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PARTNERSHIP FOR ACTION ON COMPUTING EQUIPMENT

PROJECT 2.1

GUIDELINE ON ENVIRONMENTALLY SOUND MATERIAL RECOVERY / RECYCLING OF END-OF-LIFE COMPUTING EQUIPMENT

Approved by the PACE Working Group

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In addition, special thanks are extended to Co-chairs of the Project Group 2.1, Mr. Joachim Wuttke from Germany and Mr. John Bullock for their leadership in finalizing the guideline and for ensuring that all comments have been reviewed and incorporated in the guideline where appropriate.

The approved Guideline on Environmentally Sound Material Recovery and Recycling of End-of-Life Computing Equipment will be reviewed in a facility type of environment and revised to reflect the practical situation.

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1. EXECUTIVE SUMMARY

This guideline is a product of the Partnership for Action on Computing Equipment - PACE - and it covers the personal computers and peripherals that hundreds of millions of people are using around the world, and that are also being disposed around the world: central processing units (CPUs), both desktop and laptop; monitors using CRT and LCD flat screen technology; keyboards and mice; printers and scanners. These kinds of computing equipment contain many types of metals, plastics and other substances, some of which are hazardous, some of which are valuable resources, and some of which are both. To avoid exposure of people and communities to the hazardous substances, and reduce the use of resources, end-of-life computing equipment should be re-used - if possible - but if not it should be sent for material recovery/recycling at facilities that recycle electronics and that undertake environmentally sound management (ESM) in their operations, and only as a last resort be sent for final disposal.

The purpose of this guideline is to describe the chain of steps that should be taken in order to ensure environmentally sound management in material recovery facilities that recycle electronics, and to encourage operators at each step to know about, work with, and take their responsibility for human health, safety and the environment, so that the entire value chain works in both an economically and environmentally sustainable manner.

In theory, every part of end-of-life computing equipment can find continued beneficial use through the value chain, from direct reuse as a complete computer to a part of a slag-construction aggregate. In practice, there are economic limits to material recovery, and some process residues from all of the six steps will need final disposal, with careful attention for protection of the environment.

Computing equipment contains more than 60 types of metals and other materials, some in large amounts, "primary constituents" such as steel, some in small amounts, "minor constituents" such as silver, and some in very minute amounts, "micro or trace constituents" such as gold. Of course, the exact materials are different for each manufacturer, for each piece of equipment, and they are always changing as the technology changes. Facilities that recover material from end-of-life computing equipment must be prepared for new and old equipment, with new and old technology.

Some of these materials present little or no special hazard or concern, e.g., steel. Certain other materials may present a hazard when they are broken, crushed, shredded or melted, unless environmentally sound management practices are employed. In addition, other substances may be used in recycling, or may be produced. There are three main groups of substances that may be released during material recovery, and that should be of concern: original constituents of computing equipment, such as lead, mercury, etc., substances that may be added in some recovery processes, such as cyanide; and substances that may be formed by recycling processes, such as dioxins.

To protect their workers and their communities, material recovery facilities should take steps that are guided by environmentally sound management criteria. These criteria work together to both guide and assist a materials recovery facility to achieve environmentally sound management of computing equipment and its recovery. Facilities will need to obtain more detailed technical information than this guideline can provide in order to accurately determine the most appropriate and effective technology and practices, but should find that this guideline provides an overview of many material recovery steps, and how they work together.

Applying these environmentally sound management criteria, a material recovery facility must first collect end-of-life computing equipment, but only the kinds that it is prepared, qualified and licensed to accept and process. Then it must carefully remove and separate the most problematic constituents - those that contain hazardous substances that may contaminate other materials – such as mercury, batteries, CRTs, which usually need additional processing and/or environmentally sound final disposal. After that, material recovery from remaining computing equipment generally consists of a long series of steps and processes, some going on for a number of months, with each step adding value. All of these processes may also release hazardous substances, and careful worker training and protection, as well as community protection, are necessary parts of sound facility management. The general intent at each step is that complex materials should be sorted and separated as much as possible into similar types of materials, e.g., steel with steel, aluminum with aluminum, copper with copper, etc. At each step a more concentrated output material becomes a more valuable input into another process, until a material is ready for the market as a new material. And material recovery from computing equipment not only minimizes waste disposal, it can also be much more environmentally sound than mining the same raw materials.

Material recovery facilities can sometimes use manual labor in recovery processes, and can sometimes use mechanized and advanced sorting processes. Many facilities use both, depending on which is most efficient for a particular step. In developing countries and countries with economies in transition, if costs of manual labor are low, the manual disassembly path is more often taken. Even in developed countries, in some circumstances manual disassembly and sorting may also be more efficient or necessary in material recovery. It does not require significant technological skills, although worker training to safely carry out specific tasks is always important. It can produce clean sorted materials and working components, such as electronic chips and wires/cables for additional value. These steps are not without risks of exposures to hazardous substances, however, so health, safety and the environment must be strong concerns.

Mechanized material recovery processes, using shredders, grinders and separation technology, are more likely to be high speed - high volume operations, with several shredding steps followed by very modern, sophisticated identification and separation of plastics and metals by optical and X-ray technology, ferrous metals by electromagnets, copper and aluminium by eddy current, etc.

When concentrated streams of metals have been produced, they are usually further refined in metal-specific pyrometallurgical and/or hydrometallurgical processes. Scrap steel can be used in electric arc furnaces to produce new steel. Scrap aluminum can be used in secondary aluminum furnaces to produce new aluminum. Scrap copper, scrap precious metals, and some other non-ferrous (special) metals are commonly recovered from computer circuit boards and other components/fractions in pyrometallurgical processing and/or by metal-specific hydrometallurgical refining. Informal recovery operations, such as acid leaching, on circuit boards and other precious metal-bearing materials are inefficient, and expose workers, communities and the environment to cyanides, strong acids, toxic gasses and other hazards.

Some functional cathode ray tubes (CRTs) may be re-used without change, or may be used to produce televisions or other electronic displays. If they cannot be re-used, clean and sorted CRT glass may be used in the remaining CRT manufacturing facilities to produce new CRT glass. CRT leaded glass can also be used in lead smelters to produce lead.

Most screens with liquid crystal display (LCD) contain mercury lamps as backlights which have to be carefully and manually removed before processing or managed in closed, highly mechanized systems (emerging technologies). The mercury lamps should be properly packaged and sent to specialized mercury recovery facilities. Regular monitoring should be done in the working areas for presence atmospheric and environmental levels of mercury.

Plastics may be recycled if they are separated by type, are mostly free of metals and other contaminants, and do not contain certain hazardous brominated flame retardants (BFRs), unless they can be removed or can legally continue to be used as flame retardants. Plastics can be used in smelting operations as fuel and as reducing agents, if the smelter emissions are well controlled, especially for dioxins and furans.

Batteries, derived from computing equipment, now almost always based on lithium and nickel metal hydride chemistry, should be evaluated for continued use as batteries, for which there is a good market (See the PACE Guideline 1.1 for battery standards). If a battery is no longer useable, it should be processed only in specialized facilities that are permitted to safely manage hazardous characteristics such as corrosivity or toxicity. The primary metals of interest are cobalt, nickel and copper, and lithium may also become a valuable target for recovery.

Residues from processing and pollution control systems that cannot be efficiently recovered are likely to contain metals and other substances of concern, which must be carefully managed, often as hazardous waste. These include bag house filters and dust, sweepings, glass fines, phosphors, plastics and slags. Because these waste residues are likely to contain metals, plastics and halogens, disposal in an incinerator that does not have efficient pollution control systems is not suitable. Similarly because process residues may leach hazardous constituents, disposal in an uncontrolled landfill is also not suitable.

Because many residues generated in the material recovery chain are intended for further recovery processes, or for final disposal, and will be classified as hazardous waste, it is important that material recovery, energy recovery and disposal facilities be properly authorized and licensed, and comply with all applicable laws – local, national, regional, multilateral and international, which may include implementation of the Basel Convention, where transboundary movement is undertaken, as is often the case with end-of-life computing equipment.

2. INTRODUCTION

1. As the use of computers expands in all countries, their many benefits are joined by new challenges at their end-of-life. Computers contain many metals, plastics and other substances[1], some of which are hazardous (e.g., lead, beryllium, mercury, halogens), and some of which are valuable resources equipment (e.g., gold, silver, palladium, copper, aluminium, and plastics) that should not be wasted but can be recovered for use in new products. Recovery can also provide raw materials to the market with a lower environmental footprint than mining.[2]

2. Some substances like lead are both hazardous (if emitted) and valuable (if properly recovered) at the same time. Some substances, such as "high tech" metals, e.g., cobalt, platinum, rare earths, are increasingly becoming scarce, and their recovery is increasingly important.[3] And some substances may be recovered but should not be put back into commercial markets, such as mercury.

3. Recycling processes (and disposal of unrecycled residues) can release substances and expose workers and their communities to environmental and human health problems. But recycling processes can be conducted in an environmentally sound way. To avoid or mitigate problems with used and end-of-life computing equipment, they should be carefully managed through a chain of steps:

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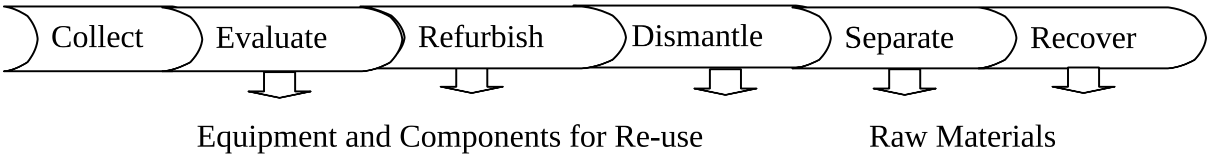
[1] “For example, computer chips made use of 11 major elements in the 1980s but now use about 60.” The Consumption Conundrum: Driving the Destruction Abroad, Oswald J. Schmitz and T.E. Graedel, Yale University, School of Forestry and Environmental Studies, 2010

[2] See, for example, http://www.epa.gov/epawaste/conserve/rrr/recycle.htm . The US EPA says that aluminum recycling saves 92 percent of the energy needed to produce aluminum from bauxite ore.

[3] See, for example, http://ec.europa.eu/enterprise/policies/raw-materials/critical/index_en.htm



5. 1st step - **collect** - This step can be challenging, but is critical. Computer equipment that is discarded in household trash may never reach the next steps, may then be lost for further beneficial use, and may be mismanaged. In some countries, informal scavengers may look at everything before it is finally discarded and used and end-of-life computers often have enough value to be collected by them. These scavengers, and informal and second-hand markets, are important sources of electronic scrap. In other countries, greater effort and expense is needed to collect computers, and it may be necessary to find ways to subsidize collection systems.[4] Special collection events are often organized, or collection may be regularly on-going in retail stores, or by mail-in collection. Charities sometimes collect computers for reuse. Collection of computers from businesses is important because of the large numbers of computing equipment that may be involved, and may be a particularly good source of recent-model computers for refurbishment, as well as for material recovery.

6. 2nd step - **evaluate** – Once it has been collected, computing equipment should be evaluated to determine whether it can still be used as computing equipment, or whether it should be used only for material recovery. This may be done at the initial collection site, or more typically at a later step before computing equipment is dismantled. Continued use of computing equipment preserves the high value added in original manufacture, conserves resources and energy needed to manufacture new computing equipment, and makes inexpensive computing technology available to persons who cannot afford to purchase new computers. The methods of such evaluation are not within the scope of this guidance (see guideline produced by PACE Project Group 1.1), but an experienced, knowledgeable person can often decide quickly - based on model, age, condition and appearance - whether computing equipment has potential market value in continuing use, or should be scrapped for materials recovery. This step overlaps to some degree with the third and fourth steps –

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[4] Examples of funding mechanisms:
- Advanced disposal fees – paid by the consumer at sale, either a visible fee (shown on the receipt as a separate item) or an 'invisible' fee (just part of the total sale price).
- Levy on import – paid by the importer of the product at the point of entry into the country (either collected and managed by the industry or by the Government)
- "waste arisings" – collection/recycling costs paid for by the producer at the time the product enters the waste stream. The costs can be based on current market share or calculated on historic market shares and may or may not include legacy and orphan wastes.
- End-User-Pays – the end-user pays a fee for the collection/recycling costs at the point of disposal
- Rate-payer – the collection/recycling costs are covered by all tax payers through their rates payments
- Short-term grant funding – grants can be awarded for short-term projects such as initial collection infrastructure and are available from a variety of sources – private sector, Trusts, government, Lottery, landfill tax etc

refurbish and dismantle - because it will sometimes be necessary to see what parts are inside, whether parts are still working, what parts need to be replaced.

7. 3rd step – **refurbish or repair** – Computing equipment that has been evaluated and can still be used as computing equipment may need to be refurbished or repaired. This includes replacement of hardware and software as needed, and cleaning, labelling and distribution, and puts a useful computer and/or component back into the market for continuing use. This guideline does not describe refurbishment or repair activities or standards, and reference should be made to PACE Project Group 1.1 for its refurbishment guideline.

8. 4th step - **dismantle** – Computing equipment often needs to be opened to see if it is working and can still be used as computing equipment, or to begin the material recovery processes. Dismantling should be done by hand if it is intended to keep a used or end-of-life computer in working condition. Computers are usually held together by screws and simple fasteners that can be easily removed, although some parts are welded or soldered and are more difficult to separate. Dismantling can also be the beginning of material recovery. Manual dismantling can recover not only working components, but also clean materials for recovery, e.g., steel cases. It may also involve powerful mechanical separation of parts and components, and may begin to release substances as dust. It will be necessary to first manually remove components such as mercury lamps, batteries, etc. before they are shredded and their contained substances, some of which are hazardous, are released and/or mixed with other materials. Toner cartridges should also be removed unless recycling or shredding equipment has been specifically designed to handle environments where high dust concentrations in air might occur. Like many organic materials in powdered form, toner can form explosive dust-air mixtures when finely dispersed in air. Hazardous substances should not be released and/or mixed with other materials. Protection of worker health and safety and the environment is necessary in such conditions, including engineered control systems, personal protective equipment such as gloves and eye protection, and more complex measures such as respiratory masks.

9. 5th step - **separate** – Separation is the process of sorting dismantled materials into separate batches and consolidating them for specialized material recovery. Computing equipment that has been evaluated to have no continuing value through refurbishment, and no remaining valuable working components, will be taken apart, manually or mechanically, and separated into steel, plastics, circuit boards, etc. Higher levels of worker and environmental protection are needed, sometimes much higher depending upon the separation process and the material being processed. Some of these separated categories can be quickly returned to markets, e.g., steel cases into a scrap steel market, while others require further separation in more complex recovery steps.

10. 6th step - **recover** – Recovery takes these separated batches of materials into more specialized processes, often into a series of them, e.g., circuit boards first into copper recovery, followed by specialized refining of the residues to recover other metals, or engineered thermoplastics into size reduction and granulation. Steel, aluminium, magnesium and glass are other examples. These processes often involve high temperature, e.g., smelting and other pyrometallurgical processes, or very strong chemicals, e.g., hydrometallurgical processing by acids or cyanide, or hazardous process emissions, and require very high levels of process technology as well as monitoring and worker and environmental protection.

11. In theory, every part of used or end-of-life computing equipment can find continued beneficial use through this chain of steps, from direct reuse as a complete computer to high quality raw material production to use, when approved and carefully controlled, as a part of a slag-construction aggregate. In practice, there are technical and economic limits to material recovery, as well as legal restrictions in some countries for reusing hazardous materials. Economic limits are reached when capital costs, transportation, etc. exceed market prices for recovered raw materials and when no subsidy program is in place to fund the service of recycling, or when markets cannot be found for certain materials. Some process residues from all of the six steps will need to be finally disposed, by state-of-the art incineration in controlled furnaces or landfills, and such final disposal requires careful attention for protection of the environment.

12. The complete chain of steps may be performed in many places, and can take a long time to finish before marketable raw materials are produced. However persons who perform one step should understand the entire chain of recovery, because each person has responsibilities to other persons at other steps. Each person in the chain should know all of the other steps and transparently work with others to ensure that all steps are environmentally sound, resource efficient and legally authorized throughout the chain. This guidance should help to carry out this responsibility of due diligence by collectors, refurbishers, material recovery processors, smelters and refiners, as well as concerned government regulators.

13. As a final introductory note, it has become clear that in some locations, particularly in developing and transition economies, some or most of the steps in the chain are being carried out within informal business sectors, by businesses that are often outside close regulatory control and often do not practice environmentally sound management, by workers who are not trained or required or even encouraged to carry out the processes that are described here. Significant harm to their health and the environment can be caused by such informal operations. It must also be recognized, however, that it is unrealistic to expect close regulatory control to be immediately adopted in these circumstances. Some steps can be taken now, such as awareness-raising and training, and it will be necessary for these informal businesses and workers, and their governments, to bring environmentally sound management

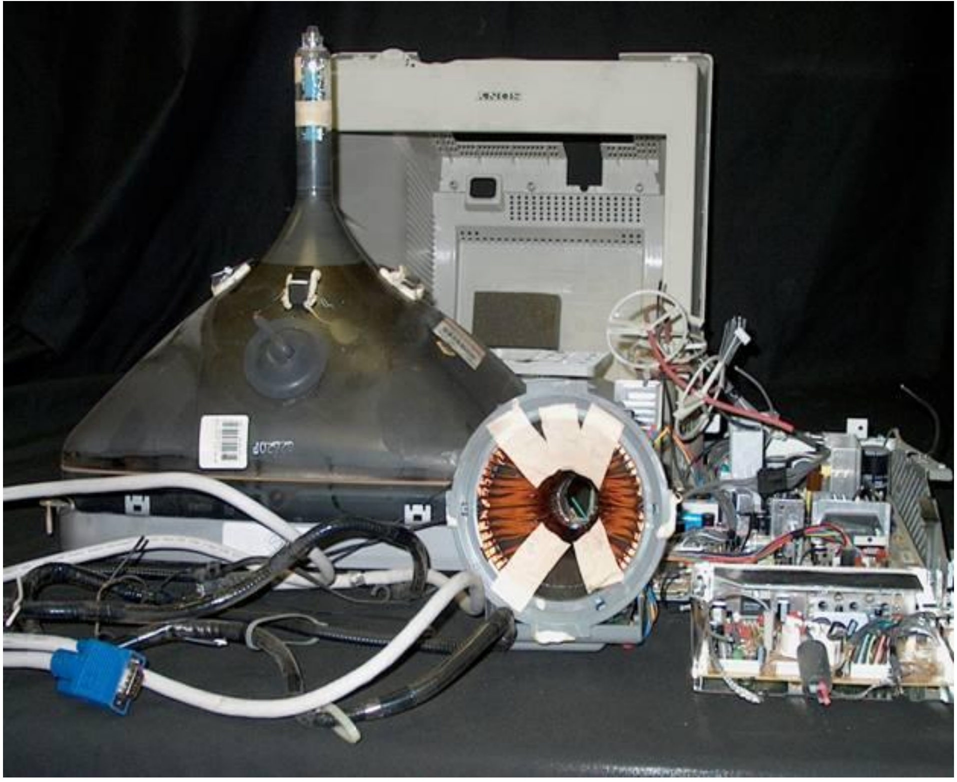
into their operations. A great deal of additional technical information may be needed for some operations. It will require time to do so with incremental advances. The environmentally sound management practices described in this guideline should be applied as soon as it is practical to do so.

3. COMPUTING EQUIPMENT COVERED BY THIS GUIDELINE

14. The scope of the PACE covers personal computers (PCs) and associated displays, printers and peripherals. This includes personal desk top computers, including the central processing unit and all other parts contained in the computer. Personal notebook and laptop computers, including the docking station, central processing unit and all other parts contained in the computer. Computer monitors, including the following types of computer monitor: (a) cathode ray tube; (b) liquid crystal display; (c) plasma. Computer keyboards, mouse, and cables. Personal computer printers: (a) including the following types of computer printer: (i) dot matrix; (ii) ink jet; (iii) laser; (iv) thermal; and (b) including any computer printer with scanning or facsimile capabilities, or both. In general terms, a personal computer consists of

A. a central processing unit (CPU);

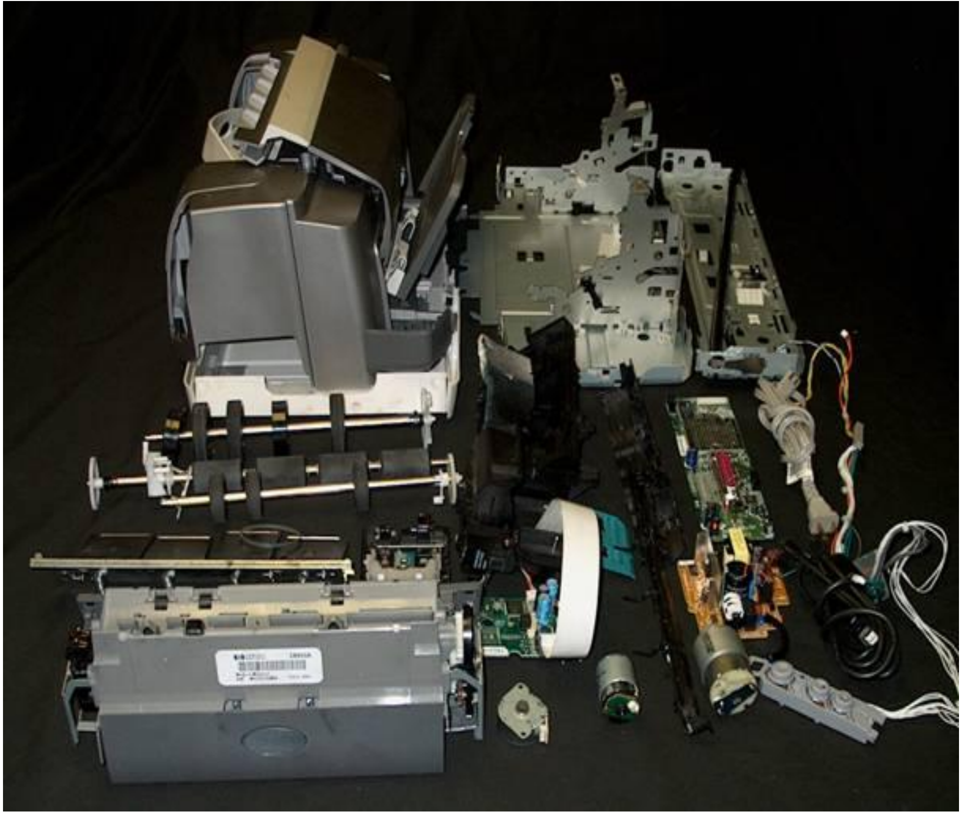
B. a monitor or display (CRT or flat screen display);



C. devices to input information, and to interact with and adjust the display, such as a keyboard and a mouse;

In a desktop computer, these parts are separate. In a notebook computer, these parts are combined into a single device.

D. a printer (which may also have scanning capability);



E. a scanner (which may have printing capability);

For more details, descriptions and photographs of computing equipment, see "Manually Dismantling a Computer: Guidebook" EMPA, Swiss E-Waste Program.

4. COMPUTING EQUIPMENT: MATERIAL CONTENT

15. There have been many models and technologies for computing equipment, and in recent years an increased reduction or elimination of hazardous materials, so end-of-life computing equipment differ according to design, manufacturer, and age. Therefore the materials that may be encountered in material recovery processing will also differ. For example, while most desktop computers have a steel case, and most laptop/notebook computers have a plastic case, some might use aluminium or magnesium. Some materials that were used in early models have been replaced in later models, particularly as manufacturers have responded to safety concerns and hazardous material use restrictions. The change in popular demand from CRT monitors to LCD monitors has greatly reduced the amount of lead (from 2-3 kilograms), while introducing mercury in lamps (5-50 mg). However older equipment and materials will continue to be received and facilities should be prepared to receive computing equipment of many types, without knowing exactly what will be contained within a product or a shipment. Many times it is difficult for the recycler to receive complete information from the manufacturer regarding specific materials in a specific product, in order to plan how to best protect their workers and the environment. This will create challenges for recycling facilities, and they should prepare for higher rather than lower risks. (A facility may also be asked to accept, or find that it has received, other electrical or electronic equipment that is not covered by this guideline, and that may contain other substances. It should reject equipment that it is not prepared to manage in an environmentally sound way, or arrange for transport to an ESM facility that is prepared to accept such equipment.)

16. Following are charts that show a number of common materials in computing equipment of various types and ages. These charts require a caution: they are not intended to be a complete description of all substances contained in all end-of-life computing equipment that may be collected and received by a facility for material recovery. For example, computer manufacturers have largely eliminated the use of lead over the last several years, both in solder and in displays, because of the EU and China RoHS Directives as well as their own environmental and safety concerns. But older computers that contain lead solder and CRT displays will be received for material recovery, and so possible exposure of workers and the environment to lead will be a concern and should be controlled. Those CRTs have been replaced by newer LCD display screens, and the most recent use light emitting diodes (LEDs) for backlighting, but older (and some current) models use mercury lamps, and so exposure to mercury will be a concern and should be controlled. Again, it is important to understand that some equipment may contain different substances than are listed here, e.g., selenium in old laser printer drums, lead in soldered components, beryllium in copper alloys, and it is important for material recovery facilities to prepare for a wide range of substances and

hazards. Some environmentally sound steps, such as engineered collection of airborne dust and fume, will protect against many substances. In other cases it is necessary to know the unique characteristics of computing equipment that is being processed. Whether computing equipment is new or old, it is important to know what and how substances may be released and expose workers and the environment to possible harm. These substances include not only those listed below already contained in computing equipment, but also added processing substances, such as acids, and new substances created during processing, some of which may also be hazardous. Some substances listed below as minor or trace constituents can nevertheless exhibit serious toxicity or other hazardous characteristics. Placement on a list is not an indicator or relative environmental or human health concern.

17. Many substances in these charts of computing equipment present little or no special hazard or concern, e.g., steel in the cases of CPUs, or copper in wire particularly in the early steps of recycling, such as manual dismantling. Some substances, however, may be quite hazardous, and facilities should obtain and maintain current Material Safety Data Sheets. Some materials can present a hazard when computing equipment is broken, crushed, shredded, melted, incinerated or landfilled, unless environmentally sound management practices are used. For example, beryllium in copper-beryllium connectors poses little or no risk when computing equipment is manually dismantled, but if beryllium is reduced to fine airborne dust, and especially if it is melted and creates fume that is not controlled and is inhaled by workers, it can permanently scar the lungs, leading to serious health problems and death. In addition, it is not only the substances in computing equipment, such as those listed above, that are of concern. Other substances may be used in recycling, or may be produced or arise as emissions. For example, poly vinyl chloride insulation on wire is not hazardous in normal handling, but if it is burned to recover copper without proper emission control equipment and systems, it may create dioxins, furans and other combustion emissions. Three main groups of substances, that may be released during recycling, incineration or landfilling, should be of concern:

(i) original substances that are constituents of computing equipment, such as lead, mercury, cadmium, etc.;

(ii) added substances that are used in recycling processes, such as cyanide or strong acids; and

(iii) new substances that may be formed (sometimes unintentionally) by recycling processes, such as dioxins.

Table 1: Desktop Computers

Primary Constituents:	**Locations in Device**
Iron and Fe compounds[1]	Case, components
Plastics[2]	Case, circuit board, connectors, components
Copper (Cu) and compounds (including brass)	Circuit board, wires, connectors
Aluminum (Al)	Heatsinks, components
Poly Vinyl Chloride (PVC)	Wire and cable
Glass, ceramic, semiconductor	Circuit boards, components
Nickel (Ni) and compounds	Components, fasteners
Tin (Sn)	Solder, components
Minor Constituents	**(typically less than 0.1%)**
Liquids (organic solvents and water)	Capacitors
Lead (Pb)	Solder, components
Beryllium (Be)	Connectors
Lithium	Batteries ("coin" or "button" cells
Silver (Ag)	Solder, components
Carbon (C)	Batteries, components
Micro or Trace Constituents	**(typically less than 0.01%)**
Titanium (Ti) and compounds	Circuit board, components
Paper	Components
Tantalum (Ta) and compounds	Components
Neodymium (Nd)	Components
Zinc Oxide (ZnO)	Components
Gold (Au)	Components
Lithium (Li) and Compounds	Batteries, components
Oil/lubricants	Fan
Calcium carbonate (CaCO3)	Components
Talc	Components
Cadmium (Cd)	Components
Arsenic (As)	LED indicator lights (gallium arsenide)
Magnesium (Mg)	Components
Selenium (Se)	Components
Palladium (Pd)	Components
Vanadium (V)	Components
Tungsten (W)	Components

1) Iron alloys may contain a wide variety of elements, such as Cr, C, Ni, Co, C, Si and Mn.
2) Plastics may contain a wide variety of additives, including plasticizers, flame retardants. etc.

Table 2: Laptop Computers

Primary Constituents:	**Location in Device**
Plastics[1]	Case, circuit board, connectors, components
Iron (Fe) and compounds[2]	Case, frame, charger, batteries
Glass/ceramic/semiconductor	Display, components, circuit board, connectors
Copper (Cu) and compounds (including brass)	Circuit board, wires, connectors, batteries, heatsinks
Aluminum (Al)[3]	Batteries
Lithium (Li) and Compounds	Batteries
Cadmium	Batteries
Cobalt	Batteries
Flame retardants	Circuit board, components, structural plastics
Liquids (organic solvents and water)	Batteries, capacitors
Nickel (Ni) and Compounds	Components
Tin	Solder, components
Minor Constituents	**(typically less than 0.1%)**
Silver (Ag)	Solder
Lead (Pb)	Solder, components
Poly Vinyl Chloride (PVC)	Wire and cable
Beryllium (Be)	Connectors
Micro or Trace Constituents	**(typically less than 0.01%)**
Tantalum (Ta) and compounds	Components
Mercury (Hg)	LCD screen backlights
Liquid crystal polymer	LCD screen
Gold (Au)	Connectors, components
Fluorine (F) and compounds	Components, circuit board
Titanium (Ti) and compounds	Circuit board, components
Calcium carbonate (CaCO3)	Components
Talc	Components
Oil/lubricants	Fan
Lead oxide (PbO)	Components
Paper	Components
Indium tin oxide (ITO)	Display
Arsenic	LED indicator lights (gallium arsenide)
Palladium (Pd)	Components
Magnesium (Mn)	Components
Tungsten (W)	Components
Gallium (GaAs)	LED/lighting
Germanium (Ge)	Components
Vanadium (V)	Components

1) Plastics may contain a wide variety of additives, including plasticizers, flame retardants, etc.

2) Iron alloys may contain a wide variety of elements, such as Cr, C, Ni, Co, C, Si and Mn.

3) Percentage of Al (or magnesium in some cases) will be much higher if used in casing.

Table 3: Displays (CRT, LCD)

Primary Constituents:	**Location in Device**
Iron (Fe) and compounds[1]	Case, components
Lead (Pb)	CRT glass, solder
Plastics[2]	Case, circuit board, connectors, components
Glass/ceramic/semiconductor	Circuit board, components
Copper (Cu) and compounds	Circuit board, wires, connectors
Flame retardants	Circuit board, components, structural plastics
Poly Vinyl Chloride (PVC)	Wire and cable
Aluminum (Al)	Heatsinks, components
Minor Constituents	**(typically less than 1%, more than 0.1%)**
Paper	Circuit board, components
Nickel (Ni) and Compounds	Components, fasteners
Tin (Sn)	Solder, components
Carbon	Components
Liquid crystal polymer	LCD screen
Micro or Trace Constituents	**(typically less than 0.1%)**
Liquids (organic solvents and water)	Components, capacitors
Mercury (Hg)	LCD screen backlights
Cadmium (Cd)	LCD screen phosphor
Zinc oxide (ZnO)	Components
Silver (Ag)	Solder, components
Tantalum (Ta) and compounds	Components
Lead oxide (PbO)	Components
Titanium (Ti) and compounds	Circuit board, components
Arsenic	LED indicator lights (gallium arsenide)
Gold (Au)	Connectors, components
Calcium carbonate (CaCO3)	Components
Talc	Components
Indium tin oxide (ITO)	Display
Palladium (Pd)	Components
Tungsten (W)	Components

1) Iron alloys may contain a wide variety of elements, such as Cr, C, Ni, Co, C, Si and Mn.

2) Plastics may contain a wide variety of additives, including plasticizers, flame retardants, etc.

Table 4: Printers (Ink Jet, Laser)

Primary Constituents:	**Location in Device**
Plastics[1]	Case, circuit board, components
Iron (Fe) and compounds[2]	Case, components
Copper (Cu) and compounds	Circuit board, wires, connectors
Glass, ceramics	LCD screen, circuit board, components
Poly Vinyl Chloride (PVC)	Wire and cable
Flame retardants	Circuit board, components
Minor Constituents	**(typically less than 1%, more than 0.1%)**
Aluminum (Al)	Heatsinks, components
Nickel (Ni) and Compounds	Components, fasteners
Lead (Pb)	Solder
Ethylene Glycol	Inks
Liquids (organic solvents, water)	Components, ink
Micro or Trace Constituents	**(typically less than 0.1%)**
Tin (Sn)	Solder, components
Carbon	Components, inks, toners
Paper	Circuit board, components
Silver (Ag)	Solder, components
Titanium (Ti) and compounds	Circuit board, components
Gold (Au)	Connectors, components
Lead oxide (PbO)	Components
Arsenic	LED indicator lights (gallium arsenide)
Tantalum (Ta) and compounds	Components
Zinc oxide (ZnO)	Components
Calcium carbonate (CaCO3)	Components
Talc	Components
Palladium (Pd)	Components
Tungsten (W)	Components

1) Plastics may contain a wide variety of additives, including plasticizers, flame retardants, etc.
2) Iron alloys may contain a wide variety of elements, such as Cr, C, Ni, Co, C, Si and Mn.

18. Some recycling processes are more likely than others to release these substances, and such processes, such as open burning, should be completely avoided or should be undertaken only with proper engineering controls, such as melting, smelting, shredding, etc. These processes will create fume and fine dust particles as well as larger pieces, and those fine particles may rise into the air, may contain any or all of the many materials in computing equipment, and so may be hazardous. Workers need protection through engineered ventilation systems – pulling fume and dust away from workers – and personal protective

equipment, such as dust masks and respirators. Dust that is pulled away from workers must not be simply discharged to the outside air and community, but must be filtered and collected in baghouses and properly managed, through recycling if feasible, and through final disposal, sometimes hazardous waste disposal.

19. While this guideline deals with computing equipment, recycling facilities are likely to also receive, or be asked to accept, other end-of-life products with very different constituents, hazards and risks. A recycling facility should only accept equipment and materials that it knows and understands, should make this known to the public and its suppliers, and should have a receiving procedure that will identify and reject other types of equipment and materials that it is not capable of safely managing or does not want to accept for any reason. A recycling facility should also try to know about other facilities that can safely manage other kinds of unwanted material, so that it can direct customers to those facilities, or send computing equipment that it cannot manage by itself.

5. INITIAL RECYCLING FACILITY PRACTICES

5.1 Facility Measures to Support Environmentally Sound Management

20. To protect workers and communities, material recovery facilities should take steps that are guided by the following ESM criteria (all of which are described more fully in the paragraphs immediately below):

i. Top Management Commitment to a Systematic Approach
ii. Risk Assessment
iii. Risk Prevention and Minimization
iv. Legal Requirements
v. Awareness, Competency and Training
vi. Record-keeping and Performance Measurement
vii. Corrective Action
viii. Transparency and Verification

21. *Top Management Commitment to a Systematic Approach:* A material recovery facility should have the clear commitment of top management to a systematic policy approach to achieve and continually improve environmentally sound management in all aspects of facility operations, including pollution prevention and environmental health and safety. Adequate financial and human resources should be made available. The policy should be documented, implemented, and communicated to all personnel, as well as to contractors and visitors as appropriate. Policy performance should be reported and reviewed

periodically by top management. In larger material recovery organizations, specific management representative(s) should be appointed to oversee the implementation of the policy through design, implementation and maintenance of a management system.

22. *Risk Assessment:* Material recovery facilities conduct heavy industrial operations involving powerful machinery, very high temperatures and strong and hazardous chemicals. While each facility will be different, with different operations and locations, they will all present multiple risks to workers' health and safety, and potential environmental impacts both within and beyond the facility location. Material recovery facility management should seek to identify and document hazards and risks to worker health and safety and to the environment that are associated with their own existing and planned material recovery activities, products and services. It is especially important to identify emergency situations and accidents that might occur, and how to respond to them, and these response procedures should be periodically tested and reviewed, especially after the occurrence of accidents or emergency situations. Plans and emergency procedures should be designed to prevent and mitigate EHS impacts during responses to incidents. These plans and procedures should also be provided to local emergency response agencies such as police and fire departments and hospitals and other medical facilities, and their comments should be incorporated for improvement. The hazards and risks of eventual site decommissioning and closure should also be identified and a site plan should be prepared, including remediation, with financial mechanisms to secure long term care if it would be necessary.

23. *Risk Prevention and Minimization:* Once material recovery facility management has assessed the hazards and risks of facility activities, products and services, it should systematically seek to minimize or eliminate these hazards and risks. This systematic approach should first address significant existing environmental and health and safety risks, as well as noncompliance with applicable legal requirements. It should consider technological, operational and business changes, including improved procedures, improved equipment, and different business practices. These should include engineering controls, e.g., process isolation, ventilation and dust control, emergency shut-off systems; administrative and work-practice controls, e.g., health and safety training, medical surveillance; and personal protective equipment, e.g., respirators, protective glasses, gloves. Beyond significant existing hazards and risks, a material recovery facility should look to continually improve the design of the workplace, process, installations, machinery, operating procedures and work organization with the aim of eliminating and/or reducing EHS hazards and risks at their source. All of these improvements should be documented and communicated to all personnel, as well as to contractors and visitors as appropriate. It is particularly important to have good communications to suppliers and buyers of recovered materials about the content and risks associated with those materials in the very specific circumstances of material recovery processing.

24. *Legal Requirements:* Material recovery facilities dealing with used and end-of-life computing equipment are required to have all operating permits, licenses, or other authorizations that apply to their operations, especially if these materials are defined by their nation or other governmental entity as being “waste”, as is often the case. A facility should always be in compliance with these permits, licences and authorizations. A systematic approach to environmentally sound management includes evaluation at regular intervals to identify applicable law, including amendments and new laws, and to determine how these requirements specifically apply to the facility and its operations. A systematic approach also includes periodic communication, and a sound working relationship, with competent authorities. Because material recovery operations may involve further operations by other facilities, including transboundary movement of supplies, wastes and products, a material recovery facility should also take care to ensure both its own compliance and the compliance of downstream material recovery operations with applicable international laws and laws of other concerned countries.

25. *Awareness, Competency and Training:* Facility managers should ensure that all people engaged in material recovery operations are well trained to carry out their responsibilities in a safe manner, and that such training is regularly updated and repeated. This means that employees must be trained not only in how to carry out facility operations, but also must be given an appropriate level of awareness of hazards and risks, and must achieve competence with respect to the effective management of these hazards and risks, including how to respond to and deal with foreseeable emergencies or accidents. This should follow from the Risk Assessment and Risk Prevention and Minimization steps described above. Worker competence also requires access to special tools associated with material recovery operations, test equipment, materials handling equipment, and information such as provided by material safety data sheets or other comparable sources for all substances, and training in understanding and using these. Where possible, photographs and diagrams should be added to written instructions to train workers in material recovery operations.

26. *Record-keeping and Performance Measurement:* A systematic approach to environmentally sound management includes the creation and maintenance of documents that record the details of that management. When an operating procedure has been documented, it can be properly executed in a consistently safe manner, and regularly improved. Documents that record the training of employees can be reviewed to ensure that such training is complete for the appropriate work assignment. Inspections, testing and assessment of used computing equipment can be reviewed to ensure that efficient and environmentally sound management is taking place in accordance with facility and legal requirements. Records of shipments received, process results, and shipments made to other material recovery facilities will assist in facility performance review, and in ensuring that downstream facilities use environmentally sound practices. There is little or no activity at a materials recovery facility

that will not be improved by appropriate records of that activity, accompanied by periodic review with intent to improve.

27. *Corrective Action:* A materials recovery facility should take appropriate action to address risks to worker health and safety and the environment that it identifies in Risk Assessment or that are brought to its attention by others, such as Competent Authorities or concerned third parties. Deficiencies in achieving ESM should also be addressed. Preventative and corrective actions should be appropriate and proportionate, and should be documented. The need for corrective action should be presented to senior management, as well as the results of such action.

28. *Transparency and Verification:* Material recovery facilities deal with end-of-life computing equipment that may be hazardous to the health and safety of their workers and the environment. They should have regular scheduled inspection and monitoring of these hazards, following documented procedures. If possible, such inspections/audits and monitoring should be conducted by persons independent of the facility operations, or should be conducted by third parties. Such documented inspection and monitoring procedures may be regulatory requirements, but should in any case be used as part of a systematic approach to environmentally sound management. A facility's environment, health and safety policy, and its inspection and monitoring schedule and results should be available to the public, workers, and to customers and clients who perform due diligence investigations of facility activities and operations. A material recovery facility should also examine the documentation of downstream material recovery operations to assure itself of their environmentally sound management.

5.2 Potential Material Recovery from Computing Equipment

29. In theory, everything used in computing equipment can be reused or recovered and made into a new material. In practice, recovery of specific materials is driven primarily by their economic value, primarily found in precious metals and other metals, but which may also include plastics and glass. End-of-life computing equipment, when collected in sufficient volume and brought into a material recovery industry, are a useful source of copper, tin and steel, gold, silver and palladium, among others. CRT glass recovery is also possible (currently) and environmentally preferable, as using old CRT glass in the manufacture of new CRTs significantly decreases the required energy inputs for the glass furnaces. Recycling of engineered plastics from computing equipment is also technically feasible and can be economically viable, especially when plastics are carefully separated by type. Plastic is sometimes not recovered because of the presence of brominated flame retardants, unless the BFRs can be removed, or the recovered plastic has continued uses that

require flame retardants. In some countries, the use of some BFRs, e.g., penta-brominated diphenyl ether, is prohibited and in those countries should not be re-used in the production of new plastics, but must be disposed in an environmentally sound manner.[5] If plastics are mixed with other types of plastics, or cannot be identified, this lowers the economic value. However, the plastic fraction that cannot be recovered from computing equipment may also contribute to energy-efficient recycling processes as reducing agents or fuel substitute in smelters and refiners.

30. There has also recently been increasing interest in recovery of "critical materials" or "special materials" such as platinum group metals, gallium, indium, rhenium, "rare earths", cobalt and antimony. Because of unique properties, these materials have an important role in modern applications and manufacturing, including computing equipment. There is a concern, however, that commercial access to these materials may become limited or even unavailable, for geological, economic and political reasons, and modern industry may thus be seriously disrupted.[6] In some cases, e.g., platinum group metals, high market prices lead to profitable recovery. However for other metals, such as the rare earth elements for which recovery is technically very challenging, these concerns of scarcity have not caused market prices to rise to the point where a profit can be made from recovery. For the mix of metals contained in computing equipment, some steps taken to recover precious metals enable the more efficient recovery of other "critical metals" in subsequent processing steps, with advanced technology, but not all of the "critical metals" contained in computing equipment are recovered. However there is on-going research to more efficiently recover these materials, their market prices are currently rising, and there are proposals to subsidize their recovery, so there may be opportunities in the future to further broaden the scope of recovery from computing equipment.

5.3 Collection/Receiving

31. As set forth above, material recovery is driven by the economic value of recovered material that has been collected in sufficient volume. Collection is a necessary first step. While this guideline does not encompass collection, it is important for a material recovery facility to collect and receive only those kinds of equipment that it can safely accept and process. A facility should define and publish a list of equipment that it will accept, and/or a list of items it will not accept ("Do Not Accept List"). A facility must avoid accepting materials and equipment that it does not have the capability to manage and process in an

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[5] EU Directive 2003/11/EC; the EU RoHS directive also limits the use of polybrominated biphenyls in electronic products.

[6] See, for example, U.S. Department of Energy, Critical Metals Strategy, December 2010; European Commission, Enterprise and Industry, Critical Raw Materials for the EU, July 2010; U.S. National Academy of the Sciences, Critical Minerals and the U.S. Economy, 2008.

environmentally sound manner, and personnel must be trained to reject other unwanted materials. However a facility should also know about other facilities that process other types of materials and equipment, so that it can direct these materials and equipment to a capable and environmentally sound destination

5.4 Evaluation and Initial Sorting

32. When suitable computing equipment has been collected and received at a material recovery facility, the recovery processing can begin. To maximize recovery, electronic equipment must be evaluated and sorted for selection of the best following steps, and for the best value.

33. Material recovery from computing equipment generally consists of a long series of steps and processes, some going on for a number of months, with each step adding value. The general intent of first material recovery processing is that complex materials should be sorted as much as possible into similar types of materials, e.g., steel with steel, aluminium with other aluminium, copper with other copper, glass with glass, high impact polystyrene (HIP) engineered thermoplastic with HIP engineered thermoplastic, etc. Some steps can produce a quick result, for example, removal of a steel case which can be recycled at a steel furnace. Other steps take longer; concentrating a material for the next step, i.e., the output product of one process will become the input into another process. For example, dismantling or shredding a computer is followed by separation steps to remove steel, aluminium, plastic, etc. Each step will vary according to the content of waste and scrap, the desired end products, and the capabilities of particular facilities. In some cases, it is useful to send materials that are recovered in processing to more specialized facilities for further recovery or refining that may be in different countries or on different continents. This conforms to Article 4, Section 9 of the Basel Convention, as well as the recognition that "economically and environmentally sound management of some wastes will be achieved at specialized facilities located at greater distances from the point of generation."[7] Typical material flows in material recovery from end-of-life computing equipment are shown in Figures 1-7.

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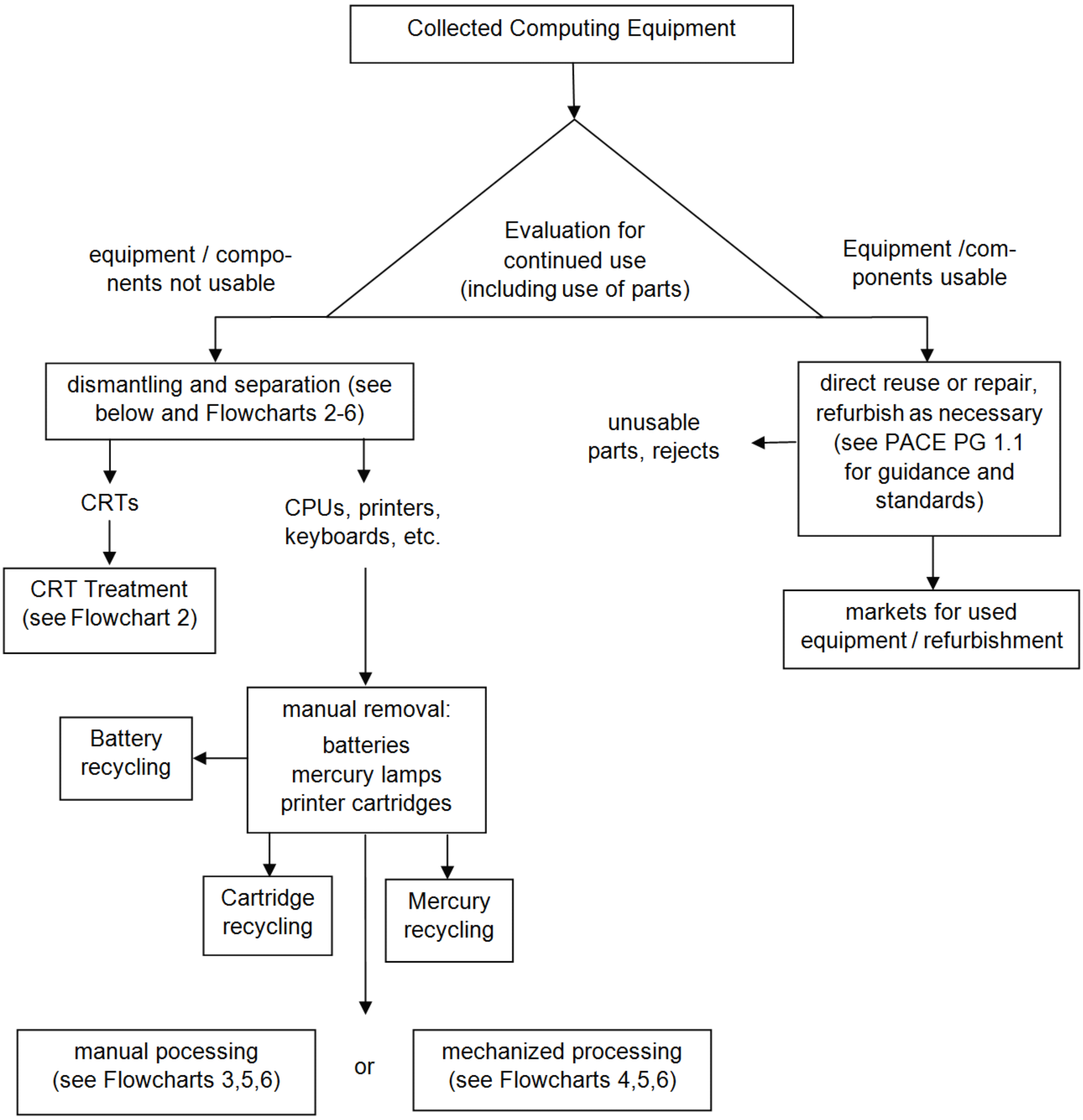
[7] Guidance Document on the Preparation of Technical Guidelines for the Environmentally Sound Management of Wastes Subject to the Basel Convention, http://www.basel.int/meetings/sbc/workdoc/framewk.doc

Fig. 1: Overview of Initial Steps



34. To maximize recovered value, it is necessary to sort as cleanly as possible, in order to avoid contamination that will prevent or complicate further recovery steps, as well as to avoid subsequent losses of valuable materials. When separation begins with complex materials such as computing equipment, its separation may not be perfect. Steel from computing equipment may contain small amounts of non-ferrous metals and plastics, which cannot be recovered from subsequent steel production. Similarly, aluminium streams may contain small amounts of steel and non-ferrous metals, which cannot be recovered from subsequent aluminium production. Losses of these unrecovered portions should be carefully

kept small and within the tolerances of further processing, e.g., steel furnaces and aluminium smelters. If a steel-works receives material that is not well separated, and is instead contaminated with other materials, the steel-works will reject the shipment. In addition, even if a steel-works will accept a shipment of steel scrap with small concentrations of other metals, it may not recover all these metals, since if they are not steel alloy elements they will be unwanted, and so these contaminant portions are losses of otherwise valuable metals. This can be of particular concern with losses of copper and the precious metals into steel, aluminium and plastic streams, because the primary economic value of materials recovered from computing equipment is in those metals. Mechanized processing operations therefore guard against undue losses of circuit boards into their steel, aluminium and plastic shipments, and many recyclers remove circuit boards before beginning shredding operations, for this economic reason.

35. Careful separation to avoid losses is also important for environmental reasons, because the recovery and recycling of metals requires significantly less energy and ecosystem disruption than in extraction of these metals from ores. For example, the energy required to produce aluminium from scrap is only 5% of the energy required for production from ore. Gold is present in many computer circuit boards at a 40-70 times higher concentration than ore, and does not have to be mined at very low concentrations, e.g., as low as one gram of gold per tonne of rock, with great use of energy and chemicals such as cyanide. If possible, shredding of computing equipment should occur in operations that are dedicated to treat only electronic waste, e.g., computers, mobile phones, rather than in operations that also treat other devices, e.g., stoves, refrigerators, so that the loss of precious metals will be minimized. Indeed, circuit boards are often processed by themselves, because subsequent sorting out of other materials will cause some loss of precious metals into the other materials, from where they cannot be recovered in an economical way.

5.5 Dismantling

5.5.1 Manual Dismantling and Separation / Initial Removal of Hazardous Substances

36. As Figure 1 indicates, material recovery processes should begin with careful manual separation of equipment components such as cathode ray tube monitors (CRTs), LCD displays, printers, laptops and desktops. Then each type of equipment will be further separated for separate recycling and material recovery processing, following procedures that are appropriate for that type of equipment. For example, processing of printers will begin with manual removal of ink and toner cartridges, so that these cartridges can be recycled in their own way, e.g., by refilling and rebuilding (see Section 7.4 Ink and Toner Management and Recovery). CRTs require unique handling and attention to their vacuums, phosphors and

lead (see Section 7.1.4 Cathode Ray Tube (CRT) and Non-leaded Glass Management and Recovery). Some particularly problematical contents must be carefully manually removed from laptops, LCD screens and some older scanners: e.g., batteries (see Section 7.2 Battery Management), and mercury lamps (see Section 7.3 Mercury Lamp Management)[8]. This is important because these components will be most efficiently recovered by themselves, may complicate other material recovery streams if not removed at the start, and/or are likely to release hazardous substances into the remaining electronics, the workplace, and/or the environment during subsequent material recovery processes.

37. This initial dismantling and removal of certain components from computing equipment may also be required by law, such as the EU WEEE Directive.

38. Removal of problematic components can be potentially hazardous. For example, removal of mercury lamps from LCD monitors is very likely to cause breakage, and release of mercury. (See Section 7.3 below) The lamps are located along the sides of and behind LCD screens, and are long thin fragile glass tubes. Some lamps will almost certainly break during removal and handling, so a dismantling operation should be well prepared to test its working atmosphere for mercury vapour, and to clean up visible mercury spills. Some facilities have decided not to remove mercury lamps, because of the mercury problem with breakage, and are sending the entire LCD screen to licensed mercury treatment facilities, which have special expertise.

5.5.2 Further Disassembly - Manual and Mechanized Processes

39. After problematic components have been removed, computing equipment should be further disassembled, sorted into various material streams, e.g., steel, aluminium, circuit boards, plastics and these streams should then be sent to specialized material recovery processes. These steps are shown in Figures 2-6.

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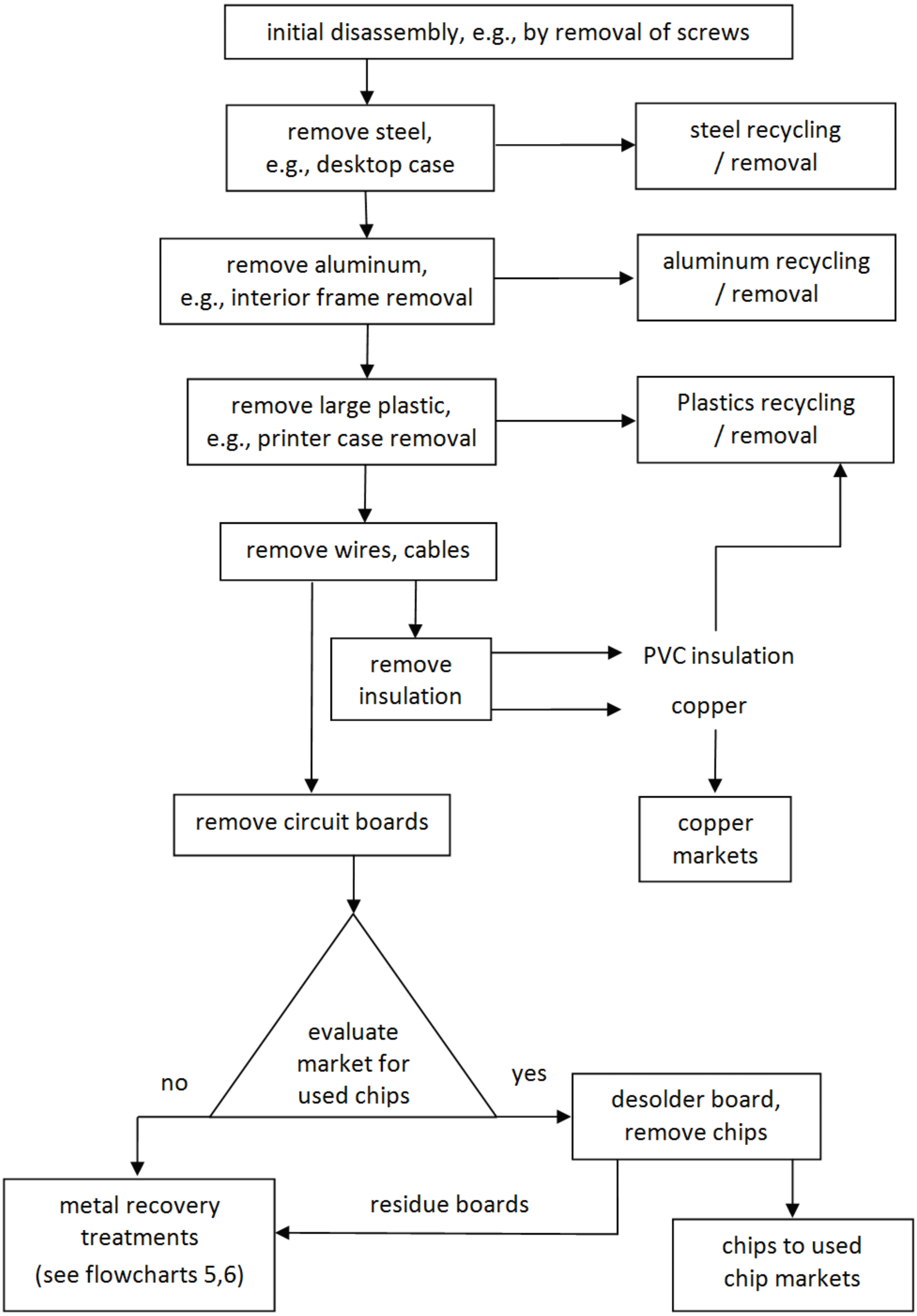
[8] Note, however, that some facilities send entire LCD screens to mercury treatment and recovery facilities, to avoid problems with mercury lamp breakage.

Fig. 2: Manual Disassembly and Separation of Materials



40. Disassembly and material separation can be done by continued use of manual labour, or by mechanized processes, or by both - a combined use of manual and mechanical steps. The decision of which methods to use is based primarily upon economics, taking into account the initial cost of machinery, the cost of manual labour, the availability of downstream processors with proper, environmentally sound recovery techniques, and the available market value of components and materials produced. Avoidance of high hazardous waste disposal costs can also be an economic incentive. In developing countries and countries with economies in transition, if costs of manual labour are low, the manual disassembly path is often taken. In industrialized countries, too, manual disassembly is often used, because it can produce more reusable computing equipment and very clean separated materials for efficient further material recovery.

41. Disassembly by manual labour does not require significant technological skills, although worker training to safely carry out specific manual tasks is always important. It provides employment for workers, and can produce clean sorted materials that can be sold. It can also facilitate careful removal of working components, as described in Figure 2, for additional value.

42. Chip recovery is sometimes a part of manual disassembly operations, because electronic chips may have higher value than raw materials, but it presents risks to worker health and to the environment that should be controlled through environmentally sound management. In order to remove chips, it is necessary to heat the solder that holds a chip to the circuit board so that the solder softens. This requires careful attention to temperature. If not enough heat is applied, the solder will not soften and the chip will not come off of the board. If too much heat is applied, the chip will be damaged. Very often the correct temperature is set by melting a larger container of solder, then placing the underside of a circuit board in contact with that molten solder. This process is successful in removing chips, but it presents risks to workers and communities. The container of molten solder, and the softened solder on the circuit board, will give off some lead fumes, and the worker may breathe them. The substances in the circuit boards, such as tetrabromo bisphenyl A, may be released as well. The source of heat may be a small charcoal or coal fire, giving off its own hazardous particulate. A worker who must remove very small chips from the circuit board is likely to be very close to the heat source, the heated circuit board, and the molten solder, all of which are concerns. The best protection for the worker is to have the chip removal done under a controlled ventilation hood, or have all of these hazardous emissions drawn away by a fan, and pulled into a collection system, such as a bag house.

43. Wire and cable recovery is also sometimes a significant part of manual disassembly operations. Wire and cable that is not damaged can be reused directly. The high-grade copper can also be recovered by manual removal of insulation with simple tools,

or by chopping wire into small pieces, followed by floatation of the small pieces of insulation, while the copper sinks. Clean insulation removed in this way might be useful as recovered plastic, and it can also be safely landfilled if necessary. On the other hand, open burning of insulation, which is widely practiced in informal operations, is dangerous and should be stopped, because the insulation is likely to be polyvinylchloride (PVC), perhaps with lead content as well, and burning will create hydrocarbon emissions and polychlorinated dioxins and furans[9].

44. Facilities that use manual disassembly should consider and ameliorate the many risks that are involved it those activities with computing equipment, such as exposures to hazardous fume and dust, strains from lifting of heavy objects and repetitive motion, cuts and abrasions from handling sharp materials and pieces, dangers to eyes from small objects, electrical shocks from batteries, etc.

45. Hand tools powered by electricity or pneumatic air can make manual disassembly much more efficient, while helping workers to avoid strains and repetitive motion injuries.

5.5.3 Mechanized Dismantling

46. Mechanized disassembly and separation of computing equipment can operate at high speeds and volumes. It consists generally of shredding of computing equipment into small pieces, followed by a variety of modern technologies that identify specific materials in those pieces, and then still more technologies that separate those identified materials into streams that can be sold as concentrated feedstocks for final recovery treatment. As described above, some initial manual removal is necessary for batteries, mercury lamps and ink cartridges, because these may release hazardous substances and may also cause damage to mechanized equipment. The industry is complex, and increasingly sophisticated, and it is beyond the scope of this guidance to describe all mechanized processes in great detail. However some typical steps involved in mechanized disassembly and processing of computing equipment are shown in Figure 3, and are further described in following paragraphs.

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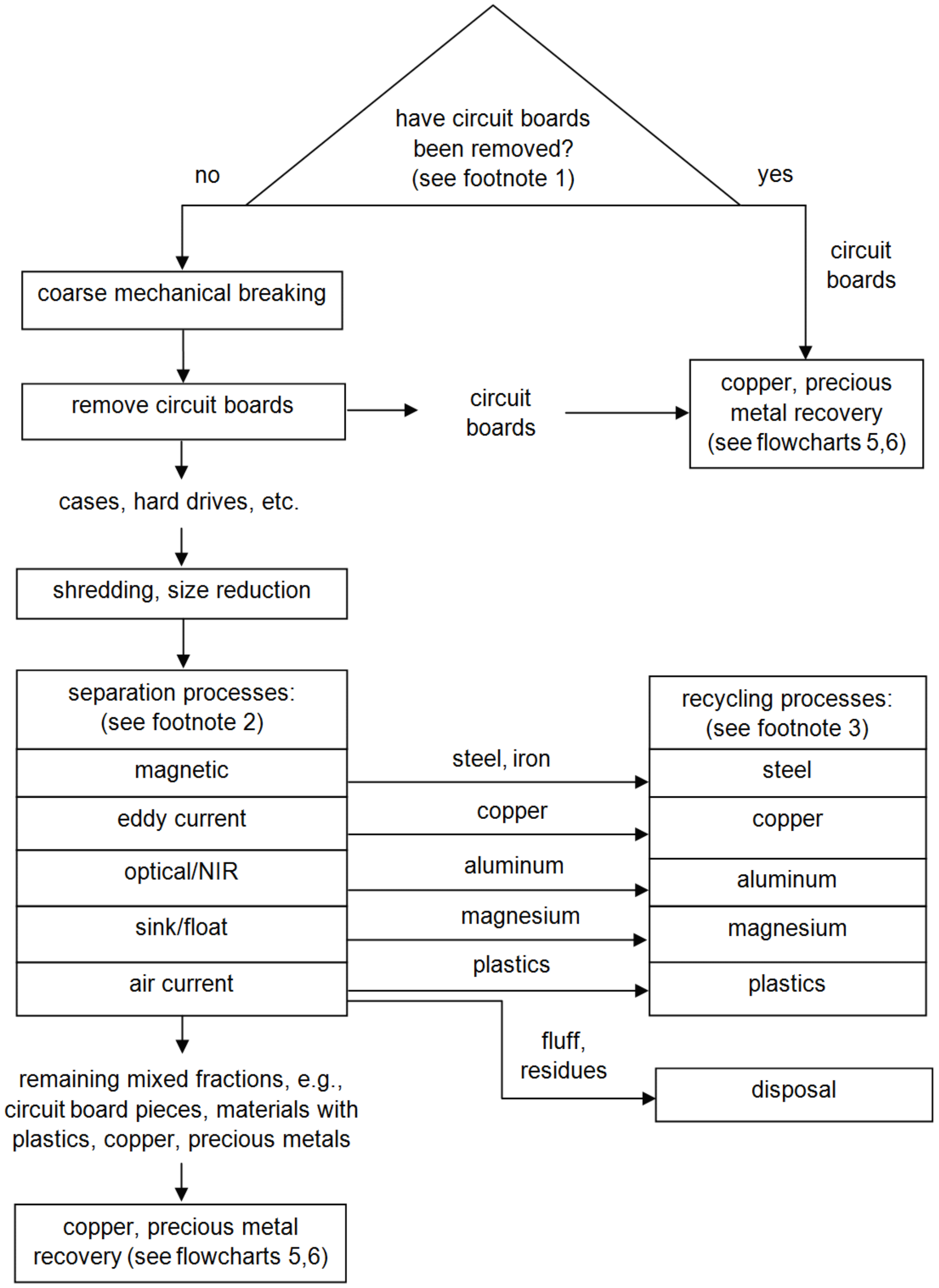
[9] Stockholm Convention on Persistent Organic Pollutants (POPs) - Guidelines on best available techniques and provisional guidance on best environmental practices - VI.L Smouldering of Copper Cables, http://chm.pops.int/Programmes/BAT/BEP/Guidelines/tabid/187/language/en-US/Default.aspx

Fig. 3: Mechanical Disassembly and Technological Separation of Materials



fn 1 – initial removal of circuit boards may be required by national law. If not required, may be removed for economic reasons, to avoid loss of precious metals into other fractions, e.g., steel.

fn 2 – this is not an exclusive list, and the types and order of separation processes will vary.

fn 3 – recycling processes vary, and should be reviewed independently for efficiency and ESM.

47. The first mechanical operation may be a coarse shredding or breaking open of a personal computer or peripheral, leaving large pieces from which circuit boards can be manually removed. Because circuit boards are more likely to contain substantial amounts of copper and precious metals, with higher economic value than steel or plastics, this initial separation will be an effective way of obtaining higher overall value from a personal computer.

48. Subsequent shredding steps then reduce computing equipment to much smaller size, in the 2-3 centimetre range. These smaller pieces are then identified by type through a sophisticated set of technologies, and are separated, one from another, into feedstocks for final recovery.

5.6 Mechanized Separation of Specific Material Streams

49. Increasingly, materials are identified by scanning them for their optical characteristics while they are moving on conveyor belts in high speed streams, and immediately separated. For example, digital cameras that are directed toward a stream of shredded pieces can recognize a predominant colour of a piece, e.g., a green circuit board, locate it in the moving stream, and can direct air jets to blow it into a separate stream. Similarly red metal, such as copper and white metal, such as aluminium, can be identified by colour and separated by directed jets of air from a moving conveyor belt.

50. Identification techniques other than colour are also used. X-ray Transmission (XRT) technology transmits X-ray energy, which is absorbed differently by different metals, e.g., copper and aluminium, based upon atomic density, and sensors can then identify particular metals and direct separation technology. Near infra-red (NIR) technology uses near infra-red light to distinguish among types of plastic, such as HDPE (high-density polyethylene) and PVC (polyvinyl chloride).

51. Magnetic separation uses magnets to divert magnetically susceptible pieces, such as carbon steel, from non-ferrous metals and plastics.

52. Eddy current separation creates an electromagnetic field around a conveyor belt of shredded pieces, which then induces an electrical resistance in moving pieces of certain metals that are electrically conductive, such as aluminium and copper. The force of that electromagnetic resistance will be stronger for more conductive metals, and that force can be used to separate them from other materials.

53. Flotation separation uses technology in which a lighter material, such as plastic, can be separated from a heavier material, such as a metal, by putting the two materials into a liquid in which the plastic will float and the metal will sink.

6. SAFELY STORING AND TRANSPORTING MATERIALS FOR FURTHER PROCESSING

6.1 On-site Storage

54. Material streams that have been created in disassembly, such as shredded copper or circuit boards, may contain small particles and dust that could be released a dispersed in wind and rain. They should be stored in appropriate containers that will not leak, such as closed metal drums or "supersacks" in protected conditions, such as inside covered, closed buildings with sealed floors, e.g., concrete, to prevent these releases and losses. It is particularly important to label all containers according to their contents, so that they are not later mismanaged or processed incorrectly, and to have labels clearly visible. Areas where materials are stored should also be labelled. A facility map should be produced that shows these storage areas and their contents, so that workers, and especially emergency responders, will know what materials and possible hazards and risks they are confronting.

6.2 Packaging and Transportation

55. When material streams that have been created in disassembly are transported to other material recovery facilities for further processing, they should be securely packaged to prevent releases and losses during transport. CRTs, for example, should be secured to pallets with shrink wrap or similar wrapping. Broken CRT glass should be packed into containers that will not leak, such as drums or supersacks. As with storage, it is particularly important to label containers according to their contents, so that they are not later mismanaged or processed incorrectly. Labels and packaging are often very specific legal requirements, under national and international law, and these requirements must be known and carefully followed[10]. There may be specific prohibitions related to computing equipment, such as restrictions on transportation of lithium batteries.

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[10] Globally Harmonized System of Classification and Labelling of Chemicals (GHS) -Third revised edition - http://www.unece.org/trans/danger/publi/ghs/ghs_rev03/03files_e.html

7. MATERIAL RECOVERY FROM SEPARATED MATERIAL STREAMS

7.1 Metals Management and Recovery

56. Computing equipment contains as many as sixty substances, many of which are metals. Some of these metals are used in computing equipment in relatively large amounts, e.g., steel in millions of desktop computer cases, while some metals are used only in very small amounts, e.g., indium in the inside coating of LCD display screens. There are ways in laboratory science to recover every type of metal contained in computing equipment, but actual recovery of useful amounts is more difficult, especially from complex substances, and recovery of all metals is simply not possible. Recovery of some metals will cause inevitable losses of others. Furthermore, of course, recovery of any metal, especially with environmentally sound management, costs money. There may be many steps required for final recovery, and it is necessary for a metal recovery facility to pay for equipment, pollution control systems, labour, supplies and operating expenses, etc. If the amount of a specific metal in computing equipment is small, and/or the market price of that metal is low, that metal is usually not recovered. For example, although indium has a fairly high current market price, the amount in an LCD display screen is very small, and the cost of recovery is high, and so indium has traditionally not been recovered from end-of-life computing equipment.[11] Lithium does not currently have a market price high enough to pay for the costs of recovery, and so the lithium contained in batteries, although available in relatively high amounts, has traditionally not been recovered. On the other hand, although the amount of gold in a circuit board is quite small, the current market price of gold is much higher, and it has traditionally been recovered. In some cases, alloys can be recycled directly back into the same alloys, which improves the economic return and can be important with critical metals.

57. The decision of which metals to recover is thus traditionally commercial – if a specific metal can be fully recovered by a facility and sold for a profit, it will be recovered. Final metal recovery from computing equipment has been done only by private industry for more than fifty years, always on this commercial profit basis. Participants in the business of metal recovery from computing equipment should be aware of the metals in their equipment and the sound environmental management of those metals, and should also be aware of their commercial options, and should consider metal recovery processes and business partners that, while using environmentally sound management, will efficiently recover those metals.

58. The actual final recovery of metals is accomplished through a series of steps which concentrate and separate them from other metals and from other materials until they are sufficiently pure to be put onto a market to be sold. In some cases, alloys are recycled back

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[11] Indium has been recovered from LCD display manufacturing facilities, where it is more concentrated.

into the same alloys, which can be important with critical metals. These steps are sometimes categorized as pyrometallurgical and hydrometallurgical processes, but they all have the purpose of concentrating and separating one or more desired metals from other materials, and they are frequently used, one after the other, by the same metal recovery facility to finally achieve a marketable metal product. However these processes are quite often in metal-specific businesses and facilities, e.g., a steel company will only produce steel and its alloys, an aluminum company will only produce aluminum and its alloys, and they will not produce copper or gold. Some facilities will produce multiple metals, such as an integrated non-ferrous metal smelter, but there is no company or facility that recovers and produces all metals.

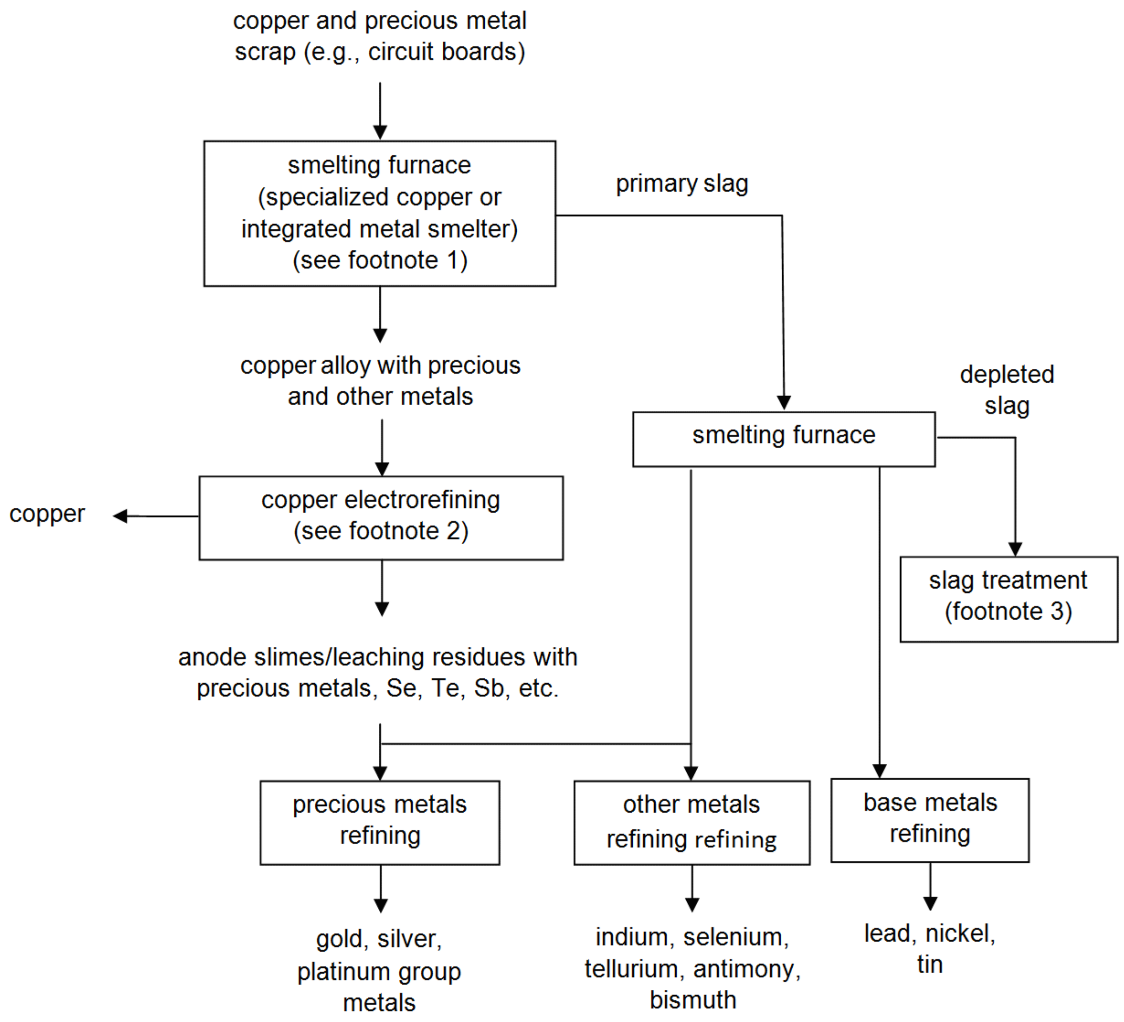
7.1.1 Pyrometallurgical Processing

59. For many years, high volume metal recovery from computing equipment has used large scale pyrometallurgical processes for steel, for aluminum and for copper and non-ferrous metals. Pyrometallurgical processing involves the use of heat to the melting temperatures of the material mix to separate and extract the desired metals at a higher concentration. Metal scrap of many types is commonly processed in a smelting furnace. Smelting is a process in which metals and/or metal-bearing materials are melted at high temperature, and then, while molten, other materials are added to achieve separation through oxidation and/or reduction, or to change the metal alloy composition. As described in more detail below, strong environmental, health and safety concerns are raised by these operations, and these environmental concerns should be minimized and controlled through engineered systems, such as scrubbers and bag houses, and through good material management practices. Due diligence should be performed by suppliers of computing equipment to these operations to ensure environmentally sound management. Examination of a facility’s track record of environmentally sound management and tracking of all incoming and outgoing materials and wastes can inform such due diligence.

60. Scrap steel, such as steel in computer cases, can be used in electric arc steel furnaces to produce new steel. The steel used in computers is not significantly different from steel used in other devices and products, and there are no special problems with this scrap material. While this guidance cannot go into detail regarding the production of steel in such furnaces, a facility that produces steel scrap from computing equipment should know that steel furnaces create their own environmental concerns, including dust and gas emissions, and production of slag. These environmental concerns can be minimized and controlled through

engineered systems, such as scrubbers and bag houses, and through good material management practices[12].

Fig. 4: Metal Recovery - Pyrometallurgical Recovery of Copper and Precious Metals



fn 1 – smelters differ in process flow and metals produced. For treatment of materials with plastic content, e.g., circuit boards, special emission pollution control treatment is required for all smelters.

fn 2 – either (1) copper anode directly electrorefined to cathode, and electrorefining residues (slimes) are further treated, or (2) copper alloy is leached, leachate is then electrorefined to cathodes, and leaching residues are further treated. Residues without value are disposed.

fn 3 – slag is stabilized and made suitable for construction products. Residues without value are disposed in controlled disposal operations.

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[12] For additional information regarding steel recycling, see World Steel Association: http://www.worldsteel.org/ .

61. Scrap aluminum will be used in secondary aluminum furnaces to produce new aluminum. As with steel, the aluminum used in computing equipment is not significantly different from aluminum used in other devices and products, and there are no special problems with this scrap material. These aluminum furnaces melt scrap aluminum and remove impurities with fluxes, often chlorine-based, and as with steel furnaces, will create slags and air emissions in the process. Air emissions can be minimized and controlled through selection of flux materials and through emissions control equipment, such as scrubbers and bag houses[13].

62. Scrap copper, scrap precious metals, and some other non-ferrous metals are commonly recovered from computer circuit boards and other components/fractions in integrated smelting-refining processes[14] or in a copper smelting process, followed by metal-specific refining at other locations or companies. This has been the established high volume method of non-ferrous and precious metal recovery from computing equipment. The typical steps are shown in Figure 5. The smelting-refining process is particularly useful and efficient for very complex articles such as circuit boards, which contain many metals in relatively low concentrations and in small pieces that are tightly bonded to a plastic substrate and that cannot be efficiently separated through mechanized shredding and technological separation processes. In the smelting process, circuit boards and all of their components and substances are melted in a furnace, and the precious metals and other non-ferrous metals dissolve into the molten copper. Carbon is added to the molten copper to chemically reduce desired metal oxides to their elemental state, so that they will sink. This carbon may be in the form of coke, or the plastic in the circuit boards themselves, or plastics that are otherwise not efficiently recovered, can also serve as the source of such carbon.

63. The primary product of smelting is a relatively pure copper, not quite market grade, and still containing the dissolved precious and other non-ferrous metals in a complex alloy. This complex copper alloy is poured from the smelting furnace into slabs or granules that can be leached and/or electrolytically treated to recover pure copper. At the end of this copper production, the precious and some other non-ferrous metals remain behind, and will then be processed in a number of additional metal-specific steps, usually a series of distinct hydrometallurgical steps (see description below), by which individual precious metals refined to their market grades.

64. Additional metals can also be extracted along the way, each metal with its own chemistry and separation processes, either from reprocessing primary copper smelting slag, or from processing copper cell residues, or from flue dust captured in the offgas system. As

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[13] For additional information regarding aluminum recycling, see World Aluminum Association: http://www.world-aluminum.org/.

[14] An integrated smelter refinery combines many recovery steps in one location/flowsheet. This comprises usually all the steps from a copper smelting furnace via other metal recovery steps (e.g. lead, tin, special metals) down to a precious metals refining.

said above, whether this additional metal recovery takes place depends upon market demand and price, process technology available, and the cost of additional process steps. Successful copper/integrated smelters operate a number of refining processes in close proximity to the smelting operation, to minimize transaction and process costs, and maximize profitable recoveries.

65. The copper smelting process, and subsequent refining processes for copper and precious and other non-ferrous metals, can also present significant environmental concerns, if not equipped with appropriate technology and well-managed in an environmentally sound way. Copper smelting is a high volume, high temperature operation that creates metal fume and metal oxide particulate. These may be released, exposing workers and nearby communities, unless the emissions are well controlled. The most problematic emissions from smelting of scrap from computing equipment are lead, beryllium, and polychlorinated dioxins and furans. These releases can be well-controlled, but only through properly engineered processes and emission control systems, and these systems are expensive to construct and operate, and require attention and sound management. Copper smelters have a particular concern with the formation of polychlorinated dioxins and furans, because their formation may be catalyzed by copper particles in the furnace air emissions. To prevent formation, the initial oxidation should be at a temperature of 850 deg. C. (1600 deg. F.) or higher, with a residence time of 2 seconds, with excess oxygen, to ensure destruction of hydrocarbons. Smelter exhaust emissions should then be rapidly reduced to a temperature of 200 deg. C. (400 deg. F.) or less at the inlet to a bag house or electrostatic precipitator. Most copper smelters do not install these systems, because they are very expensive to construct and operate, and they are not needed for mining concentrates and relatively pure copper scrap. It is the complex electronic components and/or halogenated plastics in computer circuit boards that require the specialized emission control systems. There are, in fact, relatively few smelters located in the EU, North America and Japan that do construct and operate such systems, and these smelters in turn receive circuit boards and other components of computing equipment from many countries that do not have such copper smelting operations. For additional information regarding copper recycling, see the International Copper Study Group: http://www.icsg.org.

7.1.2 Hydrometallurgical Processing

66. Hydrometallurgical processes involve dissolving metals in strong acids, or in cyanide in the case of gold, and selectively precipitating the metals, one by one in specialized procedures in a pure form. For some metals such as copper, hydrometallurgical refining is used after smelting to initially achieve higher purity of copper, such as the electrolytic

refining of copper described above. Then, after the copper has been removed, the residues undergo a series of additional hydrometallurgical steps to extract additional metals.

67. While copper smelting, a pyrometallurgical process, is the established high volume method of non-ferrous metal recovery from computing equipment, some facilities are investing in hydrometallurgical metal recovery operations. In some cases, hydrometallurgical processes may be applied directly to some parts of computing equipment, without prior smelting, especially if the metal scrap is already higher grade or relatively pure. For example, gold-plated copper connectors are sometimes stripped of their gold before further processing to recover the copper. Similarly some of the gold on a circuit board may be visible and can be removed by immersion into cyanide or aqua regia, a combination of concentrated nitric acid and concentrated hydrochloric acid. However not all gold in computing equipment can be removed by direct hydrometallurgical processing without additional steps. Recovery of additional gold that is contained within circuit board components and interior layers, as well as other metals such as silver and palladium, requires first grinding of the board and its components into very small particles prior to such cyanide or acid leaching. After dissolution of the target metals, the leachate solution is then filtered to remove unwanted material, and the target metals are electrolytically removed or selectively precipitated by addition of a metal, such as zinc, or a reducing agent, such as SO2, hydrazine hydrate or ferrous sulfate.

68. Direct hydrometallurgical operations used for material recovery from computing equipment are smaller and less expensive to establish than large pyrometallurgical operations, because much less equipment is used, and fewer operations are performed. Processing of selected computing equipment is relatively quick, compared to smelting-refining, and it can produce a relatively pure form of gold, but the efficiency and range of further metals that can be recovered is limited. Residues of direct hydrometallurgical processing of computer equipment may be sent to integrated smelter-refiners for additional processing to complete recovery and to recover additional metals. Participants involved in metal recovery from computing equipment should evaluate environmentally sound pyrometallurgical and hydrometallurgical operations for all aspects of processing and recovery and determine what best meets their needs.

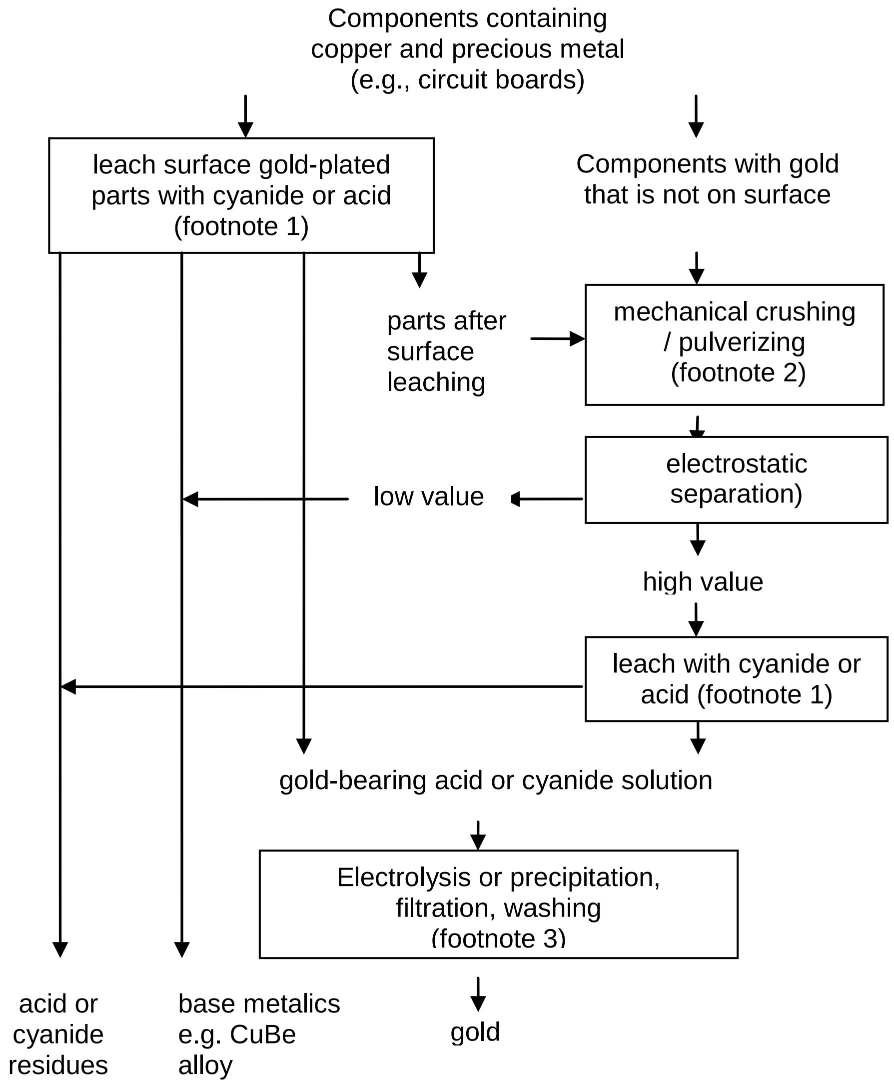
69. Typical steps in direct hydrometallurgical recovery of gold are shown in Figure 6. Industrial hydrometallurgical operations that are permitted, licensed or otherwise authorized are required to take special measures to contain and handle the solid and liquid chemicals, fumes and vapors, and process residues in order to be environmentally soundly managed. As with pyrometallurgical operations, strong environmental, health and safety concerns are raised by these operations, and due diligence should be performed by suppliers of computing equipment to these operations to ensure environmentally sound management. Examination of

a facility’s track record of environmentally sound management and tracking of all incoming and outgoing materials and wastes can inform such due diligence.

7.1.3 Informal Sector Acid Leaching

70. Informal material recovery operations are not licensed or permitted, and may operate without any government knowledge or oversight. Some of these recovery operations use cyanide or acid leaching processes on selected parts of computing equipment, such as visible gold-plated parts of circuit boards, to recover that visible gold. As some of the gold typically contained in a circuit board is not visible, however, but is contained inside of ceramics and plastic parts or resins in the circuit board, informal acid leaching is an inefficient method with gold recoveries being as low as 20-25%. Silver and palladium, often present in circuit boards, are generally not recovered. Unfortunately, both the residue boards and spent process chemicals are discarded by informal operators after visible gold has been removed. There are serious worker health concerns, especially when this process is performed in informal operations. Cyanide is poisonous, especially in the form of hydrogen cyanide, and aqua regia is very corrosive and requires very careful handling. Aqua regia also gives off chlorine gas emissions, and its reactions with metals give off nitrogen oxides. These gasses are acrid, choking and hazardous. After its use, the remaining aqua regia requires careful neutralization before disposal, a step not taken in informal operations. These informal operations should therefore be avoided, because they lead to high losses of valuable resources while presenting high risks of injury to workers, and environmental problems with discard of residues and of untreated spent cyanides and acids.

Fig. 5: Metal Recovery - Hydrometallurgical Recovery of Gold



fn 1 – gold plated parts can be leached or stripped of gold by cyanide or by a combination of very strong hydrochloric and nitric acids.

fn 2 – gold that is inside plastic or ceramic components will not dissolve in ordinary leach steps. Circuit boards must be ground to fine powder to expose precious metals, which can then be leached and precipitated.

fn 3 – after gold has been dissolved in cyanide or hydrochloric and nitric acids in combination, it can then be removed from solution by electrolysis or precipitated by addition of other substances, e.g., aluminum, or other base metals can be dissolved in nitric acid alone, leaving gold as a precipitate.

7.1.4 Cathode Ray Tube (CRT) and Non-leaded Glass Management and Recovery

71. Some CRTs removed from computing equipment can still be used as CRTs in rebuilt computer monitors, or can be used as the CRT components of television displays. If a CRT monitor cannot be reused as a monitor or other display screen, it may still be recycled for its copper and glass[15]. There is still some manufacturing of new CRTs, where the recovered glass can be used, although it is limited and diminishing and the market will be replaced in the future by other screen technologies, i.e., LCD. Figure 6 shows typical steps in CRT processing and material recovery. The CRT itself is a large vacuum tube, with a clear barium glass front panel coated with phosphors, and a rear funnel portion made of leaded glass. The vacuum must be carefully released through an opening designed for this, allowing air to slowly enter the tube, or else an implosion may occur when the tube is broken, throwing out sharp glass shards that can injure workers. After release of the vacuum, the copper yoke at the small end of the CRT, and the wires and circuit board, can then be removed for recovery of copper.

72. The remaining glass is made of two parts - the front panel made of clear barium glass, and the funnel-shaped rear portion made of leaded-glass, joined by a leaded-glass glue called frit. The two parts must be separated if they are to be recycled as glass, because they contain different substances, and the recycling processes and temperatures are different. The separation can be done by electrically-heated wire, or by mechanical saw, but in either case there will be a release of fine particles or vapour that will be hazardous to breathe, and workers need to have respiratory protection.

73. The inside of the front panel contains a thin coating of several phosphors - substances that emit light when energized by a CRT's electron beam. These phosphors will be exposed when the front panel is separated from the back funnel glass, or when the CRT is broken, and although they are slightly sticky and will not ordinarily fall off the front panel; they can be easily rubbed off. A number of types of phosphors have been used, including zinc sulfide, but cadmium sulphide was used in the past and protection of workers should be based upon the possibility of possible hazardous exposures to cadmium dust. Some more recent CRT phosphors use rare earths, e.g. europium and yttrium, and in the future it may be economically beneficial or desired to recover these materials rather than dispose of the phosphors. Phosphors are classified as hazardous wastes in some countries (see below).

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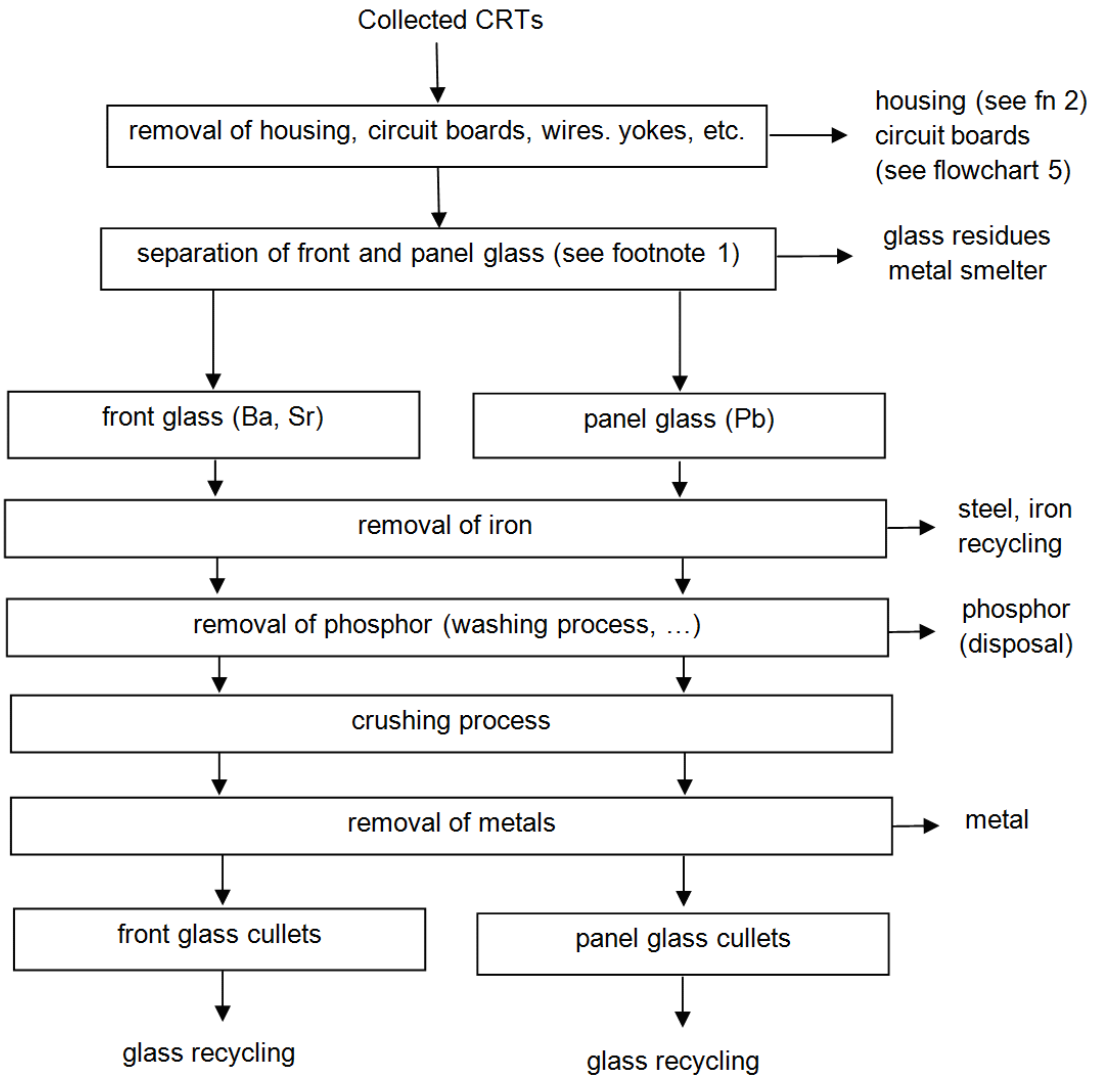
[15] The entire CRT devices contain as well the circuit boards, power supplies and other metals that need to be removed mechanically and/or manually and which are further treated.

Fig. 6: CRT Treatment



fn1: a thermal treatment is used to separate the two different glasses; front panel without lead and rear funnel will be recycled in different processes

fn2: depending on the content of hazardoeus flame retardents the plastic can be recycled or may have to be disoposed of

74. Many CRTs are large and heavy, and workers should be protected from heavy lifting strains. Engineering controls should be used to control and reduce exposures to hazardous substances, such as silica, lead particles and phosphors. Dust masks, safety glasses, protective clothing and work gloves should be provided to workers and used to minimize exposure to contaminants, and should not be taken back to the workers' homes. Good workplace cleanliness, including careful hand washing and prohibition of eating and

smoking in work areas, will also help to protect workers, and they should be trained to recognize hazards and risks. If CRT breakage occurs outside of the intended areas of separation, facilities should have written procedures and training for such events, and should promptly clean up broken glass, shards and dust and properly dispose of them. Clean-up workers should use protective personal equipment to reduce their exposures, and facilities should have clean-up plans and kits of supplies and equipment for such incidents.

75. The separated and recovered leaded glass has long been a problem in personal computer recycling, especially in informal enterprises. Although CRTs are still being manufactured, and clean leaded glass can be used in this manufacture, the market will continue to decline, and there is often insufficient value in CRT glass to economically support its shipment to facilities where it can be used to make new CRT glass or other leaded-glass applications, and so it is often discarded to places where lead may leach into soil and groundwater. Leaded glass should instead be used as a source of new lead in lead smelting, or serve as a flux in copper smelting. Leaded glass from which phosphors have been removed can be safely land disposed in an engineered and controlled landfill, if necessary, and if such a facility is available and permitted to accept leaded glass. The phosphors themselves are classified as hazardous waste in some countries[16] and should be disposed in properly authorized facilities.

7.1.5 Plastics Management and Recovery

76. As with metals contained in computing equipment, recovery of plastics from computing equipment involves an economic question - will the value of the recovered plastics exceed the costs of recovery, and provide a profit. Some types of plastics used in computing equipment are high value engineered thermoplastics, types which can be repeatedly softened by heat and hardened by cooling, and so are valuable to recycle. If these engineered thermoplastics can be recovered in a consistent, steady stream of raw material, they can be sold for a profit. However it is necessary to also separate plastics that contain flame retardants, such as the plastics commonly used in CRT cases, and especially brominated flame retardants (BFRs) such as tetra-, penta-, octa- and deca-brominated biphenyl ethers from plastics that do not. Many buyers will not accept plastics with BFRs, and those buyers who can accept them must use processes that will not release the BFRs or create substances such as brominated dioxins and furans. There may still be some markets for plastics that contain BFRs, where they will be used in the same way, as flame retardants, but it should be noted that some BFRs are prohibited in some countries, e.g., pentabrominated diphenyl ether and octabrominated diphenyl ether, and in those countries should not be re-

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[16] EU Waste List, code 190211*

used in the production of new plastics, but must be disposed in an environmentally sound manner.[17] The plastic recovery processing described below may create exposures to BFRs, and perhaps dioxins in low temperature processing, and precaution is necessary.

77. Manual disassembly of computing equipment can produce reasonably well-separated streams of plastics in the cases of laptop/notebook computers and peripheral equipment. Mechanized disassembly can also produce high volumes of plastics separate from other components, and are commonly used to recover large volumes. After removal, the plastic pieces may need to be further cleaned, particularly of contaminating substances like paints, labels, and imbedded metal pieces.

78. To maximize resale value, plastics must then be sorted by polymer type (e.g., HIP, ABS thermoplastic), and by color (e.g., white, black). Identification of polymer type can be difficult, especially for older computing equipment. A United States coding system may be useful for some plastic, using a ‘Recycle Triangle’ with a numbers and letters, but many plastic parts in computing equipment are not identified. In addition, some plastics are made up of more than one type, or may have a fiber added for strength. In mechanized recovery operations, there are increasingly sophisticated scientific techniques for polymer recognition and separation.

79. After plastic has been cleaned and sorted into a specific type, it will need to be reduced in size to make it manageable for storage, transportation, or further processing. This can be done by hand tools such as scissors, shears, etc., or by baling, shredding and size grading. Some mechanized operations combine heating, rapid cooling and cutting into grain. These smaller pieces are then typically heated and forced (extruded) through a die to form strings and pellets for final sale as plastic raw materials.

80. While initial collection and handling of unbroken plastic parts and cases should not involve any exposure to hazardous substances, subsequent processing that involves breakage of recovered plastics may cause concerns. Plastic particles, additives and brominated fire retardants may be released, causing exposures to workers. A common practice in informal operations of melting BFR plastics at low temperatures is highly likely to create halogenated dioxins and furans. Size reduction and granulation can also generate heat and, if not properly managed, open smoke and fire. After granulation, the plastic will be molded into a desired shape under elevated pressure and temperature, and there may again be exposure to substances contained in the plastic and new substances such as halogenated dioxins and furans. Even when BFRs are not present, workers should be protected with ventilation and personal protective equipment from inhalation of hydrocarbons and additive stabilizers.

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[17] EU Directive 2003/11/EC

81. If plastic types cannot be separated by type, a mix of different types of plastics may have little if any economic value, although some mixed plastics may be used for materials such as lumber or pallets. If no use or market as plastic can be found, smelters with appropriate emissions control systems may use a limited volume of plastics in the metal recovery process, where they serve as a source of heat and substitute for other hydrocarbon fuels and as a reducing agent. Alternatively, incinerators with energy recovery systems, as well as appropriate emissions control systems, may recover energy content from plastics.

7.2 Battery Management and Recovery

82. Batteries used in computing equipment are of two types, both now based on lithium chemistry. There is a very small lithium battery on the primary circuit board (the "motherboard"), about the size of a coin and sometimes called a "coin cell" or "button cell." There is a much larger rechargeable lithium-ion battery in a laptop/notebook/netbook computer that provides operating electrical power. Older computers used rechargeable nickel metal hydride (NiMH) batteries (and occasionally also NiCd), and so these will also be found in end-of-life computers. This larger battery must be removed and not shredded, unless the shredding equipment has the necessary pollution control equipment to manage such operations, and is licensed and permitted to do so. If it remains in equipment when it is shredded, it will break open and will leak caustic electrolyte, causing risk to workers, risk of fire, damage to equipment, and contamination of other materials. Batteries may also still contain an electrical charge, and if their handling brings them into contact with a conducting metal, they will rapidly discharge (a "short circuit"), causing heat and possibly a fire.

83. Once removed, batteries may be evaluated for further use, for which quality standards should be set[18]. If batteries are not suitable for re-use, they should be sent for material recovery and recycling to specialized facilities. In order to prevent unintentional discharge of electricity remaining in unwanted batteries, which can generate heat, their individual contacts must be covered (e.g. with tape or wax), or individual batteries must be packaged separately so that battery contacts are not connected by some other conductor.

84. The primary metals of economic interest in these batteries are cobalt, nickel and copper. As demand for lithium increases, this may also become a valuable target for recovery.

85. At a battery recycling facility, fluid battery electrolyte should be removed before recovering metals. This can be done manually, or in a furnace by pyrolysis (decomposition using heat). There is no market for recycled electrolyte, which cannot be recovered as pure

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[18] Refer to PACE Project Group 1.1 for standards for further use of batteries

electrolyte, so it does not make sense to manually remove it. Plastic battery components can also be manually separated, but due to their contamination with metals they are not recycled as plastics. They can serve as a source of heat and carbon in subsequent processing, and so are more commonly not separated. The output of pyrolysis is a metallic alloy and a slag. The slag can be used as additive for concrete, stone wool or ceramics, and the metal alloy can be treated in a hydrometallurgical step to recover cobalt, nickel, copper and iron. Lithium will be concentrated in the slag, from where it could be recovered if lithium prices are attractive enough to make the process economically viable. Offgases from pyrolysis (and calcining, see below) require a thorough cleaning process, including dust collection, and the dust can be fed back into the furnace.

86. As an alternative to pyrolysis, batteries can also be calcined (decomposition with heat, intended to remove organic material such as plastic components), but this yields a lower recovery compared to full pyrolysis and subsequent hydrometallurgical step. It also puts a higher burden on the environment, because the plastic components, which could contribute energy to the pyrolysis operation, are not optimally utilised, resulting in higher energy consumption and CO_2 generation. After calcination, batteries can be either opened or shredded and further separated by magnetic and/or eddy current separators to produce an iron/steel fraction (recycled in the steel industry) and a mixed fraction of cobalt and nickel that can be recovered by selective leaching and precipitation. Such shredding and grinding generates additional dust and creates a risk of losses of Co and Ni (as metal oxide dusts) to the environment, if dust suppression and collection systems are not used.

87. In case a calcining process is used, an advance sorting of batteries by their type of chemistry, especially for NiMH and Li-ion is recommended to optimise material recovery and recycling efficiencies. State-of-the-art pyrolysis processes can well cope with mixed fractions of NiMH and Lithium-Ion cells, while still yielding high metal recovery rates.

7.3 Mercury Lamp Management and Recovery

88. Computer monitors that use flat screen liquid crystal display (LCD) technology contain one or more small lamps for illumination, usually located along the outside edge of the screen. While new technology sometimes uses light emitting diodes (LED) for these lamps, most LCD screens contain fluorescent mercury vapour lamps. These mercury lamps will often break during handling and mechanized processing, and will release their mercury vapour, and so they must be carefully removed, by manual labour, so they are not put in mechanized processing such as shredding, unless the shredding equipment has the necessary pollution control equipment to manage such operations, and is licensed and permitted to do so, such as at mercury treatment facilities. Even with careful removal, some breakage is very

likely to occur, and engineering controls or personal protective equipment to prevent inhalation of mercury vapour should be used at all times. See "Manually Dismantling a Computer: Guidebook" EMPA, Swiss E-Waste Program. Some facilities have decided not to remove mercury lamps, because of the mercury problem with breakage, and are sending the entire LCD screen directly to mercury treatment facilities.

89. Once removed, mercury lamps (as well as spill collection and cleaning residues) should be sent to mercury recovery facilities. These specialized facilities will heat the lamps, and mercury-bearing residues, in a closed furnace (a retort), driving the mercury vapour into a cooling chamber where it will be condensed and collected as pure mercury.

90. Because mercury lamps may still be broken during removal or other processing, a facility should regularly test its working areas and worker breathing areas for the presence of mercury vapours in excess of worker safety standards, and its floors and working surfaces for mercury, which otherwise may be transported into other areas. The amount of mercury in a single lamp is quite small, about 5mg, and some of this mercury will evaporate into mercury vapour in the working atmosphere. In addition, there may be multiple lamps broken over time. Exposures to these vapors can be dangerous to human health and the environment. A closed container or room where there are broken lamps may accumulate a high concentration of mercury vapour. A facility that handles mercury lamps should have written procedures and kits of equipment for cleanup of mercury spills, and trained workers to carry out those procedures. Some facilities may prefer to send the entire LCD screen or mercury-containing device directly to specialized mercury treatment facilities, rather than trying to remove very fragile mercury lamps.

91. After removal of mercury lamps, LCD screens are generally not hazardous, and can be safely disposed, such as by state-of-the-art incineration. The critical metal indium is used in small amounts to coat the inside of these screens, and research is being undertaken to see if efficient recovery, now or later, may be achieved.

7.4 Ink and Toner Management and Recovery

92. Print cartridges from end-of-life printers consist of an outer plastic case and typically contain residual amounts of ink or toner, plastic and metal parts, and integrated printheads or smart chips. Some contain circuit boards. These print cartridges are recyclable and in some cases may be reusable or refillable. Opinions differ as to how many times a cartridge can be re-used, with some people saying that the quality of printing will deteriorate after the original use, and others saying that a cartridge may be re-used up to six times. Some commercial cartridge remanufacturing companies will only accept OEM cartridges that have

never been recycled before. Because some inks and toners (and therefore cartridges) contain materials of concern, cartridge remanufacturing should only be undertaken by specialized companies that utilize ESM techniques and provide occupational and environmental protections. In all cases of intended reuse, a cartridge should be washed, examined for cracks or worn parts, and key parts that are defective affecting quality and performance should be replaced with new components. Only compatible ink should be used for a refill. After refilling they should be tested individually for print quality.

93. Laser printer toner cartridges are more intricate and mechanical, so refilling and reuse is more limited. Because toner cartridges are not designed to be refilled, a small hole will need to be created, usually by drilling or melting, for addition of new toner powder, after which the hole is covered by tape. As with refilling ink cartridges, this can be a very messy procedure, posing occupational risks, and cartridges should be sent to specialized facilities.

94. Toner cartridges should not be shredded unless recycling or shredding equipment has been specifically designed to handle environments where high dust concentrations in air might occur. Like many organic materials in powdered form, toner can form explosive dust-air mixtures when finely dispersed in air.

95. Inks are typically solvent based liquids, and toners are typically a dry powder. Some inks and toners may contain hazardous substances, such as isopropyl alcohol or ethylene glycol, which may be released in cartridge recycling processes. For cartridges with unknown content or for which there is doubt, recycling facilities should manage them as if the contents are hazardous. If cartridge plastic contain flame retardants see Section 8.7 dealing with plastics. In all cases, skin or eye contact, ingestion or inhalation of inks and toners should be limited or avoided. Spilled ink and toner powder should be swept up and managed as hazardous waste unless there is evidence that the materials are non-hazardous.

7.5 Selenium Drum Management and Recovery

96. Some older printers contain brightly colored, shiny cylindrical drums that are made of aluminium coated with selenium. Selenium is hazardous in higher doses, and an environmental contaminant in aquatic ecosystems. A material recovery facility should not deal with these drums or attempt to recover the selenium or aluminium unless it has the specialized knowledge and equipment to safely manage these substances. Instead, they should be kept intact, removed from printers or copiers, and sent only to facilities that are licensed and permitted to manage them.

7.6 Polychlorinated Biphenyls (PCBs) Management

97. Polychlorinated biphenyls (PCBs) have not been used in computing equipment covered by this guideline. They were banned from use in the United States in 1976, and the first personal computers for commercial sale were not created until several years later. It is possible that a material recovery facility might find a PCB capacitor in other types of old equipment, such as old mainframe computers, and so it should take appropriate precautions, particularly to avoid burning or shredding such capacitors, and instead arranging for proper disposal at a specialized and licensed PCB destruction facility.

8. RESIDUE MANAGEMENT AND DISPOSAL

98. Whenever materials are recycled properly, there will often be residues that need to be managed in an environmentally sound manner. In a well-operated network of material recovery operations, the largest volume residue will be slag from the smelting operation, and that may be further recycled or used as construction material. In addition, pollution and emissions control equipment will generate hazardous residues (ash, dust, and sweeps) that are removed from filters, vacuums, and other capture mechanisms. Most of the material constituents of a personal computer can be recycled. They are often, however, not recycled for economic reasons, and so careful final disposal management (ESM) is required.

8.1 Bag house dust and filter residues

99. Unless they contain significant concentrations of zinc or precious metal, bag house filters, filter residues and dusts will not have recoverable value. On the other hand, they are likely to contain concentrations of other metals and other substances that are highly dispersible and are likely to leach into soil and ground water. They should be presumed to be hazardous wastes, tested for hazardous characteristics, and managed appropriately, such as by disposal in a controlled landfill.

8.2 Sweepings

100. Fine particles and dusts that have fallen to the floors and other surfaces at a facility should be regularly cleaned, but should not be swept up by dry sweeping, because it will disperse these particulates into the air, and into the breathing zones of workers. Fine particles and dusts should be collected by wet mopping or vacuum, and then should be managed and disposed of similarly to bag house dusts and filter residues.

8.3 Slag

101. Slag - the residue of pyrometallurgical operations - is typically a hard, dark, glassy substance. Slag from the smelting of components/fractions from computing equipment will contain, among other substances, lead, cadmium and beryllium oxide, silica, alumina, iron oxide and other oxidized metals. It is often reprocessed to recover additional metals. It may, for example, be fed into another smelting process, such as a lead blast furnace if it contains lead. Lead acts as a chemical collector metal for remaining precious metals and other non-ferrous metals such as tin, bismuth, indium and antimony. The lead produced from that furnace is then refined to produce a market-grade lead and other metals, such as nickel. Slag may also be ground to a powder, from which a desired substance can be leached with acids or other solvents.

102. If slag does not contain metal concentrations of economic interest, it may be suitable for use as building or road construction aggregate, but it must have been made stable and insoluble by high temperature processing. Smelter slag that has not been stabilized may leach hazardous metals into the ground and ground water, and should not be used in such ways. As an alternative to use as a construction aggregate, however, smelter slag may be disposed in a controlled industrial landfill, with appropriate attention to the possibility of release of substances of concern.

103. Pyrometallurgical operations for electronic fractions (e.g., circuit boards) require air pollution control systems that will capture particulate matter and hazardous gases, such as a venturi, cyclone, electrostatic precipitator or fabric filter (bag house). The particulate matter collected from such devices can often be further processed for metal recovery.

104. Hydrometallurgical refining operations will result in residual waste effluents that may contain hazardous metal concentrations, as well as acids and cyanides. These solutions may be completely reused within a refining facility, but will in any case require attention and sound management, including precipitation and filtering of metals and neutralization of acids.

8.4 CRT Glass and Glass Fines

105. Glass from CRT monitors can be used in the manufacture of new CRTs, although that display technology has largely been replaced by LCD, plasma and LED technology. There continues to be manufacturing of new CRTs in several countries, however, and sorted CRT glass cullet may find recycling opportunities in these manufacturing facilities, at least for a short while. CRT glass fines are fine sand or powder that result from CRT glass

breaking or crushing. Workers in these operations should be protected from inhalation of these fine particulates through engineered ventilation or personal protective equipment. CRT glass fines that are collected by ventilation systems or cleaning floors and other surfaces are not likely to be sufficiently clean for the purpose of glass recycling. If CRT glass and glass fines cannot be recycled into new glass, leaded glass can be used by lead smelters as a feedstock for production of new lead. It can also be used for its silicate content as a flux in copper smelters, as a substitute for other silicates. The front panel, the part which is not leaded glass, may be used in other ways after its phosphors have been cleaned. None of these alternate uses is likely to be economically valuable, but diversion of CRT glass into these operations is encouraged.

8.5 Phosphors

106. CRT Phosphors are chemical compounds that are used to thinly coat the inside front panel of a CRT when it is manufactured. They absorb energy from the CRT's electron beam, and then release that energy as visible light through the front panel. They cannot be reused, even if the CRT front panel is recycled, and they must be cleaned off of the panel glass and, presently, finally disposed as hazardous waste, or tested for hazardous substances, if not recycled. Currently there are no known recyclers of CRT phosphors, though the change in economics for rare earth metals may change economics of recycling.

107. Phosphors are today primarily made of zinc sulfide, however small amounts of other substances are added to create colours, such as red, green or blue. These are often rare earth metals, such as europium or yttrium. Some forms of rare earth metal compounds such as those containing yttrium are known to be hazardous, while others are lacking in hazard characteristic data. However other chemicals have been used in the past, such as cadmium, so caution must be taken to protect workers and the environment from phosphors in a recycling context. If the full nature of a phosphor is not well understood, it should be treated as if it were hazardous, or tested for hazardous substances to show that it is not hazardous. This includes the use of engineering and protective personal equipment to ensure that phosphors do not enter the workspace environment, are not inhaled or allowed to adhere to the skin.

108. When a CRT is separated into its front panel and rear cone, the phosphor coating on the inside front panel can be seen. It is slightly sticky, because it has to stick to the glass, but it will come off if it is touched. It should be removed by HEPA-filter vacuum, and then further cleaned off with rags or wipes, and workers performing these operations should use personal protective equipment to prevent inhalation. The vacuumed phosphors as well as the rags and wipes should then be finally disposed as hazardous waste, or tested for hazardous substances to show that it is not hazardous.

8.6 Polychlorinated Biphenyls (PCBs)

109. As said above, polychlorinated biphenyls (PCBs) have not been used in computing equipment that is covered by this guideline, and will not be found in its material recovery. If a PCB capacitor is found in other types of old electrical equipment, it should be removed and set aside. If it is not leaking, it will not present an immediate hazard. It cannot be recycled, by international law. Burning of PCBs is very likely to create dioxins and furancs, and so the PCB capacitor should be sent for proper disposal such as very high temperature, controlled emission combustion at a specialized and licensed PCB destruction facility.

8.7 Plastics

110. Plastic used in computing equipment and peripherals, primarily in cases, is another material that can be beneficially used or recycled, but sometimes is not. Much of the plastic used in older computing equipment contains BFRs and therefore cannot be sold, because BFR plastics are much less used, or have very limited markets where flame retardants are still used. Single type engineered plastics that do not contain BFRs can be re-used as that type of plastic, through reprocessing operations. However plastics are often mixed with other types of plastics, or with other and incompatible materials, such as metal pieces, which reduce or eliminate the possibility of reprocessing and re-use.

111. Plastics are hydrocarbons, and if they cannot be re-used as plastics they can sometimes be used as a fuel similar to other hydrocarbons, or as a source of carbon for chemical reduction in smelting operations. Plastics used in computing equipment may contain halogens – chlorine or bromine – or lead metal as a stabilizer, and thus are problematical to burn. Some smelters are well prepared for these constituents of concern, with comprehensive air pollution control systems, but many are not. Incineration that does not control combustion and emissions, and even worse uncontrolled burning, as may occur in informal operations, will release substantial air pollution in the forms of soot, particles of incomplete combustion, complex hydrocarbons, polychlorinated dioxins and furans, and will leave hazardous residues. However an incineration facility that has both an energy recovery system and a well-controlled emission system may be able to make efficient and environmentally sound energy recovery from plastics from computing equipment.

112. Plastic can be safely land disposed if land disposal is itself a controlled form of management, but if landfills are open to scavengers, and particularly if they are burned for size reduction, landfills are not a proper final disposal. Plastic residues require management

beginning with design to facilitate separation into clean, recyclable streams to collection and diversion into appropriate reuse, recycling and, where necessary, final disposal.

8.8 Waste incineration concerns

113. As set forth above, waste incineration of computing equipment, especially the plastic in the cases and circuit boards, may be incomplete, and hydrocarbon particles and other soot may be emitted. Some metals, particularly lead, have relatively low melting temperatures and may melt during such incineration and release fume or minute metal oxide particles. Halogenated hydrocarbons, including polychlorinated dioxins and furans, may be produced. This would be particularly true if the waste incineration were essentially informal burning and completely uncontrolled. Metals that do not melt will remain in bottom ash that, if disposed on land, may raise concerns of exposure to hazardous substances described above. And leaching from ash in land disposal conditions may be substantially faster than leaching from unburned computing equipment. Therefore, while material recovery is preferable, if incineration is necessary, burnable components which cannot be recycled must be incinerated in state-of-the-art incineration plants to avoid as much as possible landfill disposal, and if possible to efficiently recover energy. If such environmentally sound incineration is not possible, the waste may be disposed in an engineered and controlled landfill disposal.

8.9 Landfill concerns

114. Also as set forth above, land disposal of end-of-life computing equipment may create a risk of direct human contact and ingestion of contaminants, and of contaminated soil and of water in landfills that are not controlled. Some landfills are often visited by scavengers, including small children, looking for valuable materials to salvage. Land disposal of computing equipment may also place them in contact with acids from other sources, such as rotting food and garbage. Over an extended period of time, these acids may leach out hazardous substances into ground waters, lakes, streams, or wells. Only in a well-engineered, properly controlled landfill, final disposal of computing equipment is an appropriate last resort.

9. LEGAL REQUIREMENTS

115. Each facility in the chain of material recovery must comply with all applicable domestic laws and regulations, as well as all applicable laws in importing, transit, and exporting countries if international trade is involved.

9.1 Domestic Legal Requirements

116. Material recovery and recycling facilities must meet all local, state/provincial, and national laws and regulations that pertain to their operations, and must be licensed and permitted by all appropriate governing authorities in their country.

117. For example, licensing and permits should be consistent with governmental, regional and local regulatory requirements. Specific permits required may include: storage permit, air emissions permit, water permit, hazardous waste permit, and those permits required to meet landfill and other disposal regulations. Processes should be in place to ensure continued compliance with the requirements of the permits. All laws pertaining to occupational health, safety and rights must be complied with, as well as those pertaining to releases of pollutants to the environment.

118. A facility should always be in compliance with applicable laws and regulations, but laws are sometimes difficult to find and understand, and will change from time to time. Therefore, a systematic approach will be the best way to regularly identify applicable laws and regulations, including amendments and new laws, and to determine how these requirements specifically apply to the facility and its operations. Publications, newsletters, government websites and industry associations may be valuable sources of information.

9.2 Legal Requirements for International Trade

119. Because material recovery operations may involve further operations by other downstream facilities, including transboundary movement of wastes and intermediate products, a material recovery facility should also take care to ensure both its own compliance and the compliance of downstream material recovery operations with applicable laws of concerned countries, including multinational and bilateral agreements. A facility should comply with all necessary waste transport regulations, including those related to packaging manifests, bills of lading and chain of custody documentation. The Basel Convention transboundary movement controls should be implemented for end-of-life computing equipment destined for material recovery and recycling where the end-of-life computing equipment contains Annex I constituents, unless it can be demonstrated that the end-of-life computing equipment is not hazardous using Annex III characteristics. For information on transboundary movement procedures see chapter 3 of the PACE Guidance Document, as well as other guidelines on transboundary movement under development.

10. COMMERCIAL CONSIDERATIONS AND ISSUES

120. One of the principal PACE objectives is to pay special attention to developing countries and countries with economies in transition, where informal economies and limited environmental infrastructures can create unique difficulties, exacerbated by unwanted receipt of computing equipment that cannot be refurbished and reused. As set forth above in Section 7.1.3, informal recovery of precious metals and other components and materials is particularly hazardous, as well as inefficient, and it is an objective of PACE to guide such informal recovery into much safer, more environmentally sound, and more efficient material recovery industries.

121. Material recovery from electronic equipment has been carried out for at least fifty years, and in developed countries it is a mature commercial activity, international in scope, with a great deal of transboundary movement to specialized recovery facilities. The primary consideration in this activity has historically been profit - the recovery of valuable metals, primarily gold, but also silver, platinum, palladium and copper, and sale of these metals to buyers. Electronic circuit boards usually have much higher concentrations of these metals than ores, so circuit boards have been collected in large quantities, and metal recovery has been a profitable business. Even as the full cost of environmentally sound management has been added to material recovery operations, in some cases requiring financial support under Extended Producer Responsibility schemes, the economic market value of recovered materials continues to be an important consideration.

122. In developing countries and countries with economies in transition, material recovery has also been carried out for profit, but not always in an environmentally unsound manner s. In order to understand and deal with such unsound material recovery practices, it is helpful to understand the economic and commercial practices and forces that influence these activities.

123. As in all businesses, there are complications that can change that profitability, sometimes causing losses. In every metals business, the market prices of metals are determined in a competitive global marketplace, and they often show great volatility over relatively short periods of time. Metals are commodities that can be purchased and sold in many places, and while transportation and some other factors are included, there is often a world standard price. In the case of gold, for example, a world standard price is determined twice each business day in London. While no one is legally required to follow that price, almost everyone in the world buys and sells gold at or near that London price. So if a producer of gold from circuit boards has high costs, that does not mean that it can charge a higher price, because no one will buy gold based upon a producer's costs. The same is true for all of the metals that are recovered from used computing equipment, e.g., copper, steel.

The producer must keep its costs competitively low, because it is selling its recovered metals into competitive markets that receive metals from mines as well as recyclers.

124. Furthermore, recovery of metals from circuit boards, just as from ores, does not happen quickly. Circuit boards must be processed to remove the metals, and then the metals must be refined to world market purity. Historically that has taken about six months from start to finish. Meanwhile, for example, the world gold price changes two times every day. So when a supply of circuit boards is first collected, the price of gold may be considerably different from the price when that gold is finally produced.

125. In large commercial metals businesses in developed countries, metals prices are hedged to protect against changes over time. While techniques to hedge are sometimes very complex, in a simple example, a large producer of gold can buy at a current price, and simultaneously sell at about the same price to someone who wants delivery only later, say in six months. Both buyer and seller lock in the current price; buyer thus avoids the risk of much higher prices, and seller avoids the risk of much lower market prices, that might occur six months later, when the gold is finally produced in pure form and is ready to be sold.

126. However small local collectors, especially in developing countries, cannot hedge in this way. They do not have access to hedging techniques and mechanisms. They do not have accurate knowledge of exactly how much gold is contained in their collections of computers, or how long it may take to accumulate a reasonable commercial quantity. They do not participate in stable metal industry networks, where metal price volatility is sometimes buffered by longstanding business relationships. So they want to extract some gold as quickly as possible, even if it is not the most efficient process, even if it is dangerous to worker health and environmentally unsound, rather than risk a lower price of gold later, when they are finally ready to sell.

127. This is a significant problem in metal recovery from end-of-life computing equipment in developing countries, for commercial as well as health and environmental reasons. Informal cyanide and/or acid leaching of gold leaves substantial residues that are not well managed, because circuit boards, after being stripped of visible gold, have much less value in the formal metal recovery industry, and are usually discarded (after the chemical agitation, becoming now even more dangerous with respect to further leaching out of hazardous substances into the environment). And without its precious metal content, a personal computer is much less valuable as well, and will also be discarded. The chain of environmentally sound material recovery may be stopped at the very beginning if a substantial amount of gold is removed at that point.

128. Because gold is removed for commercial reasons, it may be necessary for governments and industrial organizations to establish commercial practices and infrastructures that accommodate the need of informal metal recovery enterprises for prompt economic compensation, while they are being integrated into the larger and formal material recovery infrastructure.

129. Under the StEP initiative of the United Nations University, the “Best of two worlds” approach has been developed. The basic idea is to provide training and organisational structure to the informal sector in developing and transition countries in order to improve dismantling of computing equipment. The less complex (and environmentally critical) fractions derived out of this can then be further processed locally for final materials recovery. Complex critical fractions such as circuit boards or batteries, however, need to be directed to state-of-the art, large scale industrial plants, currently mainly located abroad in industrialized countries. The higher net value generated from such large industrialized processes can be the incentive to make the informal sector stop the dangerous backyard processing of circuit boards (e.g. instead of gold yields of only some 25% in backyard processing, more than 95% of the contained gold and additionally silver, palladium and copper is recovered and paid for in large industrialized processing). Prerequisite however is that the informal operators must directly profit from the obtained higher net value and thus focus on collection and dismantling, i.e. the added profit must not be absorbed in the downstream channels. The setup of an appropriate organisational structure for parts of the informal sector – also involving early payments – is one of the challenges that need to be further developed. Here PACE and the regional centers of the Basel Convention could play an important part as well. However, economic considerations should not outweigh environmental and human health considerations and externalize the real impacts of recycling used and end-of-life computing equipment and disposal of residues, and should be considered as part of a sustainable development policy.

11. RECOMMENDATIONS

11.1 Goals and Objectives

130. Material recovery, energy recovery and disposal facilities must be properly authorized and licensed, and comply with all applicable laws – local, national, regional, multilateral and international. This will include national implementation of the Basel Convention whenever transboundary movement is undertaken, as is often the case with end-of-life computing equipment and residuals. For information on transboundary movement procedures see chapter 3 of the PACE Guidance Document.

131. Parties and Signatories of the Basel Convention are encouraged to implement policies and/or programs which promote the environmentally and economically sound material recovery and recycling of end-of-life computing equipment.

132. Consistent with the Basel Ministerial Declaration on Environmentally Sound Management, used computing equipment should be diverted from disposal practices, such as landfilling and incineration, by a robust collection program, to the more environmentally sound practices of reuse, refurbishment, material recovery and recycling.

133. It is very important that end-of-life computing equipment be collected effectively (which is usually not the case today, even in industrialised countries). Funding for collection should be arranged and provided where necessary.

134. Environmentally sound material recovery and recycling of end-of-life computing equipment requires setting up an effective recycling chain, comprising the steps of robust collection of used computing equipment, evaluation, testing/refurbishment/reuse if appropriate, preparing/dismantling of non-reusable computing equipment or parts, separation into material streams, final recovery of marketable raw materials, and disposal of non-recyclable fractions and processing residues. Some hazardous fractions may have to be sent to destruction facilities to ensure they are taken out of use. Parties and persons involved in each step should understand and communicate with persons involved in the entire chain. ESM recycling facilities should ensure that computing equipment and materials derived from it are only managed in environmentally sound management facilities that are licensed and permitted to manage these materials.

135. There are a number of components and materials of concern, such as batteries and mercury lamps, that may release hazardous substances in processing for material recovery and these must be identified and carefully removed to avoid their entry into more intensive processing such as shredding.

136. Environmentally sound material recovery and recycling of computing equipment is not simple, and can cause exposures to hazardous substances if not done correctly. It should be well understood, managed and performed consistent with the practices contained in this guideline, to protect workers and communities. All steps should be taken to ensure that unsound computing equipment material recovery and recycling practices are avoided, such as those where proper worker and environmental protections are not implemented (e.g., primitive and “backyard” operations) and those where there is no attempt to maximize material recovery.

137. Priority should be given to material recovery processes that adhere to and increase the benefits of the waste management hierarchy: waste prevention; waste minimization; reuse; recycling, energy recovery; and disposal. Such processes result in high efficiency recovery from computing equipment, minimize loss and final disposal of valuable materials, and reduce the use of energy, generation of greenhouse gases, and other negative environmental and health impacts.

11.2 Development of Recycling Infrastructure

138. The Basel Principles of national self sufficiency, proximity, least transboundary movement, and ESM, as well as the necessity of economic efficiency, should be taken into account when considering investments in computing equipment material recovery and recycling facilities or operations, as well as when developing domestic policies for environmentally sound material recovery and recycling.

139. Because conformance with this guideline may mean an increase in recycling costs, Parties, industry including producers and other involved stakeholders should collaborate to ensure that there is adequate financing for computing equipment material recovery and recycling. Recognizing that certification and auditing can be very expensive, the procedures needed for recovery and recycling facilities to achieve certification need to be affordable and achievable for facilities around the world. The support of multilateral and regional development banks and bilateral donors will be highly valuable in setting up significant and attractive investment programs in developing countries aimed at the development of recycling infrastructure compliant with ESM.

11.3 Facility-Level Guidelines

140. Top management should systematically plan and execute environmentally sound material recovery and recycling operations and facilities. Without the ongoing commitment

of top management, it is unlikely that a facility will consistently and increasingly perform its operations in ways that minimize its impacts on human health and the environment. Facilities are encouraged to develop and use an certified comprehensive system of environmental, health and safety management to plan and monitor their environmental, health and safety practices, which includes specific elements for environmentally sound material recovery and recycling of used and end-of-life computing equipment.

141. A certification of facility conformance with an accredited comprehensive management system is desirable, and will assist concerned governments, other material recovery facilities, and other interested persons in evaluating and approving environmentally sound material recovery operations and facilities. If possible, this certification should be made by an independent and qualified auditor, and an accredited certification body.

142. Facilities should develop a procedure to identify access and comply with applicable legal requirements. These requirements might be found in many places, such national and local statutes and regulations, as well as in permits and licenses, and special professional expertise may be needed. Regulatory agencies, government publications and news releases, legal advisors, legal journals and commercial databases, and industry associations may help to identify applicable legal requirements. Facilities should also take into consideration customary or indigenous law and international treaties, conventions and protocols.

143. Recycling facilities should dismantle and separate, through manual and mechanical processing, the computing equipment that are not directed to reuse and direct them to properly-equipped materials recovery facilities. Facilities should send potentially hazardous substances (such as batteries, items containing mercury) to processing, recovery or treatment facilities that are properly licensed to receive and utilize technology designed to safely and effectively manage the removed material. Facilities should not try to recover components or materials if they do not have proper capabilities.

144. Recycling facilities should, before beginning operations and systematically thereafter, identify hazards and assess occupational and environmental risks that exist, or that could reasonably be expected to develop. This practice of hazard identification and risk assessment should be incorporated into the facility management system, and employees should have an appropriate level of awareness, competency and training with respect to the effective management of such hazards and occupational risks. Environmental, health and safety measures should then be taken, including engineering controls (substitution, isolation, ventilation, dust control, emergency shut-off systems, fire suppression), administrative and work practice controls (regular, documented health and safety training, job rotation, safe

work practices, medical surveillance, safety meetings) and personal protective equipment (respirators, protective eyewear, cut-resistant gloves).

145. Facilities that process, smelt, refine or perform other steps in computing equipment material recovery and recycling should identify themselves to their relevant regulatory authorities. Permitting and inspecting authorities with jurisdiction should inspect and verify that these companies are practicing health, safety and environmentally sound management.

146. Material recovery facilities that process electronic equipment should perform due diligence to select downstream vendors, and to assure themselves that subsequent handlers and processors are practicing environmentally sound management. Their due diligence should look for a documented management system of hazards identification, risk assessment and corrective actions, environmental permits, compliance with applicable legal requirements, and other general principles included in this guideline.

147. A facility should monitor, track and evaluate facility performance, and maintain records to demonstrate its activities. Record-keeping and performance measurement enable an organization to make better-informed decisions regarding whether it is achieving desired results or if it is necessary to implement corrective actions. In some cases, record-keeping and performance measurement may be a legal obligation.

11.4 Design for Recycling

148. The material recovery and recycling phase of end-of-life computing equipment should be taken into account by manufacturers during product design, by considering the issues of increased recyclability and reduction in toxicity.

149. A number of materials that are being used in the manufacture of new computing equipment, such as beryllium, mercury, flame retardants, etc., have been identified in this document as substances of particular concern during the processing of end-of-life computing equipment. Manufacturers should give consideration to the use of substitute materials that perform the same function.

150. Computing Equipment manufacturers should collaborate to address the recyclability of plastics in computing equipment. Specifically, consideration should be given to greater consistency in material selection during the design stage for all computing equipment which would allow plastics recyclers to eliminate sorting steps necessary to achieve compatibility of plastics types.

11.5 Future Collaborative Steps

151. Parties of the Basel Convention are encouraged to extend the role of the Basel Convention Regional Centres to develop training and technology transfer regarding the environmentally sound material recovery and recycling of end-of-life computing equipment, in order to help developing countries and countries with economies in transition implement regulatory frameworks for the environmentally sound management of end-of-life computing equipment, including regulations on transboundary movements.

152. An audit checklist or similar tools should be developed to assist parties and others in performing inspections and due diligence audits based on this guideline.

APPENDIX I – SUBSTANCES

Most substances in computing equipment present little or no hazard, especially in the early steps of recycling such as manual dismantling, e.g., steel in the cases of CPUs, copper wire. However some materials can present a hazard when computing equipment is broken, crushed, shredded, melted, incinerated or landfilled, unless environmentally sound practices are used. Exposure limits in the workplace are set by governments, and should be checked for the locations of facilities. This appendix presents, as examples, United States Occupational Health and Safety Administration (OSHA) exposure limits in the workplace for some substances contained in computing equipment. For locations of these substances within computing equipment, refer to Tables 1-4 of this guideline, above.

1.1 Aluminium

The U.S. OSHA has set an occupational exposure limit (OEL) of 15 milligrams of aluminium per cubic meter (mg/m^3) (total dust) and 5 mg/m^3 (respirable fraction) of air for an 8-hour workday, 40-hour workweek.

See the U.S. Agency for Toxic Substances and Disease Registry (ATSDR) ToxFAQs™ for Aluminium at http://www.atsdr.cdc.gov/tfacts22.html for additional information.

1.2 Antimony

The U.S. OSHA has set an occupational exposure limit (OEL) of 0.5 milligrams of antimony per cubic meter of air (0.5 mg/m^3) for an 8-hour workday, 40-hour workweek.

See the U.S. ATSDR ToxFAQs™ for Antimony and Compounds for additional information at http://www.atsdr.cdc.gov/tfacts23.html.

Antimony and antimony compounds are listed in Basel Convention Annex 1 at Y27.

1.4 Arsenic

The U.S. OSHA has set an occupational exposure limit (OEL) of 10 micrograms of arsenic per cubic meter of air (10 $\mu g/m^3$) for an 8 hour workday, 40 hour workweek.

See the U.S. ATSDR ToxFAQs™ for Arsenic at http://www.atsdr.cdc.gov/tfacts2.html for additional information.

Arsenic and arsenic compounds are listed in Basel Convention Annex 1 at Y24.

1.6 Beryllium

The U.S. OSHA has set an occupational exposure limit (OEL) of 2 micrograms of beryllium per cubic meter of air (2µg/m^3) for an 8-hour work day, 40 hour workweek.

See the U.S. ATSDR ToxFAQs™ for Beryllium at http://www.atsdr.cdc.gov/tfacts4.html for additional information.
Beryllium and beryllium compounds are listed in Basel Convention Annex 1 at Y20.

1.7 Cadmium

The U.S. OSHA has set an occupational exposure limit (OEL) of 5 micrograms of cadmium per cubic meter of air (5 µg/m^3) for an 8-hour workday, 40-hour workweek.

See the U.S. ATSDR ToxFAQs™ for Cadmium at http://www.atsdr.cdc.gov/tfacts5.html for additional information.

Cadmium and cadmium compounds are listed in Basel Convention Annex 1 at Y26.

1.8 Chromium

The U.S. OSHA has set an occupational exposure limit (OEL)of 5 micrograms of hexavalent chromium per cubic meter of air (5 µg/m^3) for an 8-hour workday, 40-hour workweek.

See the U.S. ATSDR ToxFAQs™ for Chromium at http://www.atsdr.cdc.gov/tfacts7.html for additional information.

Hexavalent chromium compounds are listed in Basel Convention Annex 1 at Y21.

1.9 Cobalt

The U.S. OSHA has set an occupational exposure limit of 0.1 milligrams of cobalt per cubic meter of air (0.1 mg/m^3) for an 8-hour workday, 40-hour work week.

See the U.S. ATSDR ToxFAQs™ for Cobalt at http://www.atsdr.cdc.gov/tfacts33.html for additional information.

1.10 Copper

The U.S. OSHA has set occupational exposure limits of 0.1 mg of copper fumes per cubic meter of air (0.1 mg/m^3) and 1.0 mg/m^3 for copper dusts for an 8-hour weekday, 40 hour workweek.

See the U.S. ATSDR ToxFAQs™ for Copper at http://www.atsdr.cdc.gov/tfacts132.html for additional information.

Copper compounds are listed in Basel Convention Annex 1 at Y22.

1.13 Gallium

The U.S. OSHA has not set an occupational exposure limit for gallium.

1.14 Gold

The U.S. OSHA has not set an occupational exposure limit for gold.

1.17 Lead

The U.S. OSHA has set an occupational exposure limit of 50 micrograms of lead per cubic meter of air (50 $\mu g/m^3$) for an 8 hour workday, and requires additional protective action at 30 micrograms of lead per cubic meter of air.

See the U.S. ATSDR ToxFAQs™ Chemical Agent Briefing Sheets (CABS) for Lead at http://www.atsdr.cdc.gov/cabs/lead/index.html for additional information.

Lead and lead compounds are listed in Basel Convention Annex 1 at Y31.

1.18 Lithium

The U.S. OSHA has set an occupational exposure limit of 25 micrograms of lithium hydride per cubic meter of air (25 ug/m^3) for an 8 hour workday.

1.19 Magnesium

The U.S. OSHA has not set an occupational exposure limit for magnesium.

1.20 Manganese

The U.S. OSHA has established an occupational ceiling limit (concentration that should not be exceeded at any time during exposure) of 5 milligrams of manganese per cubic meter of air (5 mg/m^3) for an 8 hour workday.

See the U.S. ATSDR ToxFAQs™ for Manganese at http://www.atsdr.cdc.gov/tfacts151.html for additional information.

1.21 Mercury

The U.S. OSHA has set an occupational exposure limit of 0.05 milligrams of mercury per cubic meter of air (0.05 mg/m^3) for an 8-hour workday.

See the U.S. ATSDR ToxFAQs™ for Mercury at http://www.atsdr.cdc.gov/tfacts46.html for additional information.

Mercury and mercury compounds are listed in Basel Convention Annex 1 at Y29.

1.22 Nickel

The U.S. OSHA has set an occupational exposure limit of 1 mg of metallic nickel and nickel compounds per cubic meter of air (1 mg/m^3) for an 8-hour workday.

See the U.S. ATSDR ToxFAQs™ for Nickel at http://www.atsdr.cdc.gov/tfacts15.html for additional information.

1.23 Palladium

The U.S. OSHA has not set an occupational exposure limit for palladium.

1.26 Platinum

The U.S. OSHA has set an occupational exposure limit of 2 micrograms of soluble platinum per cubic meter of air (2ug/m^3) for an 8-hour shift.

1.27 Polychlorinated Biphenyls (PCBs)

The U.S. OSHA has not set an occupational exposure limit for polychlorinated biphenyls.

Polychlorinated biphenyls are listed in Basel Convention Annex 1 at Y10.

1.28 Polycyclic Aromatic Hydrocarbons (PAHs)

The U.S. OSHA has set an occupational exposure limit of 0.2 milligrams of PAHs per cubic meter of air (0.2 mg/m^3) for an 8 hour workday.

See the U.S. ATSDR ToxFAQs™ for Polycyclic Aromatic Hydrocarbons (PAHs) at http://www.atsdr.cdc.gov/tfacts69.html for additional information.

1.29 Selenium

The U.S. OSHA has set an occupational exposure limit of 0.2 mg selenium per cubic meter of air (o.2 mg/m^3) for an 8-hour workday.

See the U.S. ATSDR ToxFAQs™ for Selenium at http://www.atsdr.cdc.gov/tfacts92.html for additional information.

Selenium and selenium compounds are listed in Basel Convention Annex 1 at Y25.

1.30 Silicon

The U.S. OSHA has set generic particulate (dust) occupational exposure limits of 15 milligrams total particulate per cubic meter (15 mg/m^3) and 5 milligrams per cubic meter for the smaller particles (respirable fraction) (5mg/m^3) for an 8-hour workday.

1.31 Silver

The U.S. OSHA has set an occupational exposure limit of 10 micrograms of silver per cubic meter of air (10 ug/m^3) for an 8-hour workday.

See the U.S. ATSDR ToxFAQs™ for Silver at http://www.atsdr.cdc.gov/tfacts146.htm for additional information.

1.33 Zinc

The U.S. OSHA has set an occupational exposure limit of 5 miligrams of zinc oxide (dusts and fumes) per cubic meter of air (5mg/m^3) for an 8-hour workday.

See the U.S. ATSDR Toxicological Profile for Zinc for additional information at http://www.atsdr.cdc.gov/toxprofiles/tp60-c1.pdf.

Zinc compounds are listed in Basel Convention Annex 1 at Y23.

APPENDIX II – GLOSSARY OF TERMS

Note: *These terms were developed for the purpose of the report on ESM criteria recommendations, individual project guidelines, and overall Guidance Document developed under PACE, and should not be considered as being legally binding, or that these terms have been agreed to internationally. Their purpose is to assist readers to better understand these PACE documents*.

Assemblies: Multiple electronic components assembled in a device that is in itself used as a **component**.

Basel Convention: United Nations Environment Programme's (UNEP's) March 22, 1989 Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal, which came into force in 1992.

Cleaning: Removal of dirt, dust, and stains; and making cosmetic repairs.

Component: Element with electrical or electronic functionality connected together with other components, usually by soldering to a printed circuit board, to create an electronic circuit with a particular function (for example an amplifier, radio receiver, or oscillator).

Computing Equipment: Computing equipment includes: personal computers (PCs) and associated displays, printers and peripherals, personal desk top computers, including the central processing unit and all other parts contained in the computer; personal notebooks and laptop computers, including the docking station, central processing unit and all other parts contained in the computer; computer monitors, including the following types of computer monitors: (a) cathode ray tube (b) liquid crystal display (c) plasma; computer keyboard, mouse, and cables; computer printer: (a) including the following types of computer printer: (i) dot matrix; (ii) ink jet; (iii) laser; (iv) thermal; and (b) including any computer printers with scanning or facsimile capabilities, or both.

Defective/Defect: Defective **Computing Equipment** is equipment that is delivered from the supply chain and last manufacturer in a condition that is not as it was designed to be sold, or the equipment breaks or malfunctions due to a condition that is not as it was designed. Defective equipment does not include equipment that loses functional or cosmetic value as a result of normal wear and usage or as a result of consumer negligence.

Direct reuse: Continued use of **computing equipment** and **components** by another person without the necessity of **repair, refurbishment**, or hardware **upgrading**, provided that such continued use is for the intended purpose of **computing equipment** and **components**.

Dismantling: Taking apart **computing equipment**, **components**, or **assemblies** in order to separate materials and/or increase options for **reuse, refurbishment, or recycling,** and to maximize recovery value.

Disposal: Any operations specified in Annex IV of the Basel Convention (Article 2, paragraph 4 of the Basel Convention, and Appendix III in this document).

Donation: Comprises any action to transfer **computing equipment** or its **components that are still fully functioning for its intended use,** for charity to another owner without any monetary rewards, or benefits, or barter.

End-of-life computing equipment: Individual **Computing equipment** that is no longer suitable for use, and which is intended for **dismantling** and recovery of spare parts or is destined for **material recovery** and **recycling** or final disposal. It also includes off-specification or new **computing equipment** which has been sent for **material recovery** and **recycling,** or final disposal.

End-of-Use: Computing equipment that is no longer used as intended by the previous owner, but may be fully functional and used appropriately by others.

Environmentally sound management (ESM): Taking all practicable steps to ensure that used and/or end-of-life products or wastes are managed in a manner which will protect human health and the environment.

Evaluation: The initial process by which used **computing equipment** is assessed, to determine whether or not it is likely to be suitable for **refurbishment/repair** or **material recovery /recycling.**

Essential Key Function: The originally-intended function(s) of a unit of equipment or **component** that will satisfactorily enable the equipment or component to be reused.

Final Disposal: Relevant operations specified in Annex IV A of the Basel Convention (Appendix III A in this document).

Fully Functional/Full Functionality: Computing equipment or **components** are "**fully functional**" when they have been tested and demonstrated to be capable of performing the **essential key functions** they were designed to perform.

Hydrometallurgical processing: Uses of aqueous chemistry for the recovery of metals from ores, concentrates, or recyclable wastes or products. Typically Hydrometallurgy consists of three steps of (a) Leaching using an acidic or basic aqueous solution to dissolve the desired metal at ambient or elevated pressures and temperatures; (b) Solution concentration, purification, then metal recovery using methods such as: precipitation, cementation, solvent extraction, gaseous reduction, ion exchange, electrowinning or electrorefining and (c) recycling of reagents and treatment of effluents. Hydrometallurgical operations in authorised industrial scale facilities are distinct from unauthorised and illegal environmentally harmful practices in the informal sector.

Incineration: A thermal treatment technology by which wastes, sludges or residues are burned or destroyed at temperatures ranging from 850°C to more than 1100°C .

Labelling: The process by which individual or batches of **computing equipment** are marked to designate their status according to the PACE guidelines.

Landfilling: The placement of waste in, or on top of, ground containments, which is then generally covered with soil. Engineered landfills are disposal sites which are selected and designed to minimize the chance of release of hazardous substances into the environment, e.g. using plastic landfill liners and **leachate** collection systems.

Leachate: Contaminated water or liquids resulting from the contact of rain, surface and ground waters, or other pollutants with waste.

Material Recovery: Relevant operations specified in Annex IV B of the Basel Convention (Appendix III B in this document).

Mechanical Separation: Process of using machinery to separate **computing equipment** into various materials **or components**.

Potential for reuse (reusable): Computing equipment and its **components** that possess or likely to possess quality necessary to be directly reused or reused after they have been refurbished or repaired.

Pyrometallurgical processing: Thermal processing of metals and ores, including roasting, smelting, and remelting.

RoHS: Directive of the European Parliament and the Council on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment (URL: http://ec.europa.eu/environment/waste/weee/index_en.htm).

Recycling: Relevant operations specified in Annex IV B of the Basel Convention (Appendix III B in this document).

Redeployment: Comprises any action of new deployment or use by the owner of previously used **computing equipment** or its **components.**

Refurbishable: Computing equipment that can be refurbished or reconditioned, returning it to a working condition performing the essential functions it was designed for.

Refurbishment: Process for creating **refurbished or reconditioned computing equipment** including such activities as cleaning, data sanitization, and software **upgrading.**

Refurbished computing equipment: Computing equipment that has undergone **refurbishment** returning it to working condition functional for its originally conceived use with or without upgrades and meeting applicable technical performance standards and regulatory requirements and possible upgrades.

Remarketing: Any action, including marketing activities, necessary to sell previously used **computing equipment** or its **components** directly or indirectly to customers.

Remanufacture: Any action necessary to build up as-new products using **components** taken from previously used **computing equipment** as well as new **components**, if applicable. The output product meets the original OEM functionality and reliability specifications. To remanufacture a product may require the complete or partial disassembly of the unit, replacement or reprocessing of all components not meeting specifications, and testing to determine the new product is fully functional. Depending on the applied components this process may significantly change the unit's composition, purpose, and design.

Repairing: Process of only fixing a specified hardware fault or series of faults in computing **equipment.**

Reuse: Process of using again used **computing equipment** or a functional **component** from used **computing equipment** in the same or a similar function, possibly after **refurbishment, repairing, or upgrading.**

Segregation: Sorting out **computing equipment** from other (electronic) wastes for possible **reuse** or for **treatment** in downstream processes that may include **recycling/**reclamation**/refurbishment/repair/reuse/disposal**.

Separation: Removing certain **components**/constituents (e.g. batteries) or materials from **computing equipment** by manual or mechanical means.

Small and Medium Size Enterprises (SME): According to the European Commission small and medium–sized enterprises are those businesses which employ fewer than 250 persons and which have an annual turnover not exceeding EUR 50 million, and/or an annual balance sheet total not exceeding EUR 43 million.

States concerned: Means parties which are States of export, or import, or transit whether or not Parties.

Testing: Process by which used **computing equipment** is assessed against established protocol to determine whether or not it is suitable for **reuse**.

Transport of Dangerous Goods Recommendations: UN Recommendations on the transport of dangerous goods which deals with classification, placarding, labeling, record keeping, etc. to protect public safety during transportation.

Treatment: Any physical, chemical or mechanical activity in a facility that processes computing **equipment** including **dismantling**, removal of hazardous components, **material recovery, recycling** or preparation for **disposal.**

Upgrading: Process by which used **computing equipment** is modified by the addition of the latest software or hardware in order to increase its performance and/or functionality.

Used Computing Equipment: Computing equipment, which its owner does not intend to use it any longer, but is capable of being reused by another owner, recycled, refurbished, or upgraded by another owner.

WEEE Directive: Directive of the European Parliament and the Council on Waste Electrical and Electronic Equipment.

Wastes: 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 (Article 2, paragraph 1 of the Basel Convention).

APPENDIX III – BASEL CONVENTION - ANNEX IV DISPOPSAL OPERATIONS

A. Operations which do not lead to the possibility of resource recovery, recycling, reclamation, direct re-use or alternative uses

Section A encompasses all such disposal operations which occur in practice.

D1	Deposit into or onto land, (e.g., landfill, etc.)
D2	Land treatment, (e.g., biodegradation of liquid or sludgy discards in soils, etc.)
D3	Deep injection, (e.g., injection of pumpable discards into wells, salt domes of naturally occurring repositories, etc.)
D4	Surface impoundment, (e.g., placement of liquid or sludge discards into pits, ponds or lagoons, etc.)
D5	Specially engineered landfill, (e.g., placement into lined discrete cells which are capped and isolated from one another and the environment, etc.)
D6	Release into a water body except seas/oceans
D7	Release into seas/oceans including sea-bed insertion
D8	Biological treatment not specified elsewhere in this Annex which results in final compounds or mixtures which are discarded by means of any of the operations in Section A
D9	Physico chemical treatment not specified elsewhere in this Annex which results in final compounds or mixtures which are discarded by means of any of the operations in Section A, (e.g., evaporation, drying, calcination, neutralization, precipitation, etc.)
D10	Incineration on land
D11	Incineration at sea
D12	Permanent storage (e.g., emplacement of containers in a mine, etc.)
D13	Blending or mixing prior to submission to any of the operations in Section A
D14	Repackaging prior to submission to any of the operations in Section A
D15	Storage pending any of the operations in Section A

B. Operations which may lead to resource recovery, recycling reclamation, direct re-use or alternative uses

Section B encompasses all such operations with respect to materials legally defined as or considered to be hazardous wastes and which otherwise would have been destined for operations included in Section A.

R1	Use as a fuel (other than in direct incineration) or other means to generate energy
R2	Solvent reclamation/regeneration
R3	Recycling/reclamation of organic substances which are not used as solvents
R4	Recycling/reclamation of metals and metal compounds
R5	Recycling/reclamation of other inorganic materials
R6	Regeneration of acids or bases
R7	Recovery of components used for pollution abatement
R8	Recovery of components from catalysts
R9	Used oil re-refining or other reuses of previously used oil
R10	Land treatment resulting in benefit to agriculture or ecological improvement
R11	Uses of residual materials obtained from any of the operations numbered R1-R10
R12	Exchange of wastes for submission to any of the operations numbered R1-R11
R13	Accumulation of material intended for any operation in Section B