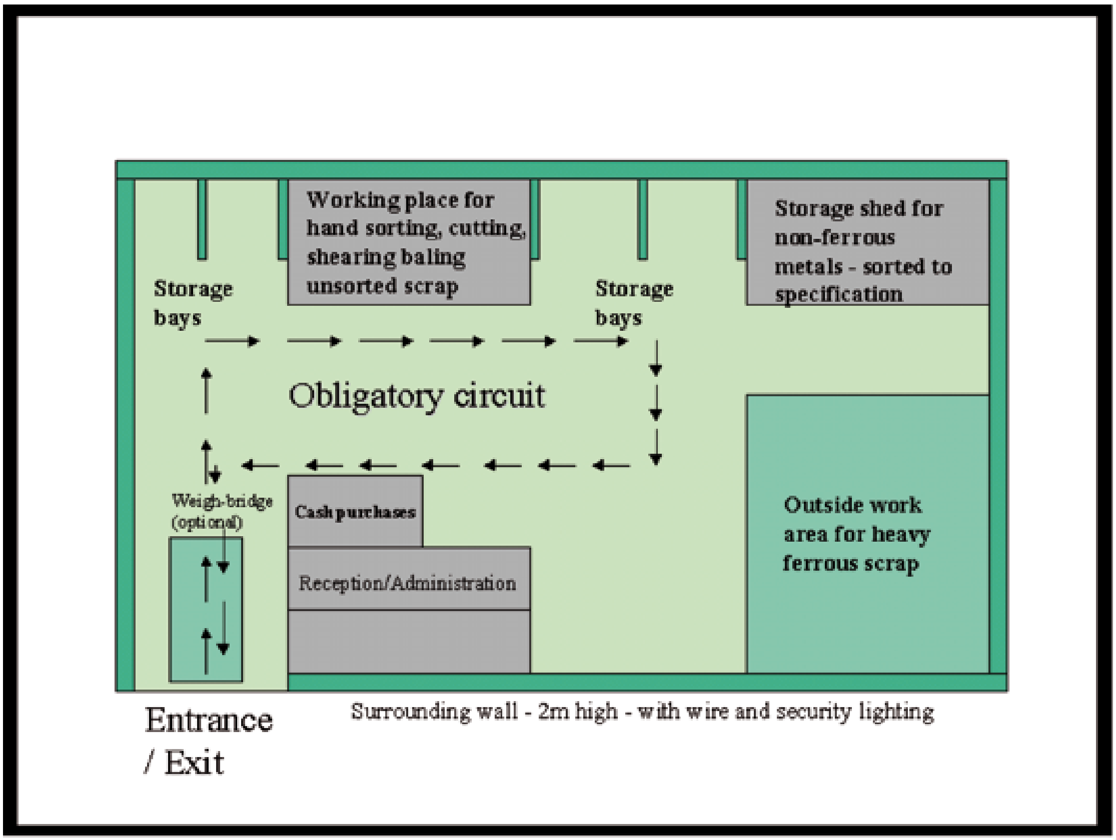

Figure 1. Diagram of a typical recovery facility (scrapyard)

86. A facility usually consists of a receiving area (including a weigh scale and cashier), a storage pad or shed, a sorting area and a shipping dock. The sorting shed is equipped with cutting tools, which are needed to cut pieces to specification size and to cut up composite pieces to separate different types of metals (an example is removing a copper pipe from a bronze valve, or stainless steel from iron). The facility may also have wire strippers and/or choppers if it accepts scrap wire and cable.

87. The entire facility should be fenced in a way that reduces windblown dust and litter and keeps out thieves: the scrap is valuable.

88. The receiving area is to allow individuals and vehicles entry to deliver scrap for the facility. The material is weighed and the seller can be paid immediately. The non-ferrous scrap is moved to the storage area.

89. The storage area should be on an impervious area to protect the ground from any contact with the scrap, and hence protect the environment, and in a building or shed to protect the inventory from the weather when necessary. The storage area should be equipped with bins or other containers (e.g., empty, cleaned drums or large cardboard boxes). Non-ferrous scrap is usually sold as small pieces. Filled containers, here or in the sorting area, must be picked up and moved, so the size of the containers must allow manual or machine (front-end loader) moving. Recommendations concerning storage and handling, transfer operations and traffic and roadways made be found in Convention for the Protection

[1] The yards are also integral to the recycling of iron and steel. Recycling of these metals usually requires bigger equipment, such as shears and balers. Some facilities have large shredders for end-of-life vehicles.

of the Marine Environment of the North-East Atlantic (OSPAR) Commission recommendation 98/1 concerning best available techniques and best environmental practice for the primary non-ferrous metal industry (zinc, copper, lead and nickel works) (see http//www.ospar.org/).

90. The sorting area should be similarly enclosed, with a paved floor. The area is equipped with tables and containers. Pieces of non-ferrous metals are cut as necessary (to meet specifications) and sorted into containers, which may be the ultimate shipping containers. Sorting must be carried out by trained people who can distinguish between different grades of, say, copper alloys (copper, brasses and bronzes) or different grades of stainless steel. This is necessary in order to meet specifications and obtain the highest possible price.

91. The purpose of the shipping dock is to enable loading of lorries for movement of the sorted scrap to smelters. Often, shipping to smelters will cross frontiers, in which case the drums or large cardboard boxes will be packed into shipping containers. A customs broker is a valuable assistant in such cases.

92. Packaging methods must conform to the United Nations model regulations on the transport of dangerous goods. See http://www.unece.org/trans/danger/publi/unrec/rev13/13nature_e.html for assistance.

93. For assistance with sorting, and especially specifications, consult http://www.bir.org/ or www.isri.org.

94. This kind of enterprise's success will usually be determined by a commercial evaluation depending on meeting international standards for form and specification and finding a market (brokers and traders are of great assistance here). Success will also depend on the global market price of the metals, which affects what will be received and how much will be paid for it.

95. Other factors affecting economic success include the cost of disposing of any residual material from the scrapyard and the cost of collection and transport.

96. The sort of recovery facility described above (a scrapyard) obtains its raw materials by solicitation. Two major sources of metal are manufacturing or fabricating plants using non-ferrous metals and automobile dismantlers (used parts dealers). Obsolete radiators, transmission cases, starter motors, alternators and the like are rich sources of non-ferrous metals. There is literature available to assist operators.[2]

97. World prices can be accessed through *Metal Bulletin* (www.metalbulletin.co.uk) or *American Metal Market* (http://www.amm.com/).

V. Establishing a reclamation facility

98. Establishing a remelt or a reclamation facility (primary or secondary) can be a major undertaking. Either requires detailed research, planning, engineering and economic analyses, skilled personnel, significant investment and more. Planning and construction times can be long, a decade or more. Hence, there must be a forecast of market demand after the facility is operational. There are considerable financial risks. Remelt facilities are the simpler of the two types of plant because they often use metals recovered in scrapyards as feedstock. Reclamation facilities are more like primary ore smelters in that the feedstock is passed through several operations to separate the desired metal(s). A typical processing plant for the reclamation of metals is shown in figure 2 below. (Note: the term "filter" in figure 2 refers generically to whatever air pollution control system is appropriate.)

99. Designing and operating a reclamation facility in an environmentally sound manner requires advanced engineering, technical skills and a high level of maintenance. It is not an undertaking for the faint of heart or the undercapitalized. A recent compendium of best technology can be found at http://www.jrc.org. Much of this technology is large and is often complex. Not surprisingly, most smelters and other metals reclamation facilities are owned and operated by major, global companies, in contrasted to secondary smelters, refiners and remelters, which are more likely to be local companies.

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[2] For example, A. A. Nijkerk, Handbook of Recycling Techniques (Nijkerk Consultancy, The Hague (distributed in the United States of America and Canada by American Metal Market, New York), 2000).

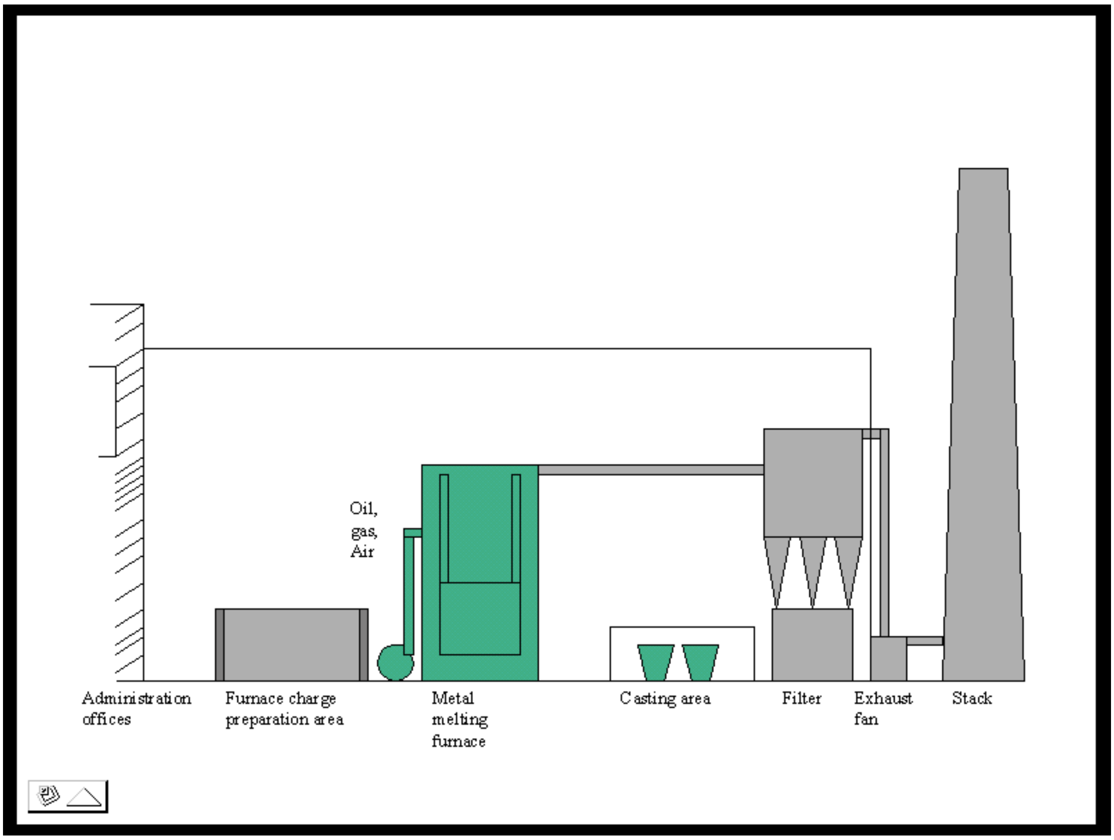

Figure 2. Diagram of a remelt facility

100. Global demand and prices for non-ferrous metals historically are cyclical: non-ferrous metals are commodities. Capacity is not cyclical because smelters are built and operating. At times of low demand (and prices), smelters operate below capacity. When demand is low, so is the demand (and price) for secondary sources. Fortunately for the recycling industry, smelters often use some small quantity of feed in the form of recyclable metals. At the time of writing (2003), world prices for non¬ferrous metals are relatively low in historical terms. These economic, market and technical factors introduce a significant degree of financial risk to the construction of new reclamation facilities.

101. In a few cases, hydrometallurgical processes offer technical alternatives to the pyrometallurgical reclamation of particular metals and feedstocks. For example, scrubber residues from nickel and copper smelters can be washed, slurried and leached with a sodium sulphite solution at a high temperature and a specified pH. Sodium sulphite is extremely selective for dissolving and complexing selenium, and all the free metallic selenium in the material dissolved into the sodium sulphite solution forms a soluble sodium selenosulphite complex. The leach solution is then boiled to evaporate the water as steam and concentrate the solution. When the solubility limit of selenium in sodium sulphite solution is reached, black selenium precipitates out, forming a black slurry which is then filtered to produce a selenium concentrate that is sold as commercial-grade selenium.

VI. Environmentally sound reclamation facilities

102. After looking as a first priority at opportunities for waste avoidance and waste minimization, options for recovery and reclamation can then be considered. This should involve first identifying a wide range of possible options, then analysing those options to determine the most attractive for more detailed analysis.

103. There is a wide range of recovery and reclamation technologies available. The applicability of technologies will be dependent on the physical form of the metal and its composition. Some technologies are applicable to metal wastes in solid form and some to wastes dissolved in water and wastewater. An indication of the range of recovery methods and their applicability to the various metals is summarized in table 2 below. The information in the table is indicative and is not intended to provide a definitive or comprehensive listing of options.

Table 2: Listing of metals recovery methods and their applicability

Recovery method	Sb	As	Be	Cd	Cr	Cu	Pb	Hg	Se	Te	Tl	Zn
From wastes in solid form												
Leaching	✓	✓		✓		✓	✓		✓	✓	✓	✓
Stripping				✓	✓	✓	✓					✓
Smelting	✓				✓	✓	✓					✓
Volatilization (thermal)		✓		✓			✓	✓				✓
From wastes in dissolved form												
Adsorption	✓	✓		✓	✓	✓	✓	✓				✓
Cementation						✓						
Precipitation		✓		✓	✓	✓	✓					✓
Concentration					✓	✓						
Solvent extraction				✓		✓	✓	✓				✓

Sb = antimony; As = arsenic; Be = beryllium; Cd = cadmium; Cr = chromium; Cu = copper; Pb = lead; Hg = mercury; Se = selenium; Te = tellurium; Tl = thallium; Zn = zinc

104. It is an essential aspect of any recovery and reclamation operation that it must be carried out in an environmentally sound manner. This involves taking all practicable steps to ensure that hazardous wastes or other wastes are managed in a manner which will protect human health and the environment against the adverse effects which may result from such wastes.

105. Reclamation facilities must have an effective management system in place to assure environmental and health protection. These facilities have the potential to emit harmful gases (such as sulphur dioxide (SO_2)) to the atmosphere, to generate metal-containing dusts and effluents and to produce solid wastes that may be hazardous. Many facilities around the world manage those emissions, effluents and residues in a protective manner. The management system must be such that all practicable steps are taken to ensure that hazardous wastes are managed in a manner that protects human health and the environment against the adverse effects that may result from such wastes.[3]

106. Some of the elements of an environmentally sound management system are that the operator:

- Must be in the business of recycling.
- Must operate with the full knowledge and authorization of the competent local authority.
- Must be in full compliance with all applicable local and national regulations and reporting requirements (which must have been established by local and national governments).
- Must maintain appropriate business records.
- Must conduct transactions based on contracts.
- Must ensure that at least one product of the process is returned to the economic mainstream.

[3] For a description of such management systems, see Basel Convention Conference of the Parties decision II/13 and H. Alter, "Environmentally Sound Management of the Recycling of Hazardous Wastes in the Context of the Basel Convention", (*Resources, Conservation and Recycling*, Vol. 29, pp. 111-130, 2000.

- Must ensure that the technology and the pollution controls employed are adequate to recycle the feedstocks successfully and to meet all applicable local laws and regulations.

- Must select feedstocks to meet specifications of form and/or grade and/or assay as agreed by the buyer and seller.

- Must have the necessary and appropriate technical and environmental expertise to operate and maintain the appropriate equipment to achieve the intended purpose(s) and ensure that the facility's personnel are capable and adequately trained.

- Must handles and store materials in a manner designed to minimize losses to the environment and may not hazardous wastes speculatively.

- Must have a programme to monitor pollutant releases from the facility and report the results to governmental institutional infrastructure bodies as required.

- Must manage residuals of the process in a manner that does not create a significant hazard to human health or the environment.

- Must have an emergency response plan for accidents and must take appropriate action in the event of accidental spillage or releases.

- Must have a programme for continuous improvement, either internally or in accordance with ISO 14000, the European Commission Eco-management Audit Scheme (EMAS),[4] Responsible Care® or other recognized programme. [12]

- Must conduct reclamation under a governmental institutional infrastructure that has the authority and capability to regulate the environmental effects of recycling and to enforce regulations.

107. The physical and chemical attributes of the waste need to be considered and documented within the environmentally sound management system. For example, as pointed out in several places in the present text, metals in dispersible forms such as dusts or powders often represent an environmental or health risk whereas with those in bulk, finished forms such as sheets, plates, beams or rods there is no or hardly any health risk. Some few metals, such as thallium and mercury, are hazardous regardless of form. These considerations will determine some of the management methods and the regulations.

108. The legal requirements of the infrastructure will vary from operation to operation and from country to country depending on the level, nature and complexity of the reclamation process and on local and/or national conditions. In some cases, a facility - and/or its competent authority - may choose to impose and meet management criteria from another country. An approach to environmentally sound management, especially for transboundary movements, has been published and can be found on the International Council on Mining and Metals web site.[5]

109. For lead, the workplace standard is extended to require workers to shower and change clothes before leaving work. This avoids carrying lead dusts to the workers' homes. For additional guidance, see the International Lead Management Center Inc., web site www.ilmc.org.

110. Pollution control objectives must be chosen against indicators of potential hazards to human health and the environment. Table 3 below lists some examples, for lead, taken from various national legislations and regulations (the table is not intended to define limits for any facility or country but rather to give an overview or examples of what limits have sometimes been set).

[4] http://europa.eu.int/comm/environment/emas/.

[5] The Global Environment and Technology Foundation, "Implementing and Assuring a Practical Approach for the Environmentally Sound Management of Hazardous Metal Recyclables", working paper (International Council on Metals and the Environment, Ottawa, 2001). See http://www.icmm.com/html/library_publicat.php?rcd=32.

Table 3. Examples of pollution control objectives for a lead smelter

Pb Emission	Typical pollution control objectives for Pb and devices (USEPA)
Discharges from stacks	Licence: < 10 mg/m^3 Typically achieved < 1mg/m^3 Device: cyclone followed by bag house
Ambient air	Policy objectives: < 1.5µg/m3 averaged over 90 days Devices used in factory to collect loose waste material and reduce fugitive emissions: vacuum cleaners, screens, filters, gas cleaning apparatus
Workplace air	Standards: 150 µg/m^3 over 8-hour period Personal protective equipment: protective respirators and appropriate clothing in areas where this is exceeded

VII. Environmental and health considerations

A. Wastes and residues

111. The identity and fate of all emissions, effluents and residues in recovery, recycling and reclamation plants must be defined when considering the potential effects of the activities on the environment and human health. As indicated earlier in the present text, the environmental and health effects from recovery and recycling plants are small; the potential effects from a reclamation facility such as a smelter are greater, whether it is reclaiming metal from ores or from recovered materials. Most recycling and smelter operations have air, water and residue controls and management in place. The potential effects from a direct remelt facility, such as a foundry or mill, are intermediate. However, those facilities too must have controls in place, whether melting virgin or recovered metals.

112. If the solid residues are hazardous, they must be carefully managed. They should not be left in open piles. Hazardous residues should be properly disposed of in lined landfills. There is a vast literature for guidance. See in particular the UNEP training manual, written especially for developing countries.[6] See also http://www.unepie.org/ and the United States of America regulations, available through http://www.gpoaccess.gov/ecfr/, on hazardous waste landfills (Title 40 of the Code of Federal Regulations, part 264, subpart N[7]).

B. Collection systems

113. The technical aspects of pre-recycling steps collection, transportation and storage must all fall within a policy framework capable of nominating players and responsibilities and determining economic incentives to ensure their long-term viability. The policy framework is required to:

114. Reduce waste generation.

115. Maximize economic and environmentally friendly waste recovery.

116. Enhance access to domestic sources of metals.

117. Provide the means to make recycling operations environmentally sound and economically efficient.

118. Some important requirements for the implementation of collection systems are as follows.

119. As a basic premise, the participation of consumers is the cornerstone for the implementation of all programmes. Therefore, consumers should be informed about which waste metals are recyclable and where the collection centres are located.

120. Environmentally unsound destinations should be prohibited.

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6 UNEP Industry and Environment Programme, Environmental Education and Training Unit and the International Solid Waste and Public Cleansing Association, *The Landfill of Hazardous Industrial Wastes: A Training Manual* (UNEP Industry and Environment Programme, Paris, 1993).

7 http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=efb7ed359ccab9aa376c2f6231caaf4e&rgn=div5&view=text&node=40:23.0.1.1.5&idno=40.

121. Collection centres should be licensed to collect and temporarily store the waste metals, provided they have appropriate storage places in line with the present technical guidelines. A minimum set of characteristics, relevant to each country, could be defined through legislation, and further steps to encourage and enforce, if necessary, the implementation of such environmental protection, such as regular inspections of storage premises, should be undertaken. The licensing process should be viewed as a resource and the information used to publish a map of the collection network.

122. Smelters should be licensed and must adopt the best available technologies if they are to be installed, or must modify their processes and/or operating practices in order to achieve high standards of environmental protection. Permanent control of emissions is also recommended.

123. Resource-sharing in consortiums could be viewed as a solution to budget constraints as such arrangements decrease the cost of operations. If pertinent, a set of rules to regulate such associations could be implemented.

124. Several models for the implementation of collection systems have been developed around the world in order to achieve specific country needs, taking into consideration country size, available transport network, local taxes and so on, and it seems to be a general trend to develop legislation based on the principle of producer responsibility although few countries around the world currently have such legislation in force.

C. Transport and storage

125. The transport of wastes, and sometimes their recovered products, must be carried out in accordance with relevant transport codes. The United Nations model regulations on the transport of dangerous goods (see http://www.unece.org/trans/danger/publi/unrec/rev13/13nature_e.html) outline good transport practice; most countries will have similar codes or standards.

126. An obligation under the Basel Convention, and for environmentally sound management, is to package and store wastes appropriately in a properly designed facility. The storage facility should provide precautions against dispersion (e.g. by wind), leakage and combustion. The relevant standards for the storage of hazardous material should be referred to. In the case of metals, problems may arise in situations where the metal or metal residue (compounds) is in a readily dispersible form such as a powder and is stockpiled without adequate protection from wind, which could result in the material being transported off site and onto the ground. If there is inadequate protection against rain and stockpiles of such material become wet, the material may be subject to leaching and the leachate may run off into surface waters or seep into groundwater. For that reason, the storage area should have an impervious surface and may even be paved.

127. Leaching may be more likely with metal-bearing residues such as drosses or slags than with the metals themselves. Often, large pieces of metal may be left on the ground with no subsequent problems.

128. All drums and other storage containers must be properly and prominently labelled. Workers must be trained to look for, and correct, corroded or leaky drums or other containers. Under no circumstances should such containers be left on the bare ground. If materials are stored that could potentially corrode containers, or liquids are stored, the paved area should be fitted with berms, drainage and sumps.

D. Emergency response

129. An action plan should be developed, and workers trained, to respond to emergencies or accidents, including proper use of personal protection equipment. Emergencies may occur on site at the facility or off site during transportation. Consideration should be given to the past history of operation and whether there have been accidents or uncontrolled releases of wastes to the environment. Part of the emergency response is remediation of a spill and correction of deviations from regulations.

130. The plan should locate and provide emergency equipment at pre-designated spots in the plant. The equipment should include fire extinguishers, personal protection equipment *such as* special clothing, face masks and respirators, spill absorbents and shovels, as required by the process and materials at the plant.

131. The emergency response plan should ensure prompt reduction of any environmental impact of an accident if one should occur. Training trials of the plan should be carried out to ensure readiness. Special handling requirements for the wastes on site should be included.

132. Insurance or other options may be needed to ensure sufficient funds to finance a clean-up or to discharge liability in the event of an accident either on site or off. Often, the local regulatory agency will be able to advise on the type and amount of insurance that would be appropriate for the type of operation and the nature of the materials being processed.

133. In most cases, the type of metals being recovered, recycled or reclaimed will not pose an extreme hazard unless the metal is in readily dispersible form. Some residues (compounds) are leached by rainwater, albeit slowly, and must be managed appropriately.

134. Most spills in any non-ferrous metals processing plant can be remediated simply by using a broom and shovel because it is unlikely the spill will be soluble in water. Spills that are soluble in water present more severe problems and avoidance is the best solution.

- **Caution: If the spilled material is toxic or dispersible, appropriate health and safety procedures must be followed. Broom and shovel may still be appropriate but workers must wear suitable protective clothing and devices. Follow all instructions given in Materials Safety Data Sheets or similar documents.**

E. Environmentally sound management

135. Some of the elements of an environmentally sound management system have already been given (see chapter VI above on environmentally sound reclamation facilities) and follow the teachings of many Basel Convention publications. The present section provides directions to additional sources of assistance.

136. The reader may wish to consult a work from the UNEP International Environmental Technology Centre that, although directed at municipal solid waste, gives advice on environmentally sound practices.[8]

F. Environmental management systems

137. International standards have been developed which define elements of environmental management systems and provide guidance in their implementation. In particular, the ISO 14000 series should be consulted, as should EMAS.

138. Implementing an environmental management system can help provide assurances that a metals recovery facility will be operated in an environmentally sound manner. An environmental management system is a management tool which provides a coherent set of organizational structures, responsibilities, practices, procedures, processes and resources to ensure that the company which uses it achieves systematic implementation of its environmental policy.

139. An environmental management system can apply to any type of organization or operation; the principles are of general applicability. Key elements of an environmental management system include:

- An environmental policy which is a statement, by the organization, of its intentions and principles in relation to its overall performance, and provides a framework for action and for setting its environmental objectives and targets.
- A clear statement of environmental objectives and targets.
- A procedure for identifying the significant environmental impacts arising from existing or planned activities.

[8] UNEP International Environmental Technology Centre and Harvard Institute for International Development, *International Source Book on Environmentally Sound Technologies for Municipal Solid Waste Management* (UNEP International Environmental Technology Centre, Osaka/Shiga, 1996).

- Programmes which will enable the organization to achieve its objectives and targets. These will include defining the responsibilities of staff, and the means and timeframe by and within which they are to be achieved.

- Programmes for ensuring that staff are trained and are aware of requirements.

- Procedures for operational control, internal and external communication and document control.

- Procedures for emergency preparedness and response.

- Procedures for monitoring performance and taking appropriate action if performance does not meet targets.

- An audit programme to confirm that the system has been properly implemented and that plant operation complies with all applicable laws and regulations.

- Periodic management review of the environmental management system.

140. The key advantages of implementing an environmental management system are that it provides a disciplined approach to environmental management and ensures that issues that may impact on the environment are identified and addressed.

141. An environmental management system should also include a plan for shut-down or closure of the facility involved. There should be a plan in place for remediation of buildings and soils and for financial assurance that a proper shut-down will occur in the event that such shut-down or closure proves necessary.

142. Building and soil remediation are important factors to be considered for reclamation and remelt facilities. They may also be important for recovery and recycling facilities which handle dispersible materials or items that can spill, such as lead-acid batteries. These factors highlight the importance of sealing or paving storage and handling areas to avoid soil contamination.

VIII. Assessment of predicted environmental impacts

143. The present chapter applies to pyrometallurgical reclamation almost exclusively. The information here will be useful to operators and competent authorities which have responsibility for an existing facility or are planning a future facility. The environmental impacts of such reclamation facilities are potentially far greater than from a recovery or recycling facility. Operators and regulators of foundries and remelt facilities may also benefit from the following discussion.

144. It is essential that, when reclamation operations are planned, the relevant regulatory agencies are consulted and the necessary approvals are obtained. Depending on the nature of the proposed operation, these may involve amendments to the licence for an existing operation or an environmental impact statement or equivalent which formally identifies and assesses potential environmental impacts from the proposed operation.

145. The regulatory authority will normally specify the requirements of the assessment. The assessment should include the identification and assessment of the predicted environmental impacts of establishing and operating the facility. It should consider site-selection issues, technology options and management of the facility.

146. Key issues for consideration in the environmental assessment of metals reclamation operations include:

- Transportation and storage of feedstocks (often wastes) and whether accidents could occur which would result in the release of hazardous wastes.

- Any production of emissions, effluents and residues as a result of the reclamation operations and their proper management.

- Monitoring of the emissions, effluents and residues, i.e., checks on the proper and safe operation of the plant and the pollution-control equipment.

147. A formal monitoring programme should be prepared to include overall objectives, targets for compliance and indicators of environmental improvement.

148. A sampling and analysis plan should be implemented. Incoming feedstock must be assayed to assure it meets the specifications for the plant's process(es) if process knowledge or generator certification is insufficient. Emissions, effluents and residues should be sampled periodically to assure compliance with regulations and the proper and safe operation of the process and the pollution-control equipment.

149. Logs of plant performance should be kept, in accordance with good international practice for operating sophisticated plants. Review of logs of operation and maintenance performance avoid costly errors and unwanted environmental releases.

150. The facility may be well advised to use an outside analytical laboratory for analyses, quality assurance and quality control. Such organizations can assist also with sampling protocols.

IX. Waste prevention and cleaner production

151. The present chapter does not address important related topics regarding cleaner production and waste prevention in the production and use of metals from ore extraction through product design to end of life; rather, it is restricted to recovery, recycling and reclamation. These latter operations minimize the amount of waste destined for final disposal and consequently contribute to cleaner production.

152. The generally accepted hierarchy of waste management begins with waste prevention and minimization through to material recovery, treatment and final disposal of wastes. Recovery, recycling and reclamation processes are naturally geared to waste prevention in order to maximize their product yield. Operators should bear this in mind and review their processes for minimizing residues and other wastes. It is not always possible or economical to minimize "wastes" from non-ferrous metals production, whether primary or secondary. Nor is it always the best environmental decision to do so: scrap waste arisings, like their primary ores, are usually in the form of mixtures, and both must be processed in a sequence of steps to produce "new" metals or alloys to re-enter commerce. The residue from one processing step is the input for the next.

153. "Cleaner production" is a term that refers to a continuous, integrated and preventive strategy applied to products, consumption and processes to reduce risk to humans and the environment. It particularly includes the concept of seeking to change the production process to avoid or minimize the generation of waste. This introduces a number of options: while the ideal solution may be the introduction of new technology and methods which drastically reduce or avoid altogether the generation of waste metals and metal compounds, it will be possible to implement only some changes in the short term and some may take many years to implement. However, careful attention to the details of even well established processes can often identify relatively simple measures to promote waste minimization: changes in operating conditions may reduce the quantity or improve the quality of the metal-bearing waste, and segregation of waste streams may render them recoverable whereas they were not recoverable when mixed.

154. Recycling, recovery and reclamation are enhanced when manufacturing plants and other producers of secondary feedstocks are educated as to specifications. If a producer of a recoverable or reclaimable residue takes care to meet the buyers' specifications, the residue will be better utilized. However, recycling is not always the best option for a particular waste stream because, in all cases, avoidance of hazardous wastes is preferable and in some cases storage is preferable to recycling. In that connection, the view has been expressed that a global effort is needed on a variety of fronts to phase out the production and use of toxic metals such as arsenic, beryllium, cadmium, lead and mercury; this would of course lead to a reduction in waste from those toxic elements. Such an effort would seek to eliminate toxic metals from batteries, solders, thermometers, barometers, paints and so on, but would beg the crucial question as to whether such metals should be recycled at all or should rather be retired from all use and thus from recycling. Thus. rather than building up infrastructure to recycle mercury, a country might simply ban most uses of mercury in favour of non-mercury alternatives.

155. The reader is referred to publications on cleaner production, such as the UNEP Technical Report series No. 7: Audit and Reduction Manual for Industrial Emissions and Wastes. See: http://www.unido.org/doc/331372.htmls or http://www.emcentre.com/unepweb/. The Basel Convention web site also has links to other cleaner production sites: http://www.basel.int/links.htm.

X. Potential environmental hazards and their control

A. Hazards and control

156. The present chapter is intended only to give examples of potential environmental hazards and their control. It is impossible to list all potential effects of metals and their compounds on the ecosystem or in the workplace, many of which are site-specific and/or require risk assessments. Nor is it possible to outline all the control technologies that have been developed across industries. The choice of a particular control technology is an engineering and economic decision driven by the applicable regulations.

157. It is not possible to give specific guidance as to emission or effluent limits. These vary from country to country depending on ambient conditions and the level of protection the local society seeks.

158. Plant operators have some knowledge of the composition of their feedstocks, products, emissions, effluents and residues. This is a starting point for determining risk from exposure. Emissions, effluents and residues are dangerous to people only when they can be inhaled, ingested, or absorbed through the skin. They are dangerous to the environment when discharged in levels beyond regulatory limits and if they are bioavailable to fauna and flora. The prime purpose of control is to prevent contact with humans and bioavailability to the environment. Not all forms of metals and their compounds are bioavailable; even some that are do not necessarily pose a hazard if within regulatory limits.

159. Recovery and recycling operations as described here (except remelting) have a low potential for releases to the environment. They are generally simple, mechanical operations. Reclamation, and to a lesser extent remelting, has a potential to discharge hazardous materials. For that reason, reclamation and remelting facilities must be fitted with pollution control equipment, properly maintained and operated in accordance with an appropriate environmental management system.

160. Generally, the constituent present at greatest concentration will be used to describe the waste. However, this may not be the constituent that has the potential to be most hazardous or cause the most harm.

161. Information on toxicity of metals is given in table 4 below, as are the regulatory limits of several countries. These are only examples, however, a relating chemical composition to biological response is not always an exact science. Single data values, such as those given as examples in table 4, are only examples and cannot be taken as absolute for all facilities in all countries as they do not take into account exposure or bioavailability.

162. Some smelters have reported dioxin emissions. Reclamation smelters should therefore be monitored for both dioxin and furan emissions. Annex C of the Stockholm Convention on Persistent Organic Pollutants lists, among the source categories with potential for comparatively high levels of formation and release of dioxins and furans to the environment:

- Secondary copper production
- Sintering plants in the iron and steel industry
- Secondary aluminium production
- Secondary zinc production

Annex C also lists thermal processes in the metallurgical industry, not mentioned above, among the source categories that may also lead to the unintentional formation and release of persistent organic pollutants. The Stockholm Convention already deals with dioxin and furan emissions from various sources and is preparing guidelines for such emissions.

163. For more information regarding the health effects of releases from primary and secondary copper smelters and refineries and releases from primary and secondary zinc smelters and refineries in

Canada, including dioxins, see http://www.ec.gc.ca/cceb1/eng/public/CuZn_e.html. Another useful source, which includes some guidance on the control of dioxins, is http://www.jrc.org/. The bibliography lists sources of these data and, in some cases, where additional information may be obtained.

164. The environmental or workplace hazard of metals and some of their compounds depends on the molecular and ionic state (species) of the metal. For example, as pointed out earlier, chromium and many of its compounds, such as green chrome (III) oxide, Cr_2O_3, are not hazardous. Here, the chromium is in the +3 valence state. However, chromium in the +6 valence state is highly toxic, carcinogenic, and in certain molecular and physical forms can be highly corrosive, hence its listing in Annex I of the Basel Convention. Another example is that certain metals are hazardous as oxides. However, slags of these metals, which may contain oxides, bind the metal oxide within a complex silicate molecular matrix, making the hazardous material less available.

165. Nevertheless, metals, like many other substances, in finely divided form are often hazardous (e.g., they may pyrophoric). Also. water-soluble compounds will be readily bioavailable, hence more likely to be hazardous.

Table 4. Examples of indicators of potential hazards

	Environmental effects — Guidelines for protection					Occupational Health and Safety	
	Water		Soil		Landfill	Toxicity	Workplace Air
Metals or Compounds	**Drinking water[1] (mg/L)**	**Ecosystem protection[2] (mg/L)**	**Residential[3]**	**Environmental[3]**	**Leaching[4] (USEPA TCLP, mg/L)**	**(LD_{50}, mg/kg body weight)[5]**	**(TWA,[6] mg/m^3)[7]**
Antimony	0.005	-	-	-	Not regulated	7000	0.5
Arsenic	0.01	0.05	43	30.50	5	763	0.2
Beryllium	-	-	-	-	Not regulated	-	0.002
Cadmium	0.003	0.2-1.8	6	0.5-10	1.0	225	0.01
Chromium (VI)	0.05	0.002	240	200.300	5 (total)	50 ($Na_2Cr_2O_7$)	0.05
Copper	2	0.002-0.004	113	30-200	Not regulated	300 ($CuSO_4$)	0.2
Lead	0.01	0.001-0.007	307	150-800	5	450 (TDL_o)	0.15
Mercury	0.001	0.00001	5	2	0.2	1 ($HgCl_2$)	0.05
Selenium	0.01	0.001	-	-	1	6700	0.2
Tellurium	-	-	-	-	Not regulated	83	0.1
Thallium	-	-	-	-	Not regulated	6 (LDL_o)	0.1 (skin)
Zinc	-	0.03	430	100-350	Not regulated	3000	1-10

Notes:
1. World Health Organization (1996).
2. Canadian Water Quality Guidelines for Protection of Freshwater Aquatic Life. Canadian Council of Ministers of the Environment (1995).
3. Environmental Quality Objectives in the Netherlands, Directorate for Chemicals, External Safety and Radiation Protection and the Ministry of Housing, Spatial Planning and the Environment (1994).
4. USEPA toxicity characteristic leaching procedure (TCLP) values, dilution attenuation factor DAF=100.
5. Lewis (1992), LD_{50} oral. Indicative only; individual compounds are likely to vary in toxicity.
6. TWA, time-weighted average airborne concentration when calculated over a normal eight-hour working day for a five-day working week.
7. American Conference of Governmental Industrial Hygienists (1994).

Explanatory notes for table 4

Chronic toxicity: A toxic effect which occurs after repeated or prolonged exposure. Chronic effects may occur some time after exposure has ceased.

Drinking water: National values may differ from those of WHO. See http://www.epa.gov/safewater/mcl.html for United States of America drinking water standards.

Ecosystem protection: Ecotoxicity data for metals and metal compounds are still not settled. OECD has yet to release its guidelines. Metals are persistent in the environment because they are elements, hence indestructible. The low value for copper (this value is still unsettled in international forums) is the reason copper compounds are used as biocides (the copper must be bioavailable). The Canadian values are for freshwater and are the lowest in the world. USEPA applies different ecotoxicity criteria and arrives at higher values, which are then corrected by a water hardness factor. For copper, for example, the value will vary widely between 1.4 and 19.6 µg/L compared to the values in table 3 of 2–4 µg/L. Copper and zinc values are for some soluble salt of these metals; the values have no meaning for the metals themselves.

Residential: The Dutch values listed here are for formerly contaminated, remediated areas and probably the most stringent in the world. Similar figures from the United States of America can differ widely. The most stringent United States figures are based on chronic soil ingestion by children.

Environmental: Same comments as for Residential.

Landfill: The USEPA toxicity characteristic leaching procedure (TCLP) extracts a waste in particulate form and analyses the leachate. The values for selected metals are based on United States of America drinking water standards (maximum contaminant levels) using a dilution attenuation factor (DAF) of 100. This means that the metal concentrations are based on the leachate's having been diluted by a factor of 100. This procedure is intended to represent the natural leaching by the organic acids from anaerobic decomposition acting on commingled household and industrial wastes in a landfill. The conservative DAF=100 comes from computer simulations of the dilution and attenuation of the leachate as it travels through the ground to water sources. The laboratory method for TCLP can be found at http://www.epa.gov/epaoswer/hazwaste/test/sw846.htm.

LD_{50} toxicity: LD_{50} is a standardized measure for expressing and comparing the acute toxicity of chemicals. LD_{50} is the dose that kills half (50%) of the animals tested (LD = "lethal dose"). The animals are usually rats or mice. LD_{50} values must be interpreted cautiously. The LD50 for cadmium is lower than for arsenic, i.e., cadmium is more toxic than arsenic. Dose is a combination of exposure, concentration and time and a moderately toxic material at a high dose can be more hazardous for workers than a highly toxic material at a low dose.

Workplace air: The values are for occupational (chronic) exposure, generally eight hours a day, 250 workdays per year.

General: Illustrative data are not always readily available for metal compounds likely to be encountered in a recovery or reclamation facility. For example, a data point is given for copper sulphate ($CuSO_4$). This salt of copper is highly soluble in water and does not represent any copper bearing residue that may be recovered or reclaimed. However, because it is soluble, it can easily be tested for LD_{50}. Note that values for zinc are listed for ecotoxicity and soil clean-up. However, many soils in the world are deficient in zinc and zinc must be added for crop production. For zinc, the LD_{50} and TWA values are high, showing low toxicity. Zinc is an essential element for humans, animals and soil.

No data are given for dioxin limits nor is there broad global agreement as to what those data should be. As an example, several countries have established differing limits for dioxin loadings in people: United States of America, 0.006, Canada 10, the Netherlands 4 and Germany 1–10 pg/kg of body weight (p = picogram = 10^{-12} grams).

B. Monitoring

166. Monitoring is an essential part of determining whether there is an environmental risk that needs to be controlled. Monitoring confirms that the operation neither poses a risk to workers or the public nor adversely affects the environment. Primarily, the safety of people and the environment should first be decided based on scientific and toxicity data and acceptable exposure limits. Then it must be established which parameters need to be controlled. Next, control (monitoring) begins. Monitoring only determines compliance with established limits. To determine if there is an environmental risk, an environmental risk assessment should be performed.

167. It is relatively easy to monitor recovery and recycling operations. Sometimes, only monitoring of ambient dust levels is needed. Monitoring of reclamation facilities is essential and becomes more complex as the equipment and processes become more complex.

168. Even metals which are bioessential for human health, in that without at least quantities of them we die, are poisonous at higher doses. Copper is a good example of such a metal. It must be borne in mind, however, that the risk which is presented by a metal will depend on many factors, such as the amount of the metal, its form, its species and on the nature of the exposure. Environmentally sound management of metals will take all of these factors into account. As an obvious example, it is not necessary to regulate new metal coins, such as the Euro, in general use as money, because they are in solid form and may not be converted to a bioavailable form. Governments may wish to examine the processes whereby their old coins are reclaimed, however, because they will be melted, generating fumes, poured into larger forms and then dissolved in acid and recovered in electrolytic processes.

169. In any case, a formal monitoring programme should be prepared. This should include objectives, targets for compliance and indicators of environmental improvement. The programme should also identify which experts will be engaged for monitoring, analytical methods, sampling plan, quality control and quality assurance.

170. The operation log of the plant is part of the monitoring programme. Premature failure of an environmental control unit can be detected by means of the operation log.

XI. Shut-down of metals reclamation facilities

171. An important aspect of any industrial processing operation, including those for metals recovery, is to ensure that any pollution that may have been caused during the operation does not threaten human health or the environment in future occupancy and use of the property. Prospective purchasers of operations and land will now routinely carry out due diligence environmental audits, including sampling and analysis of soil and groundwater, to confirm formally that pollution has not occurred, or has been properly managed to prevent future harm.

172. Generally the polluter will be held liable for pollution of land and groundwater, and it is essential for metal recovery and reclamation operations to ensure that contamination of land and groundwater has not been allowed to occur, or has been properly managed to prevent future harm.

173. In the case of metals and metal compounds, if these have been allowed to contaminate the soil they are likely to remain in the soil and concentrations will decline only slowly through processes of leaching and dispersion, because they are not subject to degradation, unlike organic compounds. Metals are usually not mobile in soil environments unless acid conditions are acid or the soil is physically moved, and the metals will generally remain adsorbed onto the soil particles close to the point at which they were released.

174. As part of shut-down and decommissioning of operations dealing with metals and metal compounds, there should be an independent formal assessment to confirm that any contamination of land and groundwater is identified and cleaned up as necessary. Generally, this should have the objective of ensuring that the land and groundwater is suitable for its future use. Metals do not degrade (they are elements and cannot be chemically subdivided). However, many mineralize in soil, becoming compounds similar to the soil itself. They sometimes undergo leaching in acid environments. Because many mineralized metals, and sometimes metals in other forms, are not bioavailable, the contamination

of a site is best judged after a site-specific risk assessment. If the metals are not mobile, it is likely that they pose no risk and hence are not of concern.

175. Usually, future use of land for industrial purposes is the least sensitive use, and often in an industrial land-use setting relatively high concentrations of metal contaminants, in the absence of dust, will not adversely affect the health of workers or the community. Other uses of the land, such as residential, are more sensitive, with the incidental ingestion of soil being higher and with children being exposed, and the potential effects on plant life are also a potentially limiting factor. If there is potential for land which has been contaminated with metals and metal compounds to be rezoned to allow more sensitive uses, then particular care is required to ensure that contamination is not present.

176. Where contamination of soils has occurred or waste material has been disposed of (such as in an on-site repository), then a management plan should be prepared and implemented which will ensure that the material is properly managed in the future. Arrangements should be set up which will ensure that the plan is adhered to for as long as is necessary. Procedures or notification methods must be put in place to ensure that future operators or owners of the recovery site or disposal facility site are advised of contamination issues and continue the required management activities. It may be a requirement for operators to have post-closure plans prior to being granted a permit to operate.

177. Proper financial provisioning is crucial to best practice decommissioning. The financial mechanism is required to ensure that there are sufficient funds available to close an operation and that closure costs do not become a burden in later years when revenues could be diminishing. Closure provisions should also reflect the real cost of closure. This is important as costs associated with closure can contribute significantly to overall project costs and hence the bottom line. In some extreme cases, unforeseen costs associated with decommissioning can far exceed any financial gains achieved over the life of a project.

178. Closure planning puts companies in a position to understand their potential costs early in plant life. Financial provisioning can commence at the conceptual closure-planning stage but may be highly inaccurate as the costs are difficult to predict. However, the initial cost estimate exercise helps companies focus on the areas of decommissioning where there is the greatest uncertainty in the outcomes. This enables priorities to be set for further work and for research to be undertaken to better define required outcomes and hence costs over the life of the operation.

Annex I

Glossary of terms

Ash – **(a)** Materials left over from pyrometallurgical processes such as the burning of coal or incineration of photographic film, circuit boards, copper wire, etc, that can be recycled for non-ferrous metal content.

(b) The top layer of molten metal such as lead and zinc that has oxidized in air. When it is skimmed, the ash is a clean mixture of the metal and its oxide, hence a good material for recycling.

Cake – Dewatered sludge discharged from a filter press or similar device, usually -containing about 25 to 35 % (m/m) dry solids.

Cleaner Production – The continuous, integrated and preventative strategy, applied to products, consumption and processes, to reduce risk to humans and the environment

DAF – dilution attenuation factor

Dross – Metallic oxides which float to or form on the surface of molten metal.

Drossing – A process for the removing of impurities, consisting of oxides, etc, which form on the surface of molten metal. The dross is usually skimmed from the surface of the metal by long-handled scraper tools.

Dust – Fine particles of matter. In powder metallurgy, a superfine powder, usually consisting of particles smaller than one micrometer in diameter.

Ecosystem – A natural, environmental system defined by sensitive parameters that can only be preserved by careful maintenance of those parameters within survival limits

Gate – The system of channels through which a mould is filled, including the sprue; the metal which solidifies therein.

Home scrap – Scrap materials generated on site that do not contain paint or solid coatings.

Non-dispersible – Fixed and immobile in the existing form - for example, a solid metal.

Plant scrap – See home scrap.

Powder – A substances made up of an aggregation of small particles, any dry material in a fine granulated state.

Prompt scrap – Scrap which results from manufacturing or fabricating operations.

Reclamation – A metallurgical process, usually pyrometallurgical, but hydrometallurgical for some metals and processes, whereby the recovered or recycled metal is purified and remelted or refined into a form that can be used in the same way as virgin metals.

Recovery – Taking metallic or metal-containing items and metallic pieces before they reach the waste stream or taking them out of the waste stream.

Recovery operation – A process by which materials, which are no longer fit for their originally intended purpose, are transformed into a usable state or by which materials are extracted in usable form.

Recycling – **(a)** The preparation of recovered items and pieces so that they may be used directly (e.g., in direct remelt) or sent for reclamation.

(b) The series of activities, including collection, separation, and processing, by which products or other materials are recovered from the solid waste stream for use in the form of raw materials in the manufacture of new products, other than fuel for producing heat or power by combustion.

Residue – Something that is left over.

Runaround scrap – scrap materials generated on site by casting, extruding, rolling, scalping, forging, forming/stamping, cutting, and trimming operations and that do not contain paint or solid coatings, but not scrap materials generated by turning, boring, milling, and similar machining operations, that are fed directly back into the operation.

Scaling – The oxidation product occurring on a metallic surface during heating in a nonprotective atmosphere.

Skimming - see drossing.

Slag – The material formed by fusion of constituents of a charge or of products formed by the reactions between refractory materials and fluxes during metallurgical processes. It may be somewhat vitreous in appearance and floats as a molten mass on the surface of the molten metal in the furnace.

Sludge –The accumulated settled solids separated from various types of water as a result of natural or artificial processes.

Smelter – a place or establishment where ores are smelted.

Sprue – A vertical channel through which a mould is filled; the metal slug which solidifies therein.

Sublimation – the conversion of a solid by heat to vapour without passing through the liquid state.

Sweat furnace – otherwise known as dry hearth furnaces, sweat furnaces separate metals by melting depending on their various melting points.

TCLP - toxicity characteristic leaching procedure (USEPA)

TWA – time-weighted average airborne concentration

Volatilization – The evaporation of a substance from the liquid state, with the rate of volatilization usually increased by increased temperature or reduced pressure.

Waste – substances or objects which are disposed of or are intended to be disposed of or are required to be disposed of by the provisions of national law.

Annex II

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White, C.V. and J.P. Hager, (1996), Dept Metallurgical and Materials, Engineering, Colorado School of Mines, Golden, Colorado.

Annex III

Other useful references

For general information on metals:

- International Council on Mining and Metals (ICMM), 3rd Floor, 19 Stratford Place, London W1C 1BQ, United Kingdom, Phone +44 20 7290 4920, E-mail info@icmm.com; web site http://www.icmm.com

- Australian Mineral Foundation - web site http://www.amf.com.au/amf

For information related to metal finishing:

- Metal Finishing Guidebook and Directory (annual publication)

- Transactions of the Institute of Metal Finishing (bimonthly publication), Exeter House, 48 Holloway Head, Birmingham B1 INQ, UK (e-mail <ukfinishing@dial.pipex.com>)

- Plating and Surface Finishing (monthly publication), AESF/NAMF/MFSA, Government Relations Office, 2600 Virginia Ave, NW, Suite 408, Washington, DC 20037 Fax 202/965-4037

For information on specific metals:

- Antimony, arsenic, selenium and tellurium: Minor Metals Symposium, Mining, Metallurgy and Exploration. (2000)

- Selenium: Tailings and Mine Wastes 95 Proceedings of the 2nd International Conference, Colorado State University, Civil Engineering Department.

For information relating to occupational health and safety:

- National Institute for Occupational Safety and Health, Occupational Health Guidelines for Chemical Hazards, US Government Printing Office.

For information on the environmental effects of metals and metal compounds:

- United States of America Environmental Protection Agency: http://www.epa.gov

For information on the effects of metals and metal compounds on human health:

- World Health Organization: http://www.who.int

For information on cleaner production:

- Journal of Cleaner Production (quarterly publication), Elsevier Science Ltd, PO Box 800, Oxford OX5 1DX, UK Fax +44 1865 853333.Annex IV

Annex IV

Web sites

http://www.amm.com/ref/glossary.htm. The American Metal Market - Glossary for technical terms and terms of art.

http://www.jrc.org/. European Commission Joint Research Centre.

http://www.bir.org/. Bureau for International Recycling.

www.isri.org. Institute of Scrap Recycling Industries.

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http://www.icmm.com/. International Council on Mining and Metals.

http://www.unepie.org/. UNEP Industry and Environment Programme.

http://www.unep.or.jp/ietc/. UNEP International Environment Technology Centre.

http://www.iso.ch/. International Organization for Standardization.

http://europa.eu.int/comm/environment/emas/. European Commission Eco Management and Audit Scheme.

http://www.unido.org/doc/331372.htmls or http://www.emcentre.com/unepweb/. UNEP Technical Report series No.7.

http://www.ec.gc.ca/cceb1/eng/public/CuZn_e.html.

http://www.epa.gov/safewater/mcl.html. United States of America Environment Protection Agency drinking water standards.

http://www.epa.gov/epaoswer/hazwaste/test/sw846.htm. The laboratory method for TCLP.

http://www.amf.com.au/amf. Australian Mineral Foundation.

http://www.epa.gov. United States of America Environment Protection Agency.

http://www.who.int. WHO.

www.eippcb.jrc.es. European Centre for Best Available Technology.

http://www.basel.int/links.htm Basel Convention links page giving several sites for cleaner production.

www.basel.int

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