UNITED NATIONS

UNEP

BC

UNEP/CHW.11/INF/13/Rev.1

Distr.: General
26 July 2013

English only

BASEL CONVENTION

Conference of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal
Eleventh meeting
Geneva, 28 April–10 May 2013
Agenda item 4 (e) (i)

Matters related to the implementation of the Convention: international cooperation, coordination and partnerships: Basel Convention Partnership Programme

Revised guideline on environmentally sound material recovery and recycling of end-of-life computing equipment

Note by the Secretariat

The annex to the present note contains the final revised guideline on environmentally sound material recovery and recycling of end-of-life computing equipment. The guideline was revised in order to make it consistent with section 5 of the revised guidance document on the environmentally sound management of used and end-of-life computing equipment and changes to the glossary of terms in appendix I to that document (UNEP/CHW.11/6/Add.1/Rev.1) as adopted by the Conference of the Parties at its eleventh meeting. The annex has not been formally edited.

K1352728 211013

Annex

PARTNERSHIP FOR ACTION ON COMPUTING EQUIPMENT

PROJECT 2.1

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

Approved by the PACE Working Group – 17 February 2011

Revised – 10 May 2013

Acknowledgements

The Partnership for Action on Computing Equipment (PACE) Working Group would like to express its appreciation for the efforts of the Project Group 2.1 in the preparation of the guideline on environmentally sound material recovery and recycling of end-of-life computing equipment. Members of this Project Group are identified on the next page of this guideline.

The previously approved Guideline on Environmentally Sound Material Recovery and Recycling of End-of-Life Computing Equipment has been evaluated to reflect the practical situation. The PACE Working Group would like to express its appreciation to City Waste Management Company Limited, Ghana, Evcilerkimya, Turkey, Galloometal, Belgium, Reclaimed Appliances Limited, United Kingdom of Great Britain and Northern Ireland, Recycling Facility, Serbia, Sims Recycling Solutions, India, TES-AMM, Malaysia, Umicore, Belgium, and WeRecycle, United States of America for evaluating the guideline and proposing revisions to the previously approved guideline.

In addition, special thanks are extended to Co-chairs of the Project Group 2.1, Mr. Joachim Wuttke from Germany, Mr. John Bullock, and Ms. Renee St. Denis from Sims Recycling Solutions for their leadership in finalizing the guideline and for ensuring that all proposed changes and comments from the Project Group 2.1 participants and companies who evaluated the guideline have been reviewed and incorporated in the revised guideline where appropriate. This revised guideline reflects also changes made to section 5 and to the glossary of terms in the appendix I to the revised guidance document on the environmentally sound management of used and end-of-life computing equipment as adopted by the Conference of the Parties to the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal at its eleventh meeting (document UNEP/CHW.11/6/Add.1/Rev.1).

Finally the PACE Working Group would like to express its deep sadness at the passing of Mr. John Myslicki. John contributed immensely to the work of PACE in general and for the preparation of this guideline in particular. We have lost a friend and a colleague who always worked towards protecting the environment. His enthusiasm was and remains an inspiration for us to continue this work.

Project Group 2.1 Participants

Co- chairs: 1. Mr. Joachim Wuttke, Germany
2. Ms. Renee St. Denis, Sims Recycling Solutions

Participants:

3. Mr. Andy Howarth, United Kingdom
4. Mr. Atsushi Terazono, National Institute for Environmental Studies, Japan
5. Mr. Aya Yoshida, National Institute for Environmental Studies, Japan
6. Ms. Cori Ong, TES-AMM (Singapore) Pte Ltd
7. Mr. Eric Harris, Institute of Scrap Recycling Industries (ISRI)
8. Ms. Helen Bolton, New Zealand
9. Mr. Ibrahim Shafii, Secretariat of the Basel Convention (SBC)
10. Ms. Isabelle Baudin, Switzerland
11. Mr. Jean Marie Vianney Minani, Rwanda
12. Mr. Jim Puckett, Basel Action Network (BAN)
13. Mr. Jinhui Li, BCRC- China
14. Mr. Jinya Kikuhara, Japan
15. Mr. Jose Maria Lorenzo Alonso, Mexico
16. Ms. Karen Pollard, USA
17. Ms. Katarina Magulova, Secretariat of the Stockholm Convention (SSC)
18. Mr. Mathias Schluep, EMPA
19. Mr. Matthias Kern, Secretariat of the Basel Convention (SBC)
20. Mr. Melissa Lim, Secretariat of the Stockholm Convention (SSC)
21. Mr. Michael VanderPol, Canada
22. Mr. Mostafa Kamel, BCRC- Egypt
23. Mr. Ole Thomas Thommesen, Norway
24. Mr. Otmar Deubzer, United Nations University (UNU)
25. Ms. Patricia Whiting, USA
26. Mr. Paul Hagen, Information Technology Industry Council (ITI)
27. Mr. Ramkripal Pandey, TES-AMM (Singapore) Pte Ltd
28. Mr. Richard Goss, Information Technology Industry Council (ITI)
29. Mr. Ross Bartley, Bureau of International recycling (BIR)
30. Mr. Ruediger Kuehr, United Nations University (UNU)
31. Ms. Sarah Westervelt, Basel Action Network (BAN)
32. Mr. Shunichi Honda, Japan
33. Ms. Wen-Ling Chiu, Institute of Environment and resources (IER)
34. Mr. Willie Cade, PC Rebuilders & Recyclers (PCRR)
35. Mr. John Myslicki, Consultant to SBC

Invited Technical Experts:

1. Mr. Christian Hagelueken, UMICORE
2. Ms. Heidelore Fiedler, UNEP DTIE Chemicals Branch

CONTENTS

FIGURES

TABLES

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, communities, and the environment 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, and measures should be taken to prevent the release of these substances.

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.

When applying these environmentally sound management criteria, a material recovery facility should first collect end-of-life computing equipment, but only the kinds that it is prepared, qualified and licensed to accept and process. Next, they should 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 according to specifications and quality demands of ESM downstream processors to optimize value and material recovery, including quality specifications determined between ESM facility buyers and sellers. 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 and generates employment opportunities. Even in developed countries, experience shows that manual disassembly and sorting with proper precautions is likely to be a beneficial complementary step to mechanical processing to maximize material recovery rates. Certain technological skills and, most importantly, knowledge of parts that may contain harmful substances (e.g. mercury-containing switches, PCB-containing and other capacitors, plastics with brominated flame retardants) are essential in manual disassembly and the associated treatment and disposal). Worker training and education on the risks should be part of the initial induction that all employees receive before working on the disassembly of materials with on-going continual assessment and professional development. 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 should 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. Due to new and different display technologies, the demand for recovered CRT glass has declined and will continue to do so in the future. At the same time, the traditional material recovery options for used CRT glass, particularly in lead smelters, are gradually disappearing. The alternative use of CRT glass fractions (mixed glass, separated panel or funnel glass) or safe disposal in compliance with applicable environmental law is required. New manufacturing applications for used CRT glass are emerging, e.g., glass wool insulation, building materials, abrasives and reflective material, and other uses under development. Phosphor coatings should be removed in all cases and handled in an environmentally sound manner. Nevertheless, new applications should be scrutinized to ensure that leaded CRT glass, is not used in applications where hazardous materials, could leach into the environment or harm human health or the environment.

Screens with liquid crystal display (LCD) may contain mercury lamps as backlights which should 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, if they meet criteria in the PACE guideline 1.1 for battery testing and minimum performance. 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. Electrical contacts on individual batteries should be physically covered or separated to prevent the risk of fire from unintentional electrical discharge or explosion during transportation and handling. 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 should 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, used to process hazardous waste, 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]

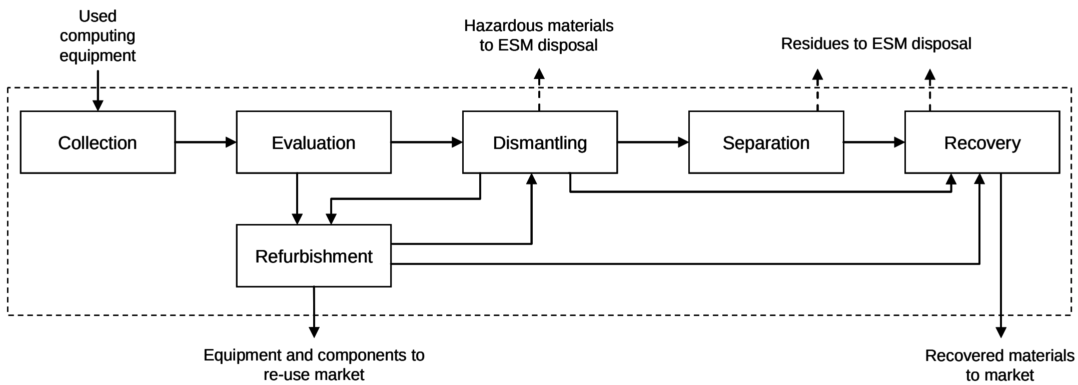
---

[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.

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, and rare earths, are becoming increasingly scarce, and/or their recovery is increasingly important for use in products. Legislation and voluntary phase-out increasingly call for the removal of hazardous materials in new products. Such materials are best stored or disposed of permanently in an environmentally sound manner. For example, the European Union's Restriction on Hazardous Substances (RoHS)[3] calls for the elimination of certain hazardous materials such as mercury, cadmium, lead, and certain brominated flame retardants in new products, with some exemptions allowed.

Fig. 1: Flow Diagram of Environmentally Sound Management of Used Computing Equipment



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

4. 1st step – **collection -** 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. This informal sector, however, must be transformed into a formal collection system, with standards and protections built in for everyone involved. Formal collection programs frequently require significant effort and expense, and it may be necessary to find ways to subsidize collection systems in any country, in order to deliver computing equipment to ESM facilities for processing[4]. Formal sector and governments should consider opportunities to engage, employ, and empower the informal sector and help transition them into formal systems, which are

---

[3] http://ec.europa.eu/environment/waste/rohs_eee/legis_en.htm

[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

consistent with applicable legal and other requirements including provisions that support protection of human health, worker safety and the environment. 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 large businesses provides an important opportunity due to both the large volumes of equipment available from one source, and the fact that a lot of this equipment is retired early and thus has significant value in the refurbishment market.

5. 2nd step – **evaluation**– Once it has been collected, computing equipment should be evaluated to determine whether it is suitable for refurbishment or for material recovery depending on its potential for reuse, facility capabilities, economics and other factors. Initial evaluation of each device can be done at the initial collection site or some other point before refurbishment or dismantling. Evaluation of individual components, on the other hand, will occur within both refurbishment and dismantling to determine which components are suitable for refurbishment or material recovery. 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 either straight to recovery or through the dismantling and separation steps first.

6. 3rd step – **refurbishment 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, with the intent of bringing a useful computer and/or component back into the market for continuing use. Depending on the type of component or part, those that cannot be repaired or reused should be sent to either ESM dismantling or recovery. 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.

7. 4th step – **dismantling** – Computing equipment often needs to be opened to see if its components are still working and can still be used in computing equipment, or submitted to 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. This type of manual separation is distinguished here from automated separation which occurs in the next step. It may also involve powerful mechanical separation of parts and components, such as shredding, which may release substances as dust and vapours. It will be necessary to first manually remove components such as mercury lamps, batteries, etc and their contained substances, some of which are hazardous, so they are not processed together with the whole device in the mechanical dismantling step so are not released and/or mixed with other materials. In the case of the LCD, to the contrary, it is well documented that mercury emission occurs, exposing the workers to high risk 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. 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.

8. 5th step – **separation** – 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 may have to pass through several separation processes before they are adequately consolidated. At the end of separation, finding the appropriate ESM recovery facilities for separated waste streams is a critical part of ESM, as this final link will largely determine the ultimate material recovery achieved in the chain, as well as the magnitude of environmental impact.

9. 6th step – **recovery** – 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.

10. 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.

11. 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.

12. 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, and by workers who are not trained, 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. Progress will likely occur in incremental advances and full ESM will take time. However, the sheer scale of the problems

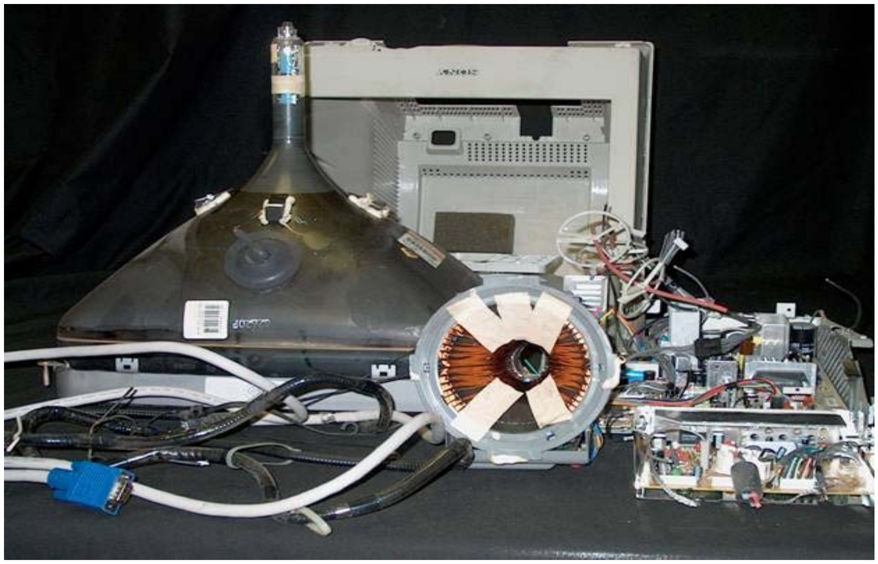
caused by irresponsible treatment of end-of-life computing equipment requires that we move swiftly to prevent more damage to communities and ecosystems, and recover more of these valuable resources that are becoming increasingly challenging to extract from nature.

3. COMPUTING EQUIPMENT COVERED BY THIS GUIDELINE

13. 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);

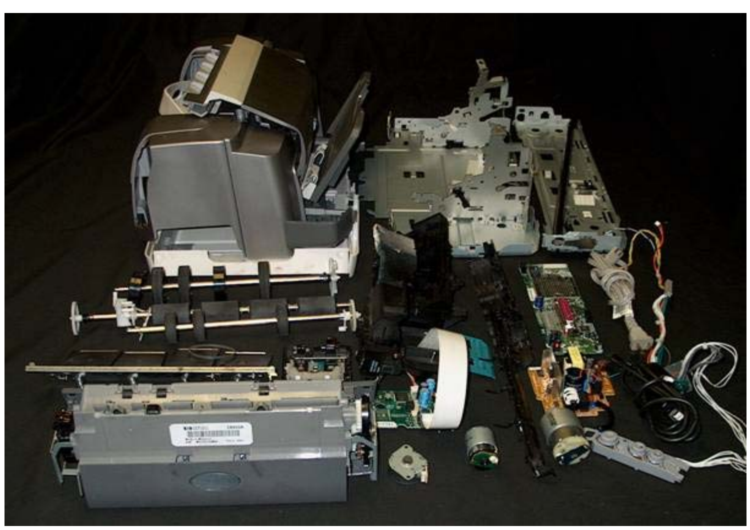
B. a monitor or display (CRT or flat screen display);



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

14. 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 consumer trends safety concerns and hazardous material use restrictions. The change in popular demand from CRT to LCD monitors has greatly reduced the amount of lead from 2-3 kg per CRT monitor to trace amounts in LCD monitors, while introducing mercury in LCD monitor lamps, ranging from 5-50 mg per monitor.

15. 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, while also being aware that it can take many years for a hazardous material that has been banned or phased out to decline significantly in the waste stream. (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. ESM requires a proactive approach here in which facilities are tracking the continuously changing composition of their supply to ensure that their process remains safe and efficient. 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. Also, it is important to track the continuously changing material compositions in products over time, so that the recovery facility can use a pro-active approach to environmentally sound recycling. 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, strong bases or other reagents; and
(iii) new substances that may be formed (sometimes unintentionally) by recycling processes, including vapors created during reactions with acids, such as nitrogen oxides or sulphur dioxide, and new compounds formed from elements present in the computing equipment that can be more hazardous than the initial form in which the element was present, such as halogenated dioxins and furans.

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, cables
Beryllium (Be)	Connectors, Cu alloys
Lithium	Batteries ("coin" or "button" cells
Silver (Ag)	Solder, components, circuit boards
Carbon (C)	Batteries, components
Micro or Trace Constituents	**(typically less than 0.01%)**
Titanium (Ti) and compounds	Circuit board, components, plastics
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)	Amber 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, case
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, cables
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	Amber 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. The following table presents average data on printed circuit boards (PCBs) in different computing equipment as of 2009. The precious metals silver (Ag), gold (Au) and palladium (Pd) are shown, as they are typically the dominant source of material value in these circuit boards. These values may change over time due to changes in design and manufacture of products.

Table 5: Precious metal content of printed circuit boards (PCBs) from computing equipment

Equipment type	**PCB weight in equipment (wt.%)**	**Metal concentration in PCBs (g/mt of PCB)**		
		Ag	**Au**	**Pd**
Computer keyboard	2%	700	70	30
LCD monitor	4%	1,300	490	99
Computer mouse	8%	700	70	30
Laptop	15%	1,000	250	110
Personal computer	13%	1,000	250	110
Printer, fax	8%	350	47	9

Source: Chancerel et al., Precious Metal Flows During the Preprocessing of Electronic Waste, Journal of Industrial Ecology, 2009

19. Certain processes are more likely than others to release specific substances within these three groups. Shredding, smelting and leaching are examples of processes that are likely to release these types of substances and should therefore only be undertaken with proper engineering controls, while other current practices, such as open burning, should be completely avoided as they cannot be executed in an ESM manner. Processes may create fumes and fine dust particles as well as larger pieces. Particles entering the air may contain hazardous substances present in computing equipment, in which case workers will need protection through engineered ventilation systems that remove fumes and dust, and personal protective equipment designed to protect against the specific hazards, 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 changeable filters, and properly managed. Such dusts may contain valuable metals to be recycled, or they may be suitable only for ESM final disposal, often as hazardous waste

20. 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. COLLECTION, DISMANTLING, SEPARATION AND MECHANIZED DISMANTLING AND SEPARATION PRACTICES

5.1 Facility Measures to Support Environmentally Sound Management

21. 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

22. *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.

23. *Risk Assessment:* Material recovery facilities conduct heavy industrial operations involving powerful machinery, very high temperatures or 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.

24. *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.

25. *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.

26. *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.

27. *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 and received by other material recovery facilities and/or refurbishers will assist in internal and external performance review of the facility´s operation. This assists in tracking and tracing materials downstream of the processing facility, which is an essential requirement, particularly for hazardous materials. This documentation of the management system and careful record-keeping contributes to a higher level of confidence that a facility is consistently performing in conformance with applicable regulations and voluntary standards. There is little or no activity at a recycling or materials recovery facility that will not be improved by appropriate records of that activity, accompanied by periodic review with intent to improve.

28. *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.

29. *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 monitorring 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 compliance with the principles of environmentally sound management.

5.2 Potential Material Recovery from Computing Equipment

30. 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.

31. There has also recently been increasing interest in recovery of "critical materials" or "special materials" such as platinum group metals, gallium, indium, rare earth elements, 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,

[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.

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 for economic and/or technological reasons. 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 material recovery from computing equipment. It is important to realize, though, that thermodynamic limits will always be a constraint, rendering 100% material recovery rates not possible.

5.3 Collection/Receiving

32. 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 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

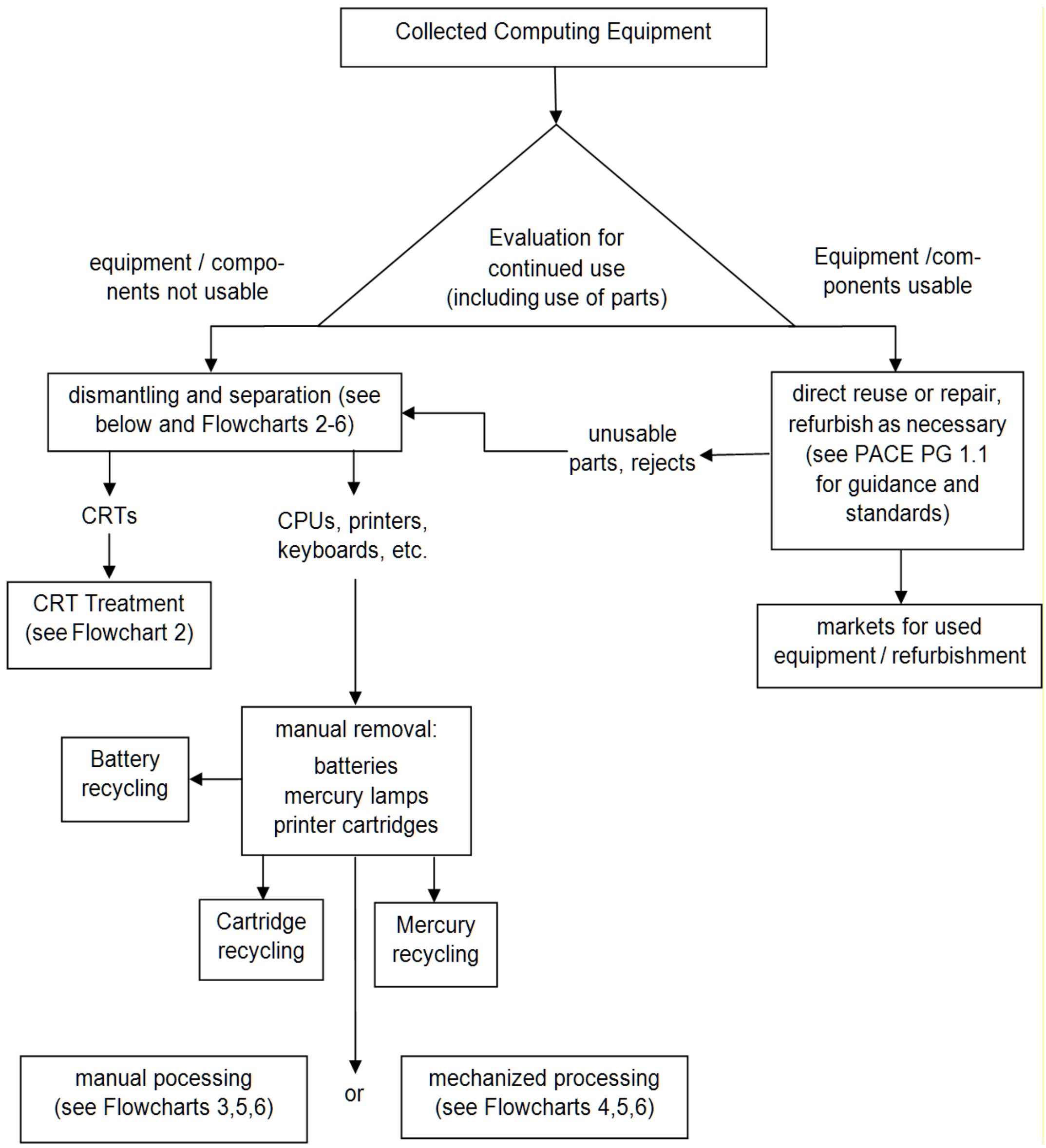
5.4 Evaluation and Initial Sorting

33. 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.

34. 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 2 to 7.

[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. 2: Overview of Initial Steps



35. 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.

36. 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 electronic components or dismantled electronic components from 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 from 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

37. 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.

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

39. 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. At the same

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

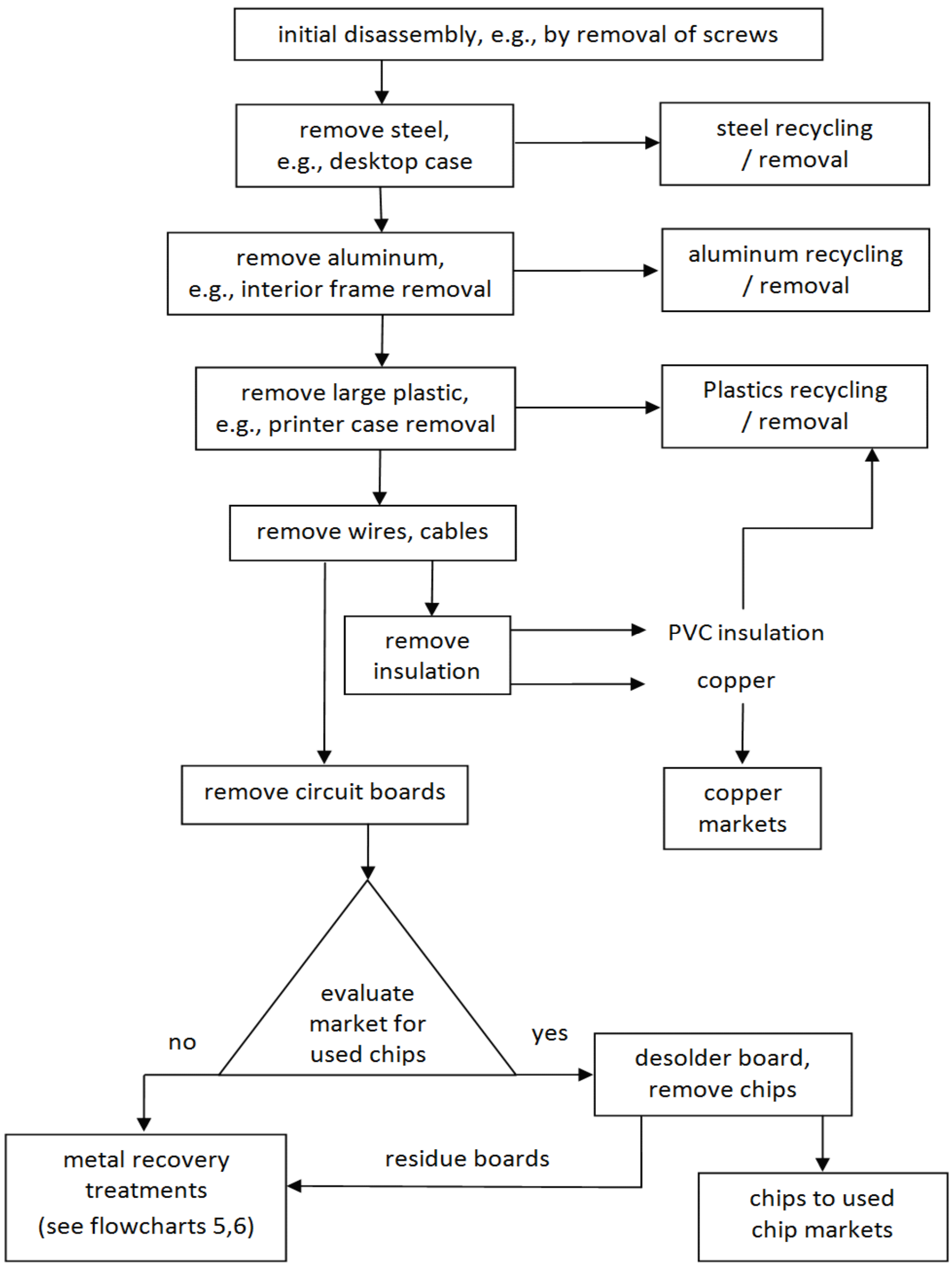
time, shredding units that claim to safely capture mercury during treatment are available on the market. With adequate precautions for human health and the environment, mercury does not need to be a barrier to effective material recovery from computing equipment.

5.5.2. Further Disassembly - Manual and Mechanized Processes

40. 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 3 to 7.

41. 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.

Fig. 3: Manual Disassembly and Separation of Materials



42. 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.

43. 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.

44. 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 sink-float separation of the small pieces of insulation, from the copper. 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 cables to remove insulation and recover copper wire, 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].

45. 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.

46. 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

47. 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 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. Mechanized separation operations are complex, and increasingly sophisticated, and it is beyond the scope of this guidance to describe all processes in great detail. However some typical steps involved in mechanized disassembly and processing of computing equipment are shown in Figure 4, and are further described in following paragraphs.

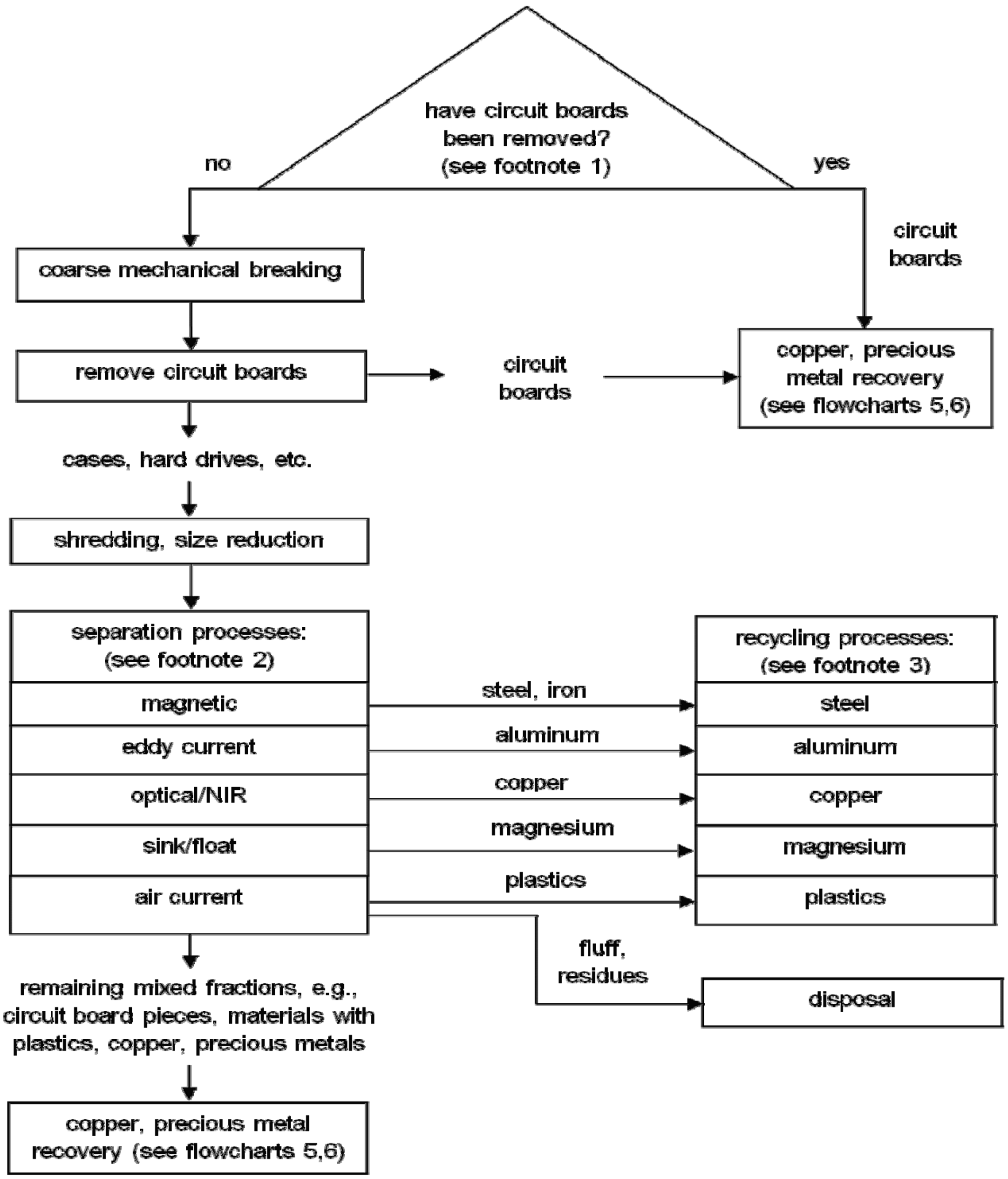
48. The first mechanical operation may be a coarse shredding or breaking open of a personal computer or peripheral, leaving large pieces from which circuit boards can be manually removed. Because circuit boards are more likely to contain substantial amounts of copper and precious

[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

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.

49. 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.

Fig. 4: 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.

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. Sink-float 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 with a density chosen so that the plastic will float and the metal will sink.

6. SAFELY STORING AND TRANSPORTING MATERIALS FOR FURTHER PROCESSING

6.1 On-site Storage

54. Computing equipment, components, and all materials derived from them, as well as chemicals used in their processing, should be stored in a manner which minimizes accidents, spills, and breakage. Proper storage should maximize value for materials recovery, and be secure from unauthorized access. Material streams that pose environmental risks should be stored in a manner which prevents contamination of air, soil, groundwater, and runoff water, such as inside covered, closed buildings with impermeable floors, e.g., sealed concrete. If other materials must be temporarily stored outside, necessary measures must be taken to ensure appropriate storage, with preventive measures to avoid dust formation, and the use of impermeable surfaces with collection and treatment of run-off water. It is not recommended to store hazardous materials outside without authorisation and in conditions that risk contamination of air, soil, groundwater, and run-off water.

55. Components which can be flammable or explosive, such as some inks and toners or batteries, should be stored in a manner that minimizes risks of fire, away from sparks or heat. In the case of batteries, they must be stored in a manner that protects battery terminals from contacting conductive materials and causing electrical discharges, explosions, or fires. Any material with small particles and dust, such as processing residuals and fines, that could be released and dispersed in the workplace or outdoors should be stored in appropriate containers that will not leak, such as closed drums or "supersacks", in protected conditions.

56. It is important to accurately label all containers according to their contents, packaging type, hazard classification (if applicable), and have labels clearly visible. Areas where materials are stored should also be labelled. A facility map should be produced and kept current, which 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

57. 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. Smaller, dispersive fractions of shredded copper or circuit boards (as mentioned in section 6.1) should be transported in properly closed containers with lining if needed. 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 and fractions thereof. For example, restrictions on the transportation of used lithium-ion batteries prohibit transport by air and require that they are protected against short circuit to prevent fire hazard.[11]

[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

[11] For more information on prescriptions and restrictions on transport of dangerous goods, facilities should consult the local (CFR 49 for the USA, TDG for Canada, ADG for Australia) and international regulations dangerous goods (The IMDG-code for international maritime transport, the IATA DGR for international air transport) or contact local authorities.

7. MATERIAL RECOVERY FROM SEPARATED MATERIAL STREAMS

7.1 Metals Management and Recovery

58. 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.[12] 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.

59. 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. It should be noted that the recovery of critical materials can be encouraged through the concept of using the valuable metals in the equipment to help pay for their recovery.

60. 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 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.

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

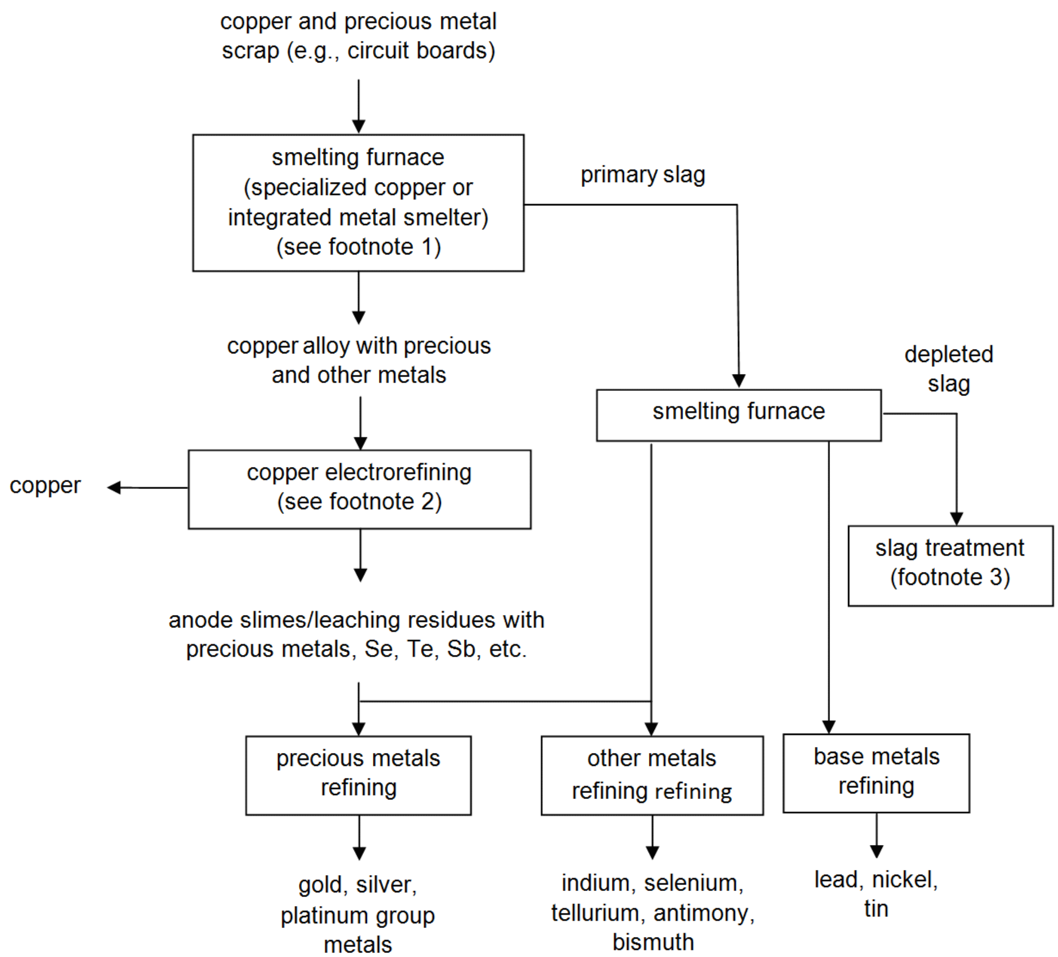
7.1.1 Pyrometallurgical Processing

61. 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 reach the melting temperatures of the material mix and the temperature at which chemical reactions can take place to separate and extract the desired metals at a higher concentration. Many types of metal scrap are commonly processed in smelting furnaces designed and operated for the specific metal they treat. Smelting is a pyrometallurgical 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.

62. Scrap steel, such as steel in computer cases, can be used in electric arc steel furnaces to produce new steel. Facilities should be aware that impurities in their steel scrap fraction, especially copper, could reduce the value of this scrap and even lead to it being rejected by steelmakers if it is too contaminated with certain elements. 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[13.]

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

Fig. 5: 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.

63. Scrap aluminum will be used in secondary aluminum furnaces to produce new aluminum. As with steel, facilities should be aware that impurities could affect the economic viability of recycling this scrap fraction. Also, for aluminium there can be a significant economic advantage in keeping certain alloys separate, which should be taken into account when operating a dismantling and separation facility. Aluminium furnaces melt scrap aluminium 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[14].

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

64. 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[15] 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. It is an efficient process for circuit boards because, in general, it allows for a quick separation between valuable (copper and precious metals) and less valuable materials, though specifics on smelting processes will vary between plants based on furnace design and operating conditions, and will determine which materials and how much of them a plant is able to process.

65. The primary product of smelting is a relatively pure metal, called blister copper, which is 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 that are treated by electrorefining or granules that are treated by leaching and electrowinning 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) which may be complemented by pyrometallurgical processes, by which individual precious metals are refined to their market grades.

66. 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 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.

67. 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

[15] 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.

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

68. 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 by adding other metals or reagents. For some metals such as copper, hydrometallurgical refining is used after smelting to achieve higher purity of copper, such as the electrolytic refining of copper mentioned above. Then, after the copper has been removed, the residues undergo a series of additional hydrometallurgical steps to extract additional metals.

69. While copper smelting, a pyrometallurgical process, is the established high volume method of non-ferrous metal recovery from computing equipment, some facilities are investting 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, during which, dust collection is imperative to prevent significant losses of precious metals. 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 SO_2, hydrazine hydrate or ferrous sulphate.

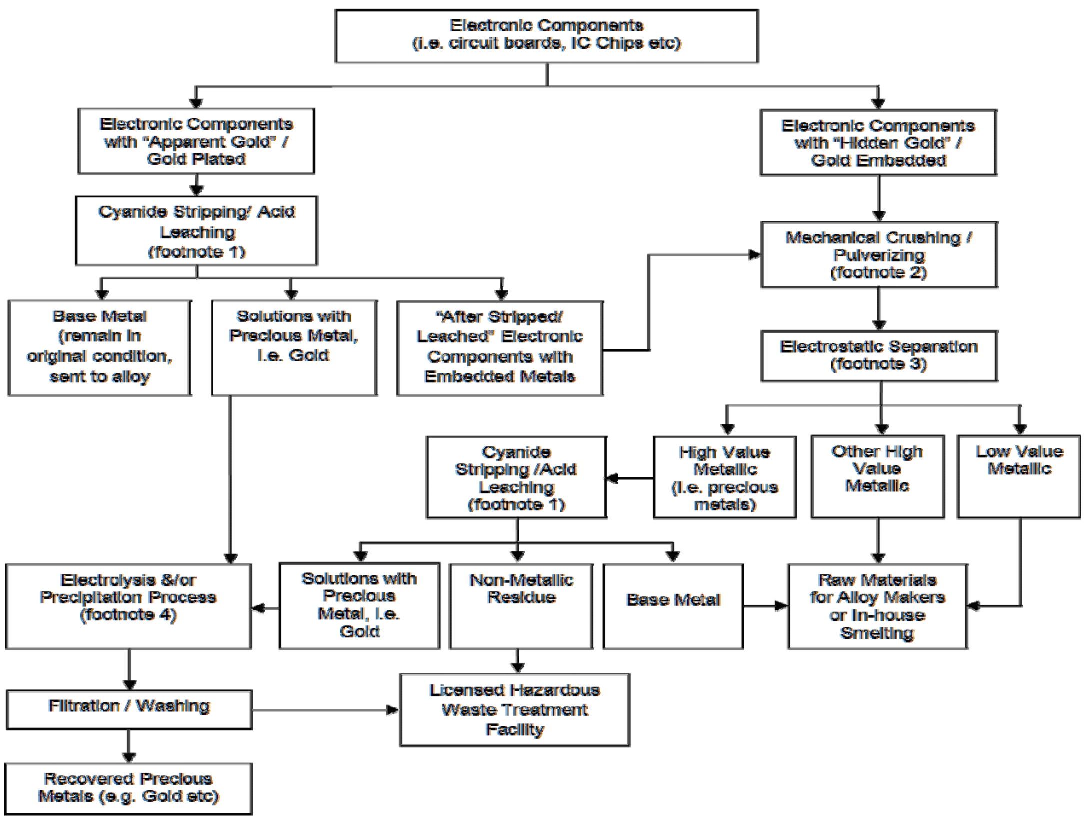
70. Direct hydrometallurgical operations used for material recovery from computing equipment are smaller and less expensive to establish than large pyrometallurgical operations, because much less equipment is used, and fewer operations are performed. Processing of selected computing equipment is relatively 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.

71. 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

72. 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.

Fig. 6: Metal Recovery - Hydrometallurgical Recovery of Gold



Fn 1 - electronic components with "apparent gold" on its surface or gold plated would be processed using cyanide stripping (or acid leaching or aqua regia processes) to remove the surface precious metal contents; the entire process should be equipped with closed loop & complete environmental protection systems such as air emission monitoring devices, cyanide & fume scrubbers etc to eliminate the environmental hazards.

Fn 2 - electronic components with embedded gold will be mechanically crushed for size reduction followed by pulverization to reduce them into smaller particles. Those electronic components with surface gold & had been "stripped/leached" would also be channeled to this process to further recover the precious metals which could be "embedded"; the entire process should be equipped with closed loop & complete environmental protection systems such as dust collecting & noise reduction systems etc to eliminate the environmental hazards.

Fn 3 - after crushed/pulverized electronic components will undergo electrostatic separation and acid leaching to ensure the optimal recovery of high value metallic, i.e. those with precious metals or non-ferrous metals content.

Fn 4 - "acid leaching" solutions *(i.e. from footnote 1 process)* can be precipitated by addition of other substances, e.g. aluminium or other base metals that can be dissolved in nitric acid alone, leaving gold as precipitate; alternatively, "cyanide stripping" solutions *(i.e. from footnote 1 process)* used to dissolve the precious metal materials from the electronic components will undergo electrolysis; electrolysis allows the reduction of metals from metallic compounds to obtain the pure form of metal, i.e. the process causes the precious metals, i.e. Gold, to dislodge itself from other metals and "deposit" at the electrodes' after electrolysis, the "Gold Deposits" scrapped off from the electrodes are re-dissolved, refined & precipitated out as higher grade gold powder (minimum 99.9%).

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 for communities which discard of residues and of untreated spent cyanides and acids.

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

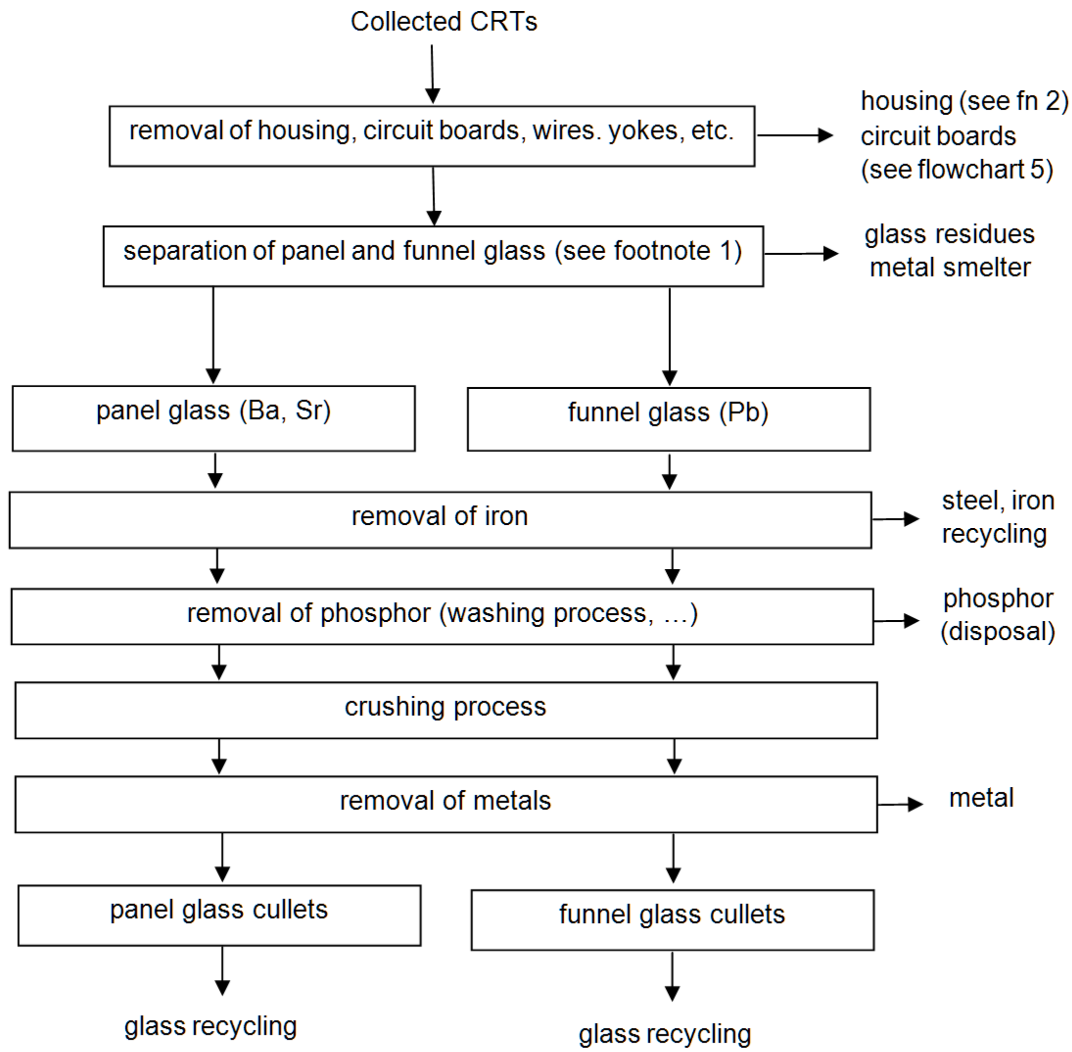
73. Some CRTs removed from computing equipment can still be used as CRTs in rebuilt computer monitors, or can be used as the CRT components of television displays. If a CRT monitor cannot be reused as a monitor or other display screen, it may still be recycled for its copper and glass[16]. There is still 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.

74. 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.

75. 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).

[16] 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. 7: 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 hazardous flame retardants the plastic can be recycled or may have to be disposed of

76. 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.

77. 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[17] and should be disposed in properly authorized facilities.

7.1.5.Plastics Management and Recovery

78. 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. It is a good management practice 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-used in the production of new plastics, but must be disposed in an environmentally sound manner.[18] The plastic recovery processing described below may create exposures to BFRs, and perhaps dioxins in low temperature processing, and precaution is necessary.

79. 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.

80. 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, e.g. density separation of flame retardant plastics from regular plastics.

81. 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

[17] EU Waste List, waste-code 19 02 11*

[18] EU Directive 2003/11/EC

pieces are then typically heated and forced (extruded) through a die to form strings and pellets for final sale as plastic raw materials.

82. 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.

83. If plastic types cannot be separated by type, a mix of different types of plastics may have reduced 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

84. 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.

85. Once removed, batteries may be evaluated for further use, for which quality standards should be set[19]. 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.

86. 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.

87. 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 electrolyte, so it does not make sense to manually remove it. Plastic battery components can also be manually

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

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.

88. 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.

89. 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

90. 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 light emitting diode (LED) technology is rapidly taking over the display market, flat panel displays using cold cathode fluorescent lamps (CCFL) containing mercury will continue to maintain a large share of the monitor waste stream for some years due to the relatively long lifetime of monitors. Unless clearly stated on the display or otherwise known, facilities should apply the precautionary principle and treat each display as if it may contain mercury 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.

91. 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.

92. 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.

93. After removal of mercury lamps, LCD screens are generally not hazardous, and can safely enter the recycling chain so that valuable metals and plastics can be recovered. 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

94. 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 refillling they should be tested individually for print quality.

95. 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.

96. 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.

97. 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

98. 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

99. 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

100. 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, depending on its composition. 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 in a personal computer can be recycled, however, much is currently not recycled for economic reasons, and so careful final disposal management (ESM) is required.

8.1 Bag house dust and filter residues

101. Baghouse filters, filter residues, and dusts may have recoverable values of zinc or precious metals, provided that the material recovery facility can safely capture and transport these. If these dusts cannot be safely managed, the material recovery facility should presume them to be hazardous wastes, tested for hazardous characteristics, and managed appropriately, such as by disposal in a controlled landfill. 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

102. 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

103. 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.

104. 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.

105. 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.

106. Hydrometallurgical refining operations will result in residual waste effluents that may contain hazardous metal concentrations, as well as acids, cyanides and caustic solutions, all of which may require different treatment and disposal methods. 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. Sludges and solid wastes created from the precipitation of metals and neutralization will have to be safely disposed of after they can no longer be further treated to recover contained metals.

8.4 CRT Glass and Glass Fines

107. 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 as it reduces the space needed for landfills.

8.5 Phosphors

108. 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.

109. 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.

110. When a CRT is separated into its front panel and funnel, 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)

111. 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

112. 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 may reduce the possibility of reprocessing and re-use.

113. Plastics as hydrocarbons may be readily recycled or reused dependent on their technological or commercial quality. When plastics or plastics residues cannot be recycled or reused under reasonable technological or commercial conditions, in preference to disposal in landfill, they may be used as a fuel similar to other hydrocarbons, or as a source of carbon for chemical reduction in smelting 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.

114. Similarly, when not recyclable or reusable, plastics or plastic residue 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

115. 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[20] 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.

8.7 Landfill concerns

116. 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, which can travel long distances into ground waters, lakes, streams, or wells, leading to much wider impacts.[21] Only in a well-engineered, properly controlled landfill, final disposal of computing equipment is an appropriate last resort.

9. LEGAL REQUIREMENTS

117. 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

118. 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.

119. 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.

120. 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

[20] "State of the art" means the state of development of modern procedures, facilities or operational methods that, as a whole, reliably substantiates the practical suitability, for achieving a generally high standard of protection for the environment, of relevant measures for limiting emissions into the air, water and soil, for ensuring the safety of plants/facilities, for providing environmentally sound waste management and for preventing or reducing impacts on the environment

[21] For more information see: Sepulveda, A., Schluep, M., Renaud, F.G., Streicher, M., Kuehr, R., Hagelueken, C., Gerecke A.C. (2009), A review of the environmental fate and effects of hazardous substances released from electrical and electronic equipments during recycling: Examples from China and India, Environmental Impact Assessment Review, 30, 28-41.

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

121. 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 on movements of waste. 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, Guidance on Transboundary Movement of Used and End-of-Life Computing Equipment, as well as other guidelines on transboundary movement.

10. COMMERCIAL CONSIDERATIONS AND ISSUES

122. 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.

123. 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.

124. In developing countries and countries with economies in transition, material recovery has also been carried out for profit, but not always in an environmentally sound manner. 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.

125. 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[22]. 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.

126. 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.

127. 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.

128. 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.

129. 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 has a higher potential chance of being 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.

130. 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.

131. 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

[22] The organization responsible for this is the London Gold Market Fixing Ltd

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

132. Material recovery, energy recovery and disposal facilities should 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.

133. 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.

134. 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.

135. 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.

136. 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 should be sent to facilities for destruction of the hazardous substances in order 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.

137. 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 should be identified and carefully removed to avoid their entry into more intensive processing such as shredding.

138. 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., informal backyard operations) and those where there is no attempt to maximize material recovery.

139. 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

140. The Basel Convention general obligations related to national self sufficiency, proximity, least transboundary movement, and ESM, as well as the necessity of economic efficiency, should be taken into account when choosing computing equipment material recovery and recycling facilities or operations, as well as when developing domestic policies for environmentally sound material recovery and recycling. However, there are currently many countries that do not possess material recovery facilities that meet the criteria for environmentally sound management. In these cases, it may be preferable to export some components that may be hazardous or require specialized processes to achieve high material recovery rates. These materials (e.g., CRT glass, mercury lamps and switches, LCD screens, batteries, plastics containing brominated flame retardants or circuit boards) should be exported for treatment in an ESM facility in compliance with the Basel Convention.

141. Because conformance with this guideline may mean an increase in recycling costs, Parties, industry including producers, importers 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.

142. Parties should be prepared to grant timely consents and other approvals for legal exports or imports of waste computing equipment to environmentally sound managed facilities.

11.3 Facility-Level Guidelines

143. 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 a 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.

144. 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.

145. 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.

146. 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, to ensure that the loss of valuable material is minimized. 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.

147. 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). Such facilities should take into consideration ILO Guidelines on occupational safety and health management systems (ILO-OSH 2001).[23]

148. 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.

149. 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.

150. 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.

[23] http://www.ilo.org/global/publications/ilo-bookstore/order-online/books/WCMS_PUBL_9221116344_EN/lang--en/index.htm

11.4 Design for Recycling

151. 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 toxicity and recyclability.

152. A number of materials that are being used in the manufacture of new computing equipment, such as beryllium, mercury, brominated flame retardants, etc., have been identified in this document as substances of particular concern during the processing of end-of-life computing equipment. Manufacturers can aid the recycling industry by providing more information on the hazardous substances in their products and how they can be safely dismantled, while also substituting in less hazardous substances that perform the same function. Manufacturers should also strive to utilize substances that reduce risks to human health and the environment across the product life-cycle.

153. 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

154. 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.

155. 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

156. 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[24]. 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.

1.3 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.

1.4 Beryllium

The U.S. OSHA has set an occupational exposure limit (OEL) of 2 micrograms of beryllium per cubic meter of air (2$\mu g/m^3$) 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.

1.5 Cadmium

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

[24] The following link will provide access to the occupational exposure limits in many countries: http://osha.europa.eu/en/topics/ds/oel/members.stm/#de

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.

1.6 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.

1.7 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.

1.8 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.

1.9 Gallium

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

1.10 Gold

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

1.11 Lead

The U.S. OSHA has set an occupational exposure limit of 50 micrograms of lead per cubic meter of air (50 µg/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 for information.

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

1.12 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.

1.13 Magnesium

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

1.14 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.

1.15 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.

1.16 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.

1.17 Palladium

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

1.18 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.

1.19 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.

1.20 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.

1.21 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.

1.22 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.

1.23 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.

1.24 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 the overall Guidance Document developed under PACE, 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.

Charitable donation: Transfer of **computing equipment** or its **components that are not waste for their intended direct reuse** for purposes of charity without any monetary rewards or benefits, or for barter.

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

Component: Element with electrical or electronic functionality connected, together with other components and usually by soldering to a printed circuit board, to create an electric or 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: The using again, by a person other than its previous owner, of **computing equipment** and **components** that are not waste for the same purpose for which they were conceived without the necessity of **repair, refurbishment**, or hardware **upgrading**.

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).

End-of-life computing equipment: Computing equipment that is waste and 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.

Engineered landfills: Engineered landfills are disposal sites that are selected and designed to minimize the chance of release of hazardous substances into the environment, for example through the use of plastic landfill liners and leachate collection systems.

Environmentally sound management (ESM): The taking of all practicable steps to ensure that wastes are managed in a manner that will protect human health and the environment against adverse effects which may result from such wastes.

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.

Evaluation: The initial assessment of used **computing equipment** to determine whether it is likely to be suitable for **refurbishment, repair, material recovery** or **recycling.**

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:

i) Leaching of an intermediate product with acid, caustic, or a complex forming solvent, often combined with oxidation to dissolve the desired element(s) at ambient or elevated pressures and temperatures;

ii) Purification of the solution by:

a) precipitation of insoluble compounds,

b) cementation of unwanted metals (using another metal to precipitate the metal in solution) or

c) solvent extraction;

iii) Precipitation of desired product, either as an insoluble compound or as a metal either by chemical or electrochemical methods.

Recycling reagents and treatment and disposal of effluents and residues are further important steps that occur throughout the process. 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 marking of **computing equipment, individually or in batches,** to designate its status according to the PACE guidelines.

Landfilling: The deposit of waste into land (i.e. underground), or onto land.

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

Mechanical Separation: 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, sludges and residues including roasting, smelting, and remelting, with the aim of recovering metals as marketable products. Pyrometallurgical operations in authorised industrial scale facilities are distinct from unauthorised and illegal environmentally harmful practices in the informal sector.

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: Any action of new deployment or use by the owner of 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: Modification of **used computing equipment** to increase its performance and functionality or to meet applicable technical standards or regulatory requirements, including through such activities as cleaning, data sanitization, and software **upgrading.**

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

Repair: Fixing specified faults in computing **equipment** and/or replacing defective components of computing equipment to bring the computing equipment into a fully functional condition**.**

Reuse: The using again, by a person other than its previous owner, of used **computing equipment** or a functional **component** from used **computing equipment** that is not waste for the same purpose for which it was conceived, possibly after **refurbishment, repairing, or hardware upgrading.**

Segregation: Sorting out **computing equipment** from other (electronic) wastes for possible **reuse** or for **treatment** in downstream processes that may include **recycling**/reclamation/**re-furbishment/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 50 million euros, and/or an annual balance sheet total not exceeding 43 million euros.

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, labelling, 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: Modification of fully functional **computing equipment** by the addition of software or hardware in order to increase its performance and/or functionality.

Used Computing Equipment: Computing equipment that is or has been used, either by its first owner or otherwise. Used computing equipment may or may not be a waste, depending upon the waste definition and its characteristics, intended destination and fate.

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).

Working Condition: See **Fully Functional.**

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