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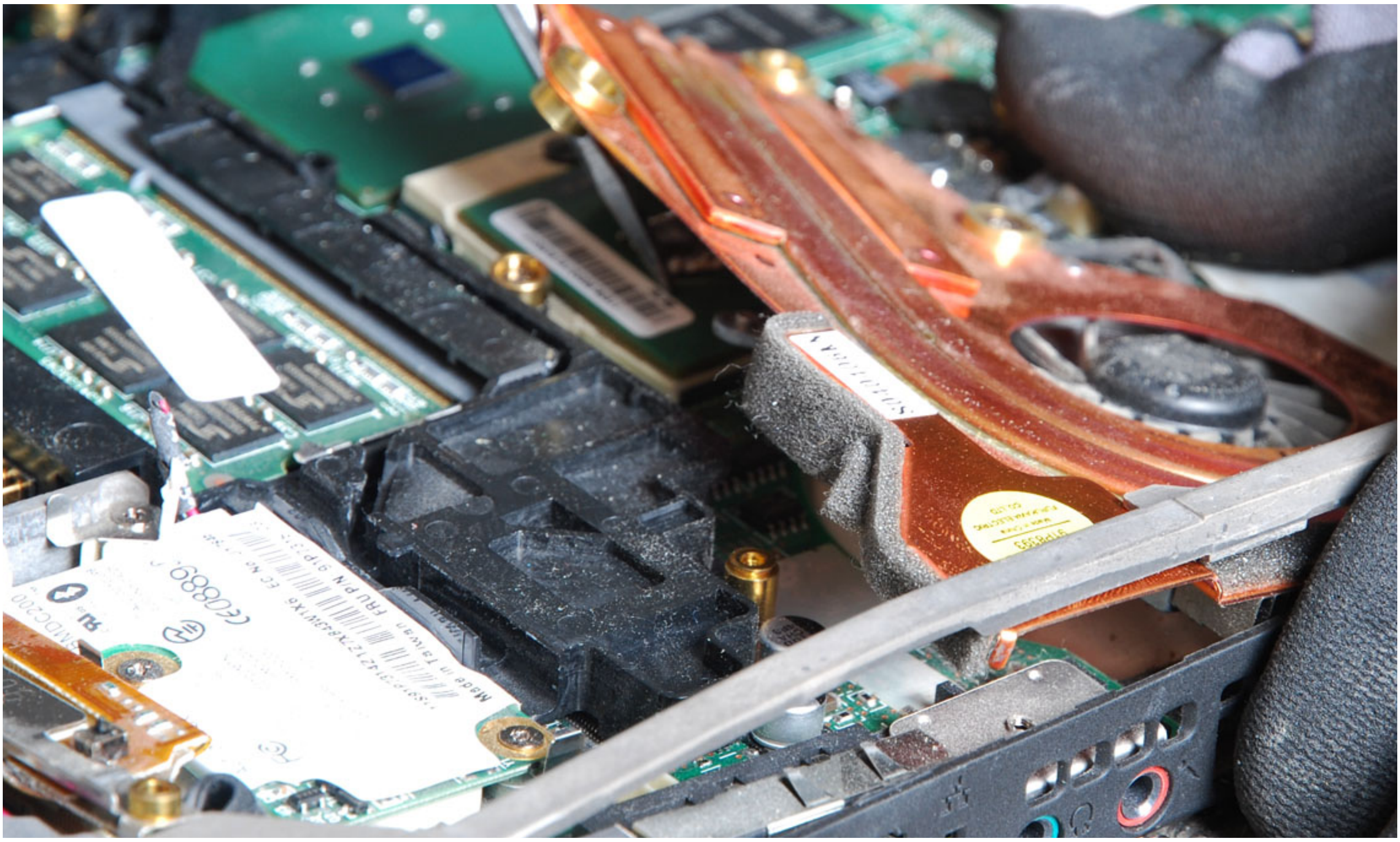

SRI SUSTAINABLE RECYCLING INDUSTRIES

Dismantling Guide for IT Equipment

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Abbreviations

ABS	Acrylonitrile butadiene styrene
CRT	Cathode Ray Tube
CCFL	Cold Cathode Fluorescent Lamps
CDD	Compact Disk Drive
CD-ROM	Compact Disc Read-only memory
CFL	Compact Fluorescent Lamps
CPU	Central Processing Unit
CU	Central Unit (= tower)
DS	Data Sheet
EEE	Electric and Electronic Equipment
EHS	Environment, Health and Safety
EMPA	Swiss Federal Institute for Material Science and Technology
FDD	Floppy Disk Drive
FL	Fluorescent Lamps
FR	Flame Retardants
H&S	Health and Safety
HDD	Hard Disk Drive
HIPS	High Impact Polystyrene
HiFi	High Fidelity
HW	Hazardous Waste
IC	Integrated Circuit (Microprocessor)
ICT	Information and Communication Technologies
LCD	Liquid Crystal Display
Li-Ion	Lithium-ion battery
LME	London Metal Exchange
MCV	Maximum Concentration Value
NIC	Network Interface Card
NiMH	Nickel-Metal Hydride battery
OPC	Organic Photoconductor
PC	Personal Computer
PCB	Polychlorinated Biphenyl
PIC	Plastic Recycling Code
PP	Polypropylene

ppm	parts per million
PS	Polystyrene
PVC	Polyvinyl Chloride
PWB	Printed Wiring Board
RAM	Random Access Memory
RoHS	Restriction of Hazardous Substances (in EEE)
TV	Television
UPS	Uninterruptable Power Supply
WEEE	Waste Electrical and Electronic Equipment
w%	weight-percent

PART A – BASICS

1 General Information

1.1 Introduction

The present guidebook on manual dismantling describes and illustrates how IT appliances can recycled through manual dismantling. it contains of 3 parts:

A) Basics: Required tools and equipment are introduced.

B) Dismantling: Required steps for dismantling of the selected IT-appliances are described and illustrated through photos. Necessary health & safety precautions are headed.

C) Downstream processes: Output fractions produced by dismantling are specified. Necessary precautions for storage and adequate destinations for recovery versus environmental disposal are headed.

End-of-life IT appliances like desktop computers, laptops or printers are part of a waste stream called e-waste or WEEE (Waste electrical and electronic equipment) which comprises various forms of electric and electronic equipment that have ceased to be of any value to their owners. The categories according to the EU WEEE Directive are listed in the following table.

Table 1. WEEE categories according to the EU directive on WEEE

No.	Category	Label
1	Large household appliances	Large HH
2	Small household appliances	Small HH
3	IT and telecommunications equipment	ICT
4	Consumer equipment	CE
5	Lighting equipment	Lighting
6	Electrical and electronic tools (with the exception of large-scale stationary industrial tools)	E & E tools
7	Toys, leisure and sports equipment	Toys
8	Medical devices (with the exception of all implanted and infected products)	Medical equipment
9	Monitoring and control instruments	M & C
10	Automatic dispensers	Dispensers

When e-waste is disposed of or recycled without any controls, there are predictable negative impacts on the environment and human health. E-waste contains more than 1,000 different substances, many of which are toxic, such as lead, mercury, arsenic, cadmium, selenium, hexavalent chromium, and flame retardants that create dioxin emissions when burned. These toxins can cause a variety of ailments, ranging from allergic reactions to brain damage and cancer.

Therefore safe and environmental sound e-waste recycling requires certain pre-treatment steps, where components containing hazardous substances are removed and recyclable materials are separated into fractions, from which secondary raw materials can be recovered without material losses.

Dismantling is the recycling technique, that leads to the highest recovery rates in the subsequent recycling and recovery steps. Dismantling of WEEE normally comprises the following main dismantling steps:

- Opening of the appliance (separation of the housing from the rest of the appliance)
- Localization, identification and removal of hazardous components
- Dismantling and separation of the remaining components into marketable fractions

For the dismantling of CRTs, aeration of the CRT-tube has to be included as an additional dismantling step to avoid implosion.

Some of the fractions produced by manual dismantling like ferrous metals, aluminium or copper can be destined directly to material recovery like smelters. The main part of the output fractions have to undergo further mechanical recycling processes like shredding, mechanical separation and so on before being supplied to recovery processes. Some of the fractions have to disposed as hazardous waste.

Depending on the available subsequent mechanical recycling facilities in the region and on the specific personal costs in the region different dismantling levels should be applied. The main dismantling concepts are headed below:

A) Hazardous components and high valuable components, like printed circuit boards are removed only and the remaining parts are destined to mechanical separation/ recycling.

B) Apart from removing hazardous components manual dismantling of components into more or less pure materials and recyclable fractions is conducted where viable with reasonable effort.

C) Appliances are dismantled up to a point, at which further separation into pure materials is not possible without mechanical shredding.

1.2 Tools & Personal Protection Equipment

1.2.1 Tools

Tools should be chosen very carefully. It is worth acquiring high quality products as the tools are exposed to heavy duty.

T1 

Screw drivers are the most used tools. Considering all different appliances, all different sizes and shapes (flat, torx, star etc.) are required. For dismantling hard drives e.g. very small star screw drivers are needed.

T2 

Beside opening screws, a **flat screw driver** can be used to release labels, rubber mountains etc. from plastics surfaces and open small casings (e.g. mice).

T3 

A **hammer** is used e.g. to crash the magnetic deflector in a CRT monitor. The back side of the hammer can be used to open glued casings.

T4 

A **side cutter** is required wherever the scissors is not strong enough, e.g. to cut off power cables

T5 

Pliers are applied very frequently to remove components that are glued.

T6 

Strong **industrial scissors** are mainly used to cut cables and wires.

T7 

A **cutter** is applied in various situations, e.g. to peel the thick cable in the CRT monitor, remove foreign material etc.

T8

A **Power Screw Driver** can be applied wherever screws are freely accessible. An investments in automatic screw drivers is worth it as it considerably saves time.

T9

A strong **industrial scale** is required to quantify the recovered material. It should at least range up to 200 kg.

T10

A **putty knife** is used to clean surfaces from stickers and other adhesive residues (e.g. CRT).

T11

A **small axe** (or a hammer) is used to remove the electron gun from the CRT.

1.2.2 Personal Protection Equipment

For the remanufacturing of electronic equipment, the following personal protection equipment is required.

P1 

Robust gloves protect the labourer from cutting his hands by sharp objects or splints. Optimal gloves are tight so that the labourer is not handicapped in executing his work.

P2 

Protective goggles should be worn whenever the hammer is applied or while removing cartridges and toners from printers.

P3 

Dust masks should be worn while equalising the pressure in the CRT monitor, while cutting the CRT tube and while handling with the printer.

P4 

Protective shoes contain steel bars and protect the worker in case of heavy components drop.

P5 

Aprons are robust and easy to clean.

PART B – DISMANTLING

2 Dismantling Computer Appliances

2.1 Computer & Laptop

DS 1 Computer


[1]

Material recovered:

Cables & Wires, → see following Data sheets

Hazardous Materials:

→ see following Data sheets

Tools:

T4, T6

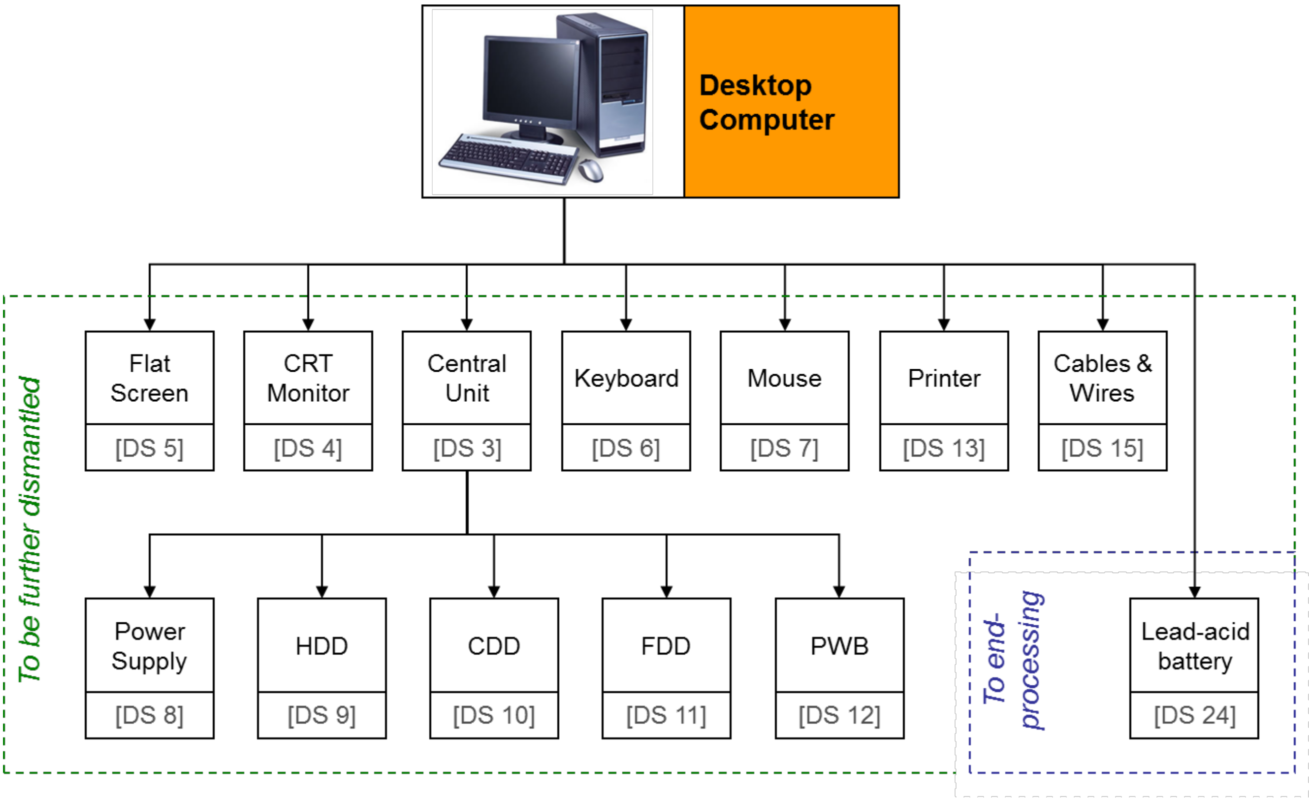
Personal protection equipment:

P1, P4, P5

General Context

The design and the size of a PC set varies significantly, but usually the core components of a PC set are the same: a central unit (CU), a monitor, a keyboard and a mouse. Additionally, a printer and other peripherals like cameras, headsets and loudspeaker may be connected to the PC set. In order to dismantle the respective components in an efficient way, it's recommendable to separate the components and dismantle them in their adequate disassembly line.

Flow Chart



Dismantling Process

Disconnect and separate the different components and dismantle them in their adequate disassembly line (see flowchart). Remove all cables and treat them as described on [DS 15: Cables & Wires]. Should the computer be powered by a large lead-acid battery, separate it from the rest and go on with [DS 24: Lead-acid battery].

Health & Safety

It should be ensured that the different components, particularly the monitor, are not broken or damaged. Personal protection equipment like gloves, apron and robust shoes should be worn.

DS 2 Laptop

[5]

Material recovered:

Cables and Wires, Aluminium, Steel, Plastics, Metal-Plastics Mix, PWBs

Hazardous material:

Battery

Tools:

T1, T2, T4, T5, T6, T7, T8, T9

Personal protection equipment:

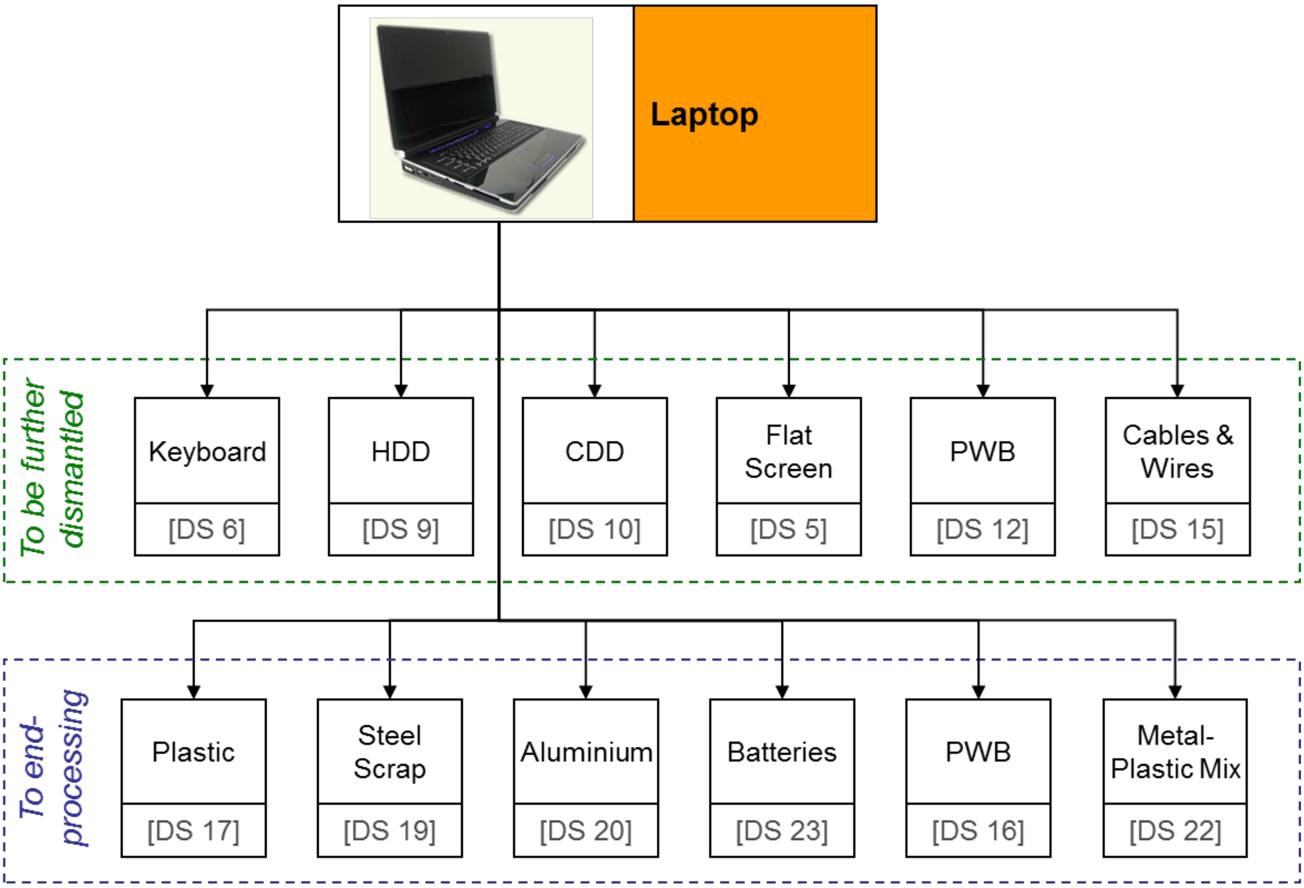
P1, P4, P5

General Context

A large variety of different laptop models exist and disassembly steps can thus vary a lot according to brand and model. A laptop usually consists of the following subcomponents: LCD screen, hard disk drive, battery, PWBs, compact disk drive, cables, keyboard, etc. To separate the subcomponents of a laptop computer can be tricky and laborious.

Dismantling of subcomponents (see chapter 2.3) does not always make sense as it is highly labor-intensive and can be processed by appropriate industries. However, the removal of hazardous substances (e.g. capacitors on PWBs) is required.

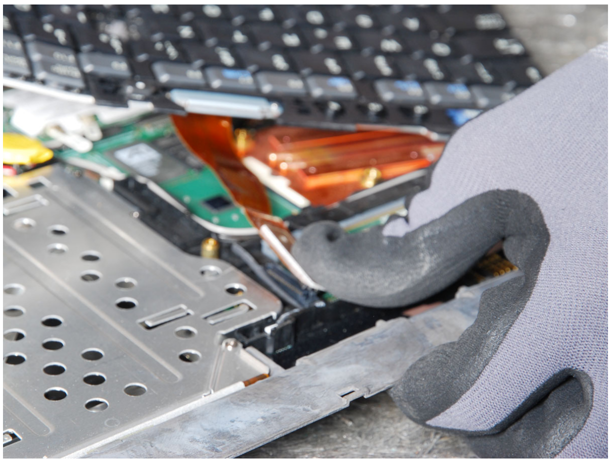
Flowchart

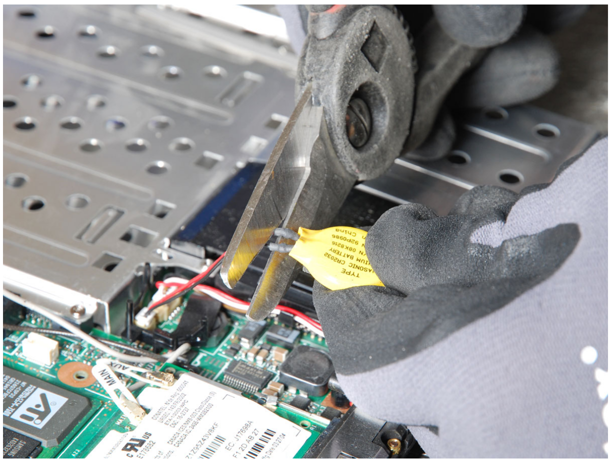
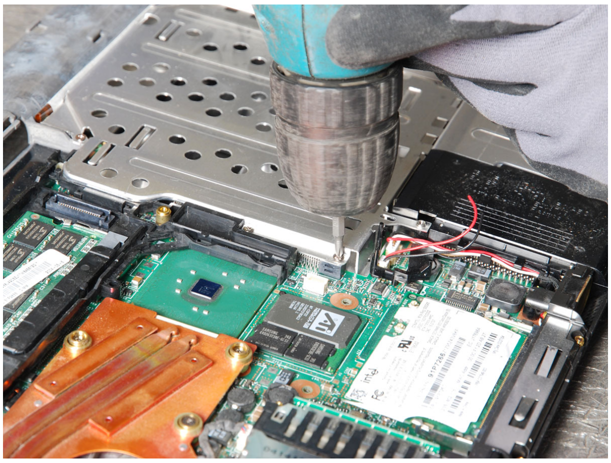


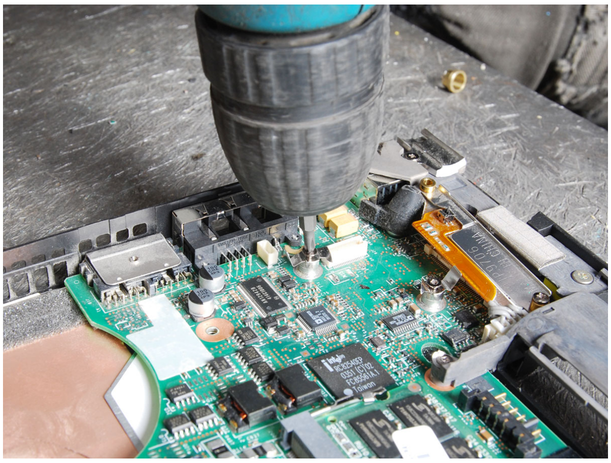
Dismantling Process

Note: As the construction of laptops can differ a lot, the dismantling steps mentioned below can vary in its order. However, the described steps show what parts the removal should focus on.

1	Remove the battery. Usually, no tools are needed to remove it. Go on with [DS 23 Battery]. Remove all cards on the bottom (memory module, wireless card, modem card, etc.). Go on along instructions on [DS 12 PWB Dismantling] or [DS 16 PWB End-Processing].	

2	Remove all drives (HDD, CDD, etc.). If you cannot find the HDD, it is hidden most likely under the keyboard or under the top cover assembly. If you cannot find securing screws for the optical drive on the bottom, they are most likely under the keyboard. Go on with [DS 9: HDD] and [DS 10: CDD].	
3	Remove all screws on the bottom of the laptop.	
4	Remove the keyboard securing strip and remove the keyboard. Go on with [DS 6: Keyboard].	

5	Remove the battery. Go on with [DS 23: Battery]	
6	Remove all screws under the keyboard and cut/disconnect all cables. Go on with [DS 15: Cables & Wires].	
7	Remove all screws securing the display assembly. Lift the LCD display off the base. If this is not possible, break the display off the main body (e.g. by hyper-extending the hinges). Go on along instructions on [DS 5: Flat Screen]. Take care the LCD backlights won't get damaged!	

8	Lift the top cover assembly off the base and put it to the appropriate fraction (e.g. [DS 20: Aluminium], [DS 17: Plastics]).	
9	Remove all screws securing the system board, the power board, the video board, etc. Disconnect all cables, connecting the boards. Go on with [DS 12: PWB – Dismantling].	
10	Remove all boards and remove the CPU (motherboard). Go on with [DS 12: PWB – Dismantling].	

11	Separate the remaining materials according to their type and go on with the appropriate data sheet (e.g. aluminium, ferrous metals, plastic, further PWBs, etc.). Make sure the plastic parts are completely free of metal pieces.	

Health & Safety

The critical step when disassembling a laptop is the removal of the cold cathode fluorescent lamps (CCFL). Avoid the damage of the CCFL during the removal of the LCD screen from the laptop body. Once the CCFLs are separated, they must immediately be put into an adequate recipient (see [DS 29: CCFL]). As these lamps contain mercury, wearing an appropriate mask is recommended.

Composition

In average, a laptop weighs 3.5 kg. Depending on brand and model, the dismantling time of a laptop may vary a lot and may take up to 30 min. The following graph shows the share by weight of the recoverable material.

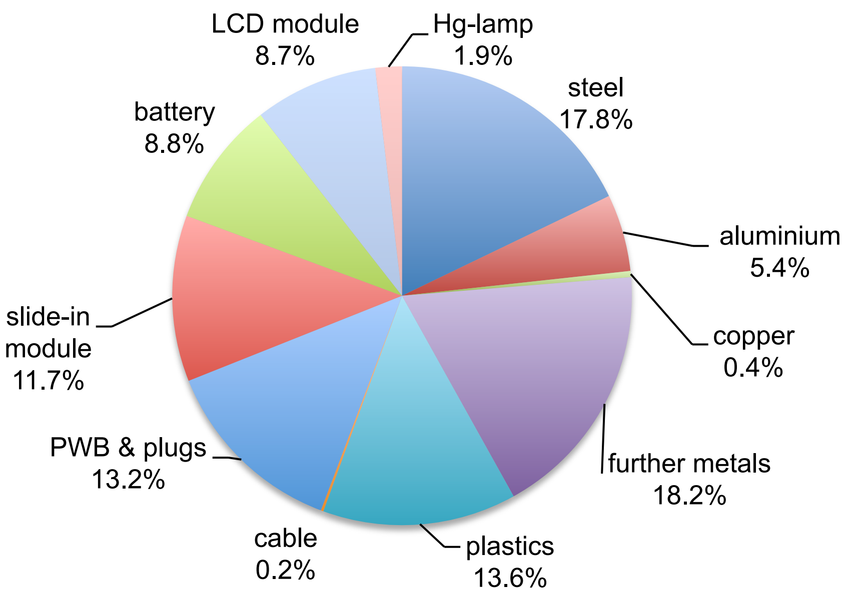


Figure 1. Composition of a laptop (ecoinvent 2010).

2.2 Primary components

DS 3 Central Unit CU

[1]

Previous dismantling steps:

DS 1

Following dismantling steps:

DS 8, DS 9, DS 10, DS 11, DS 12, DS 15

Material recovered:

Cables and Wires, Aluminium, Steel, Plastics, PWBs

Hazardous materials:

Batteries on PWBs

Tools:

T1, T2, T4, T5, T6, T7, T8, T9

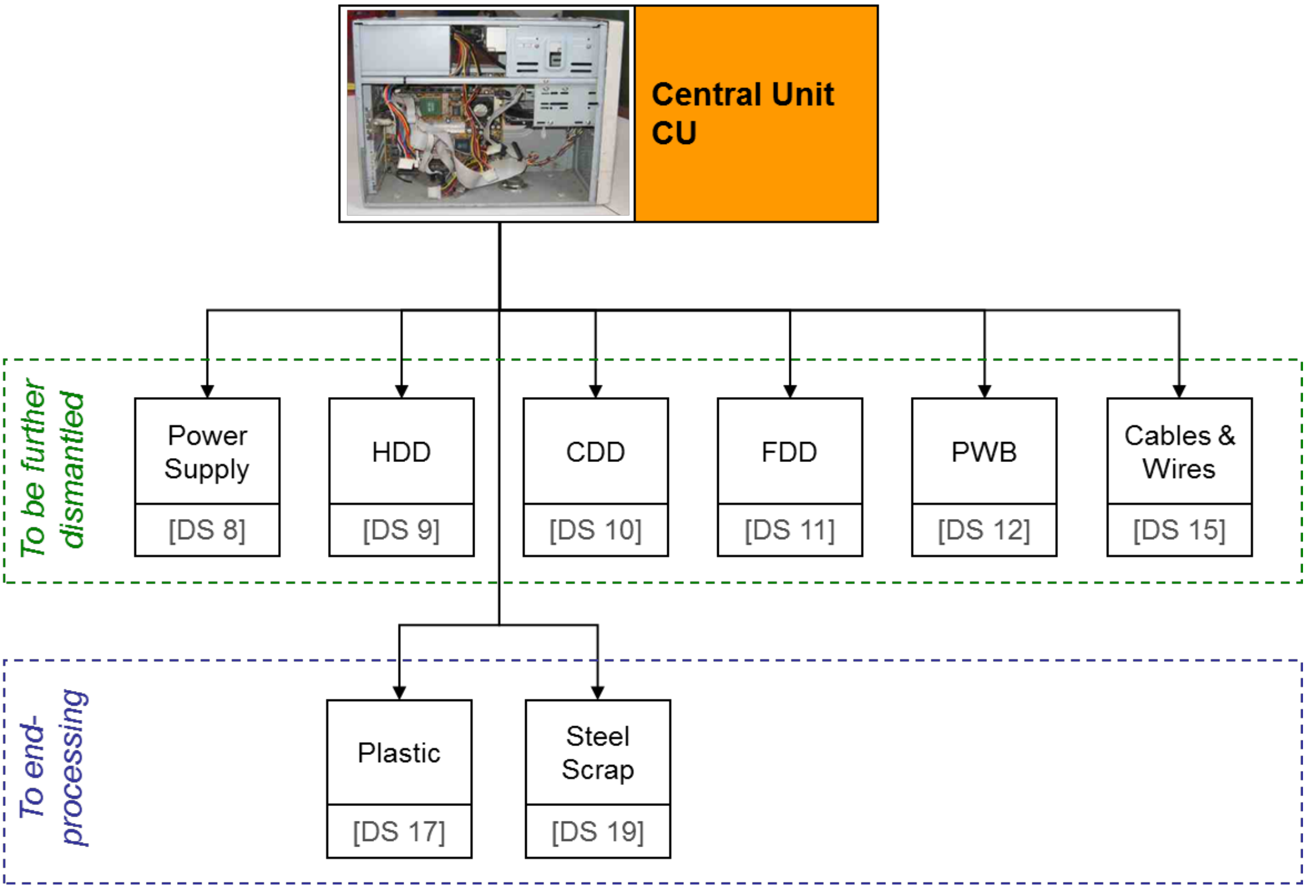
Personal protection equipment:

P1, P4, P5

General Context

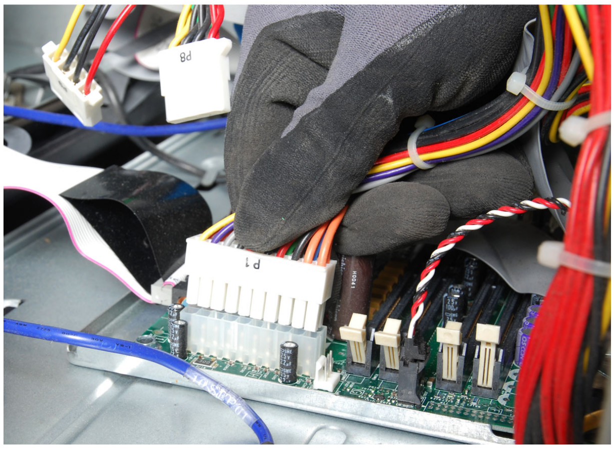
A Central Unit (CU) generally consists of a steel or plastic case, several subcomponents like hard drive, CD ROM, power supply, printed wiring boards (PWB) and cables. Dismantling of subcomponents (see chapter 2.3) does not always make sense as it is highly labor-intensive and can be processed by appropriate industries. However, the removal of hazardous substances (e.g. batteries on PWBs) is required.

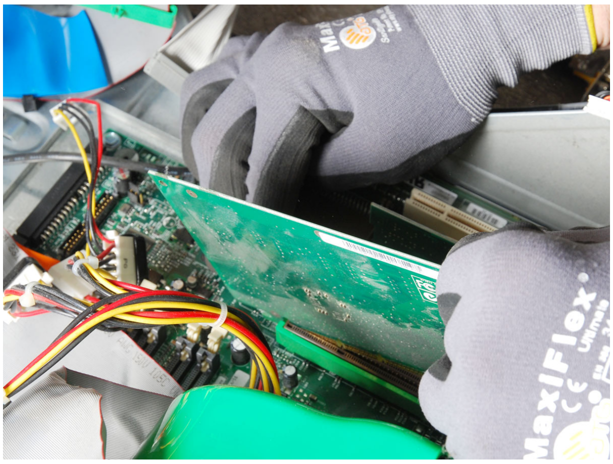
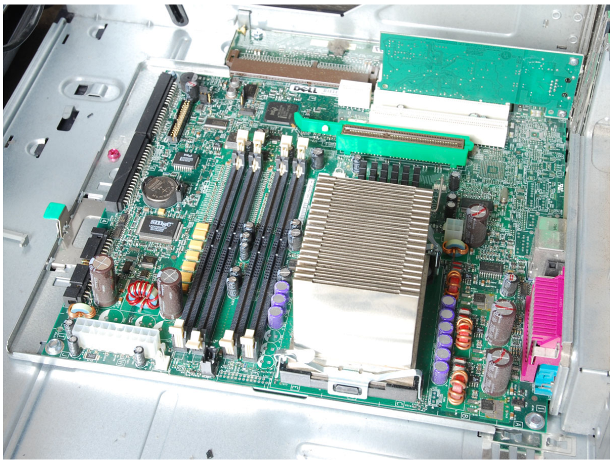
Flowchart



Dismantling Process

1	Remove the CU casing to get access to the internal components by unscrewing all screws. Use an automatic screw driver where applicable to save time. Put the cover aside.	

2	Now remove the screws holding the internal components to be able to remove them all. Unplug all the cables and wires by pulling them straight out or releasing them by applying pressure to the clip in case they have a locking clip.	
3	Once all wires and cables have been disconnected the drives (floppy drive, CD drive and hard disk drive, etc.) can be removed. Also remove the power supply. Go along with [DS 8: Power Supply], [DS 9: Hard Disk Drive HDD], [DS 10: Compact Disk Drive CDD] and [DS 11: Floppy Disk Drive FDD].	 

4	To remove the motherboard it is necessary to remove all other components first from the computer case. Along with the motherboard all other PWBs can be removed and treated according to [DS 12: PWB - Dismantling]. The number of mounting screws attaching the motherboard to the case will vary from 3-10 depending upon design. Some will be held in place with plastic clips rather than screws. For removal of plastic clips, simply pry them off with a screwdriver. The motherboard contains some components that can be removed such as RAM, Cmos battery[1], NIC (network interface card) and the CPU (central processing unit). For details, see the instructions on [DS 12: PWB - Dismantling]. Put any batteries in a separate box for adequate disposal! [DS 23: Battery]	 

[1] Cmos battery (also: non-volatile BIOS memory) refers to a small memory on PC motherboards that is used to store BIOS settings (Wikipedia 2012a).

[2] OLEDs are thin sheets of glass or plastic foils on which organic polymer compounds are printed by inkjet technology. OLEDs are

5	After removing the motherboard, the casing should be completely blank. Segregate and clean the different materials and go on with the respective data sheet ([DS 20: Aluminium], [DS 19: Ferrous Metals], [DS 17: Plastics]).	
		
6	Separate the remaining materials according to their type and go on with the appropriate data sheet (e.g. aluminium, ferrous metals, plastic, further PWBs, etc.). Make sure the plastic parts are completely free of metal pieces.	

Health & Safety

Demanufacturing a CU is relatively harmless. Although there are no critical working processes involved personal protection equipment like gloves, apron and robust shoes should be worn.

Composition

A Central Unit in average weighs 10 kg and takes 10-20 minutes to dismantle (dismantling of subcomponents excluded). The following graph shows the share by weight of the recoverable material.

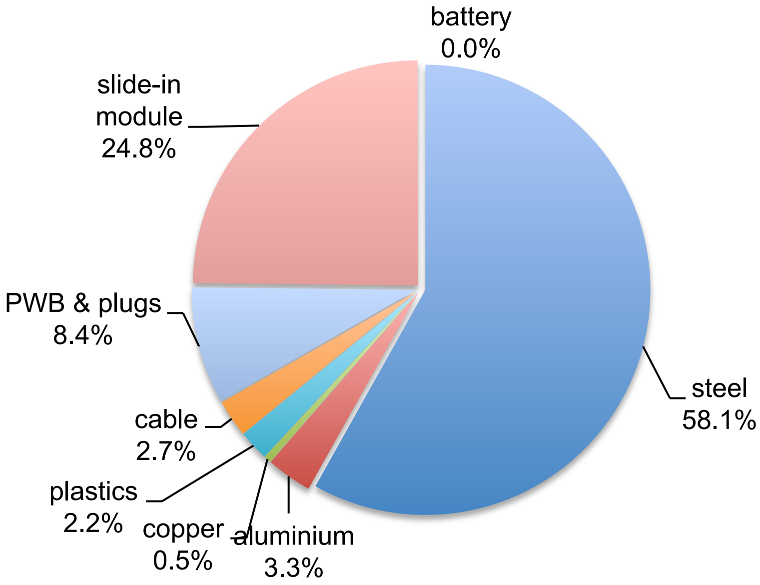


Figure 2. Material composition of a central unit (ecoinvent 2010).

DS 4 CRT Monitor

[1]

Previous dismantling steps:

DS 1

Following dismantling steps:

DS 12, DS 15

Material recovered:

Copper, Plastics (ABS/PC), Aluminium, Metal Mix, Mixed Scrap, Wiring and Cords, PWBs

Hazardous substances:

Leaded glass, phosphor layer, PWBs

Tools:

T1, T2, T3, T4, T5, T6, T8, T9, T10, cutting device for CRT glass separation

Personal protection equipment:

P1, P2, P4, P5

General Context

A CRT monitor consists of a plastic case (ABS/PC), a cathode ray tube (CRT) with an attached magnetic deflector and electron gun, printed wiring boards (PWB) and cables (see Figure 3). The CRT glass contains a large amount of lead which may be released when it brakes. Therefore it is crucial to only conduct dismantling operations on monitors in adequate facilities. Further processing of CRT glass should only happen in industrial channels that have adequate facilities.

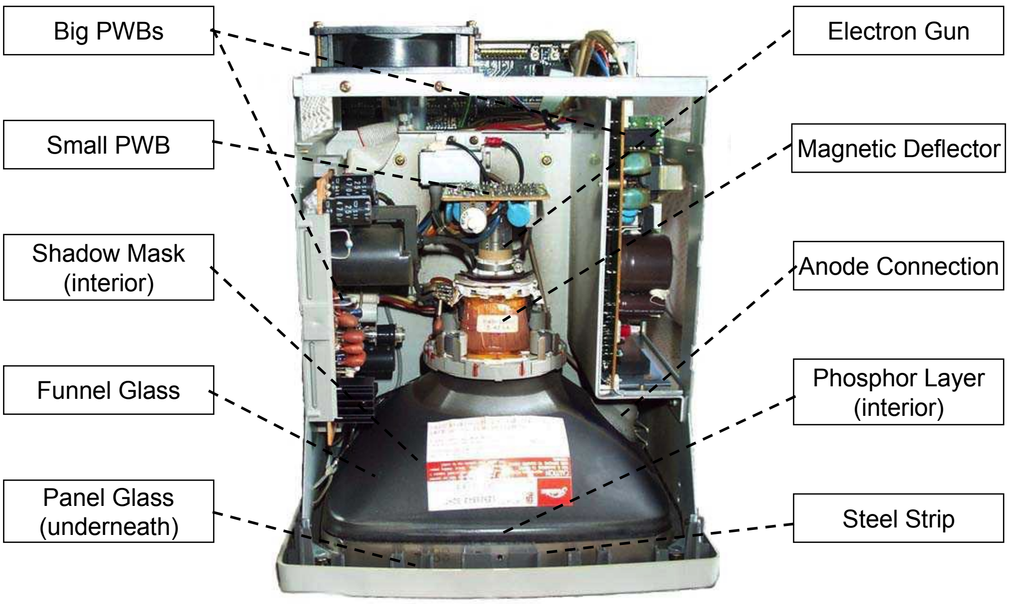
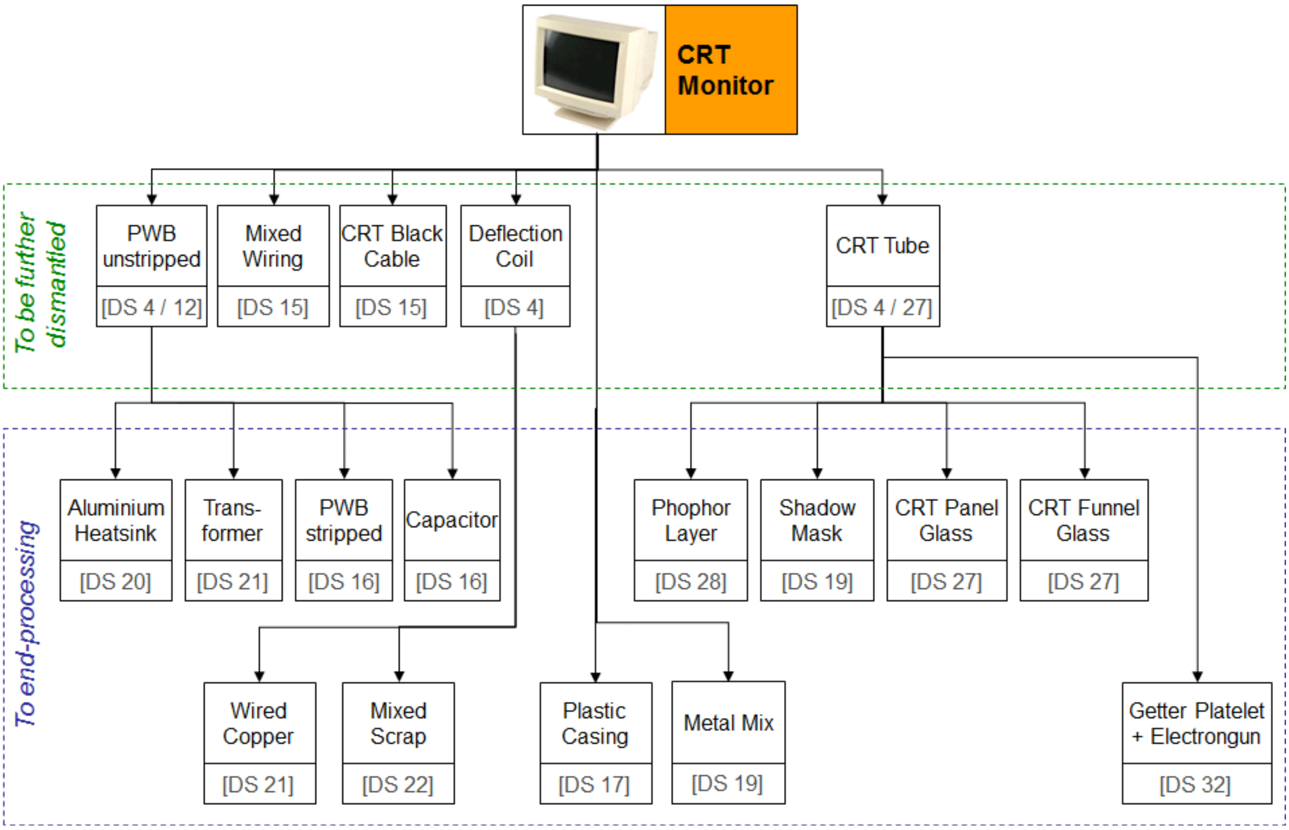


Figure 3. Components of a CRT monitor.

Flowchart

Dismantling a monitor along the principles introduced below takes **approximately 30 minutes**.



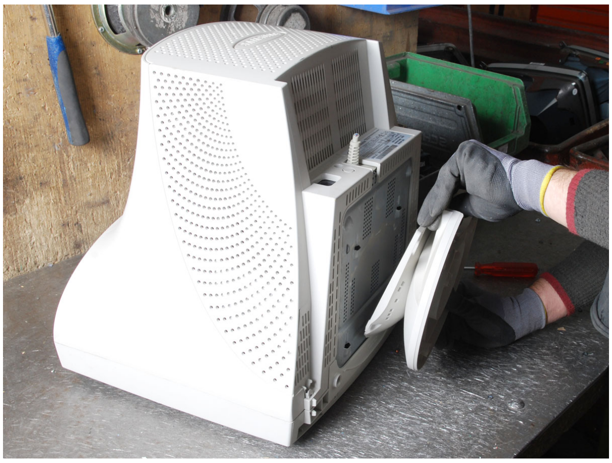
Dismantling process

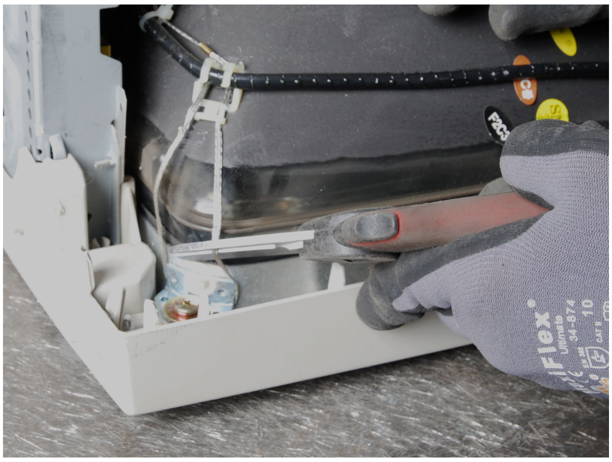
The dismantling of a CRT monitor is mainly done in two major steps:

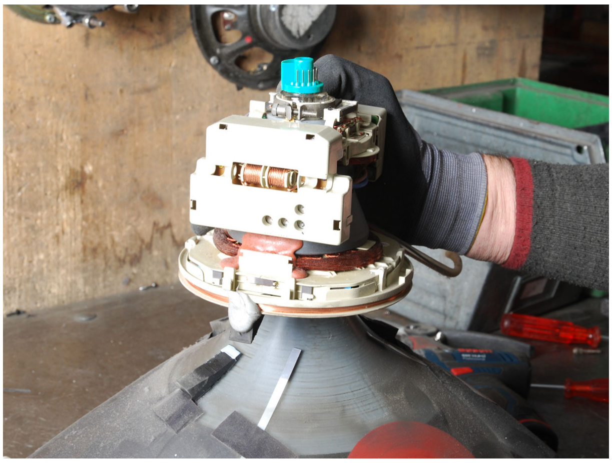
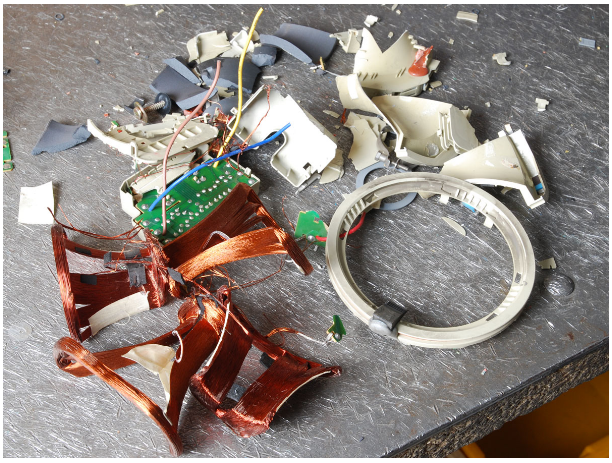
1. Separation & removal of all components from the cathode ray tube (part 1, CRT monitor)

2. Separation of funnel & panel glass, removal of phosphor layer and shadow mask (part 2, cathode ray tube)

Part 1: CRT monitor dismantling

1	Before doing anything the monitor has to be placed face down to protect the monitor screen from breaking.	
2	Remove the plastic casing by unscrewing all the screws in the cover (generally around 4). Clean the casing properly by removing all the foreign materials in the plastic such as labels, rubber mountains etc. and go on with [DS 17 Plastics].	
3	Before removing other parts from the monitor it is crucial to equalize pressure in the CRT glass body. Therefore place the side of the monitor screen with the flap (anode connection) away from your face. Remove the flap in the monitor screen with a flat screw driver and punch carefully a hole into the CRT glass where the flap was fixed.	

⚠	Equalize the pressure carefully and wear protective equipment! As the CRT body is under vacuum this dismantling step has to completed before further treatment steps to avoid possible implosion of the CRT body.	
4	Remove the cable ties around the wires, so that you can freely remove the **wires** from the monitor. Go on with [DS 15: Cables & Wires].	
5	There are generally two **Printed Wiring Boards (PWB)** in a monitor. A small PWB is attached at the base of the monitor screen by glue or a screw. A bigger PWB is attached at the back. For further processing of both PWBs, go on with [DS 12: PWB – Dismantling]. Particularly the bigger PWBs might need further dismantling.	

6	Cut off all the **wires** [DS 15: Cables & Wires] around the monitor to be able to remove the **magnetic deflector** (on top of the CRT glass) that is surrounded by copper windings. Remove the magnetic deflector carefully to avoid that the electron gun on top of the CRT gets destroyed.	
7	Remove the copper from the Magnetic Deflector by crashing it with a hammer. Strip the big wire around the monitor screen with a knife or side cutter and remove the copper [DS 15: Cables & Wires]. Clean the copper, plastic and steel and place it aside separately. Wear protective equipment. Especially goggles and gloves are crucial as splints can injure arms, hands and eyes.	 

<table>
<tr><td>8

⚠</td><td>Unscrew the CRT glass from the front plastic casing [DS 17: Plastics] and break off the electron gun from the tube with a hammer or a small axe just below the gun [DS 19: Getter Platelet + Electrogun].
Be careful so that only the glass just below the electron gun breaks (and not the complete funnel glass)!</td><td></td></tr>
<tr><td>9</td><td>Separate the remaining materials according to their type and go on with the appropriate data sheet (e.g. aluminium, ferrous metals, plastic, further PWBs, etc.).
Make sure the plastic parts are completely free of metal pieces.</td><td></td></tr>
<tr><td colspan="3">Depending on the further treatment of the cathode ray tube, it is:
1. ready for further treatment in an adequate plant. Store it properly and go on with [DS 27: CRT].
2. cut into panel and funnel glass before it is passed on to further treatment. To do so, follow the instructions below [DS 4: CRT Monitor – Part 2: CRT glass separation].</td></tr>
</table>

Part 2: CRT glass separation

According to the requirements of the company receiving the glass fraction, a separation of the panel and funnel glass (see Figure 4) might be inevitable. Different approaches are currently applied to demanufacture cathode ray tubes. Either the panel glass is separated from the funnel glass before or after crushing the glass. Separation of panel glass and funnel glass before crushing is described below. Further information on this separation step can be found in [DS 27: CRT].

Separation of panel and funnel glass before crushing

Firstly, the metal tension ring must be removed from the tube. Panel and funnel glass are separated by means of either diamond cutting technology or a heating wire, which is placed along the intersection between panel and funnel glass. Thereafter the funnel glass is suction cleaned from iron-oxide and graphite coating foam and the phosphor layer is removed from the panel glass. For transportation to end-processing, it is possibly more effective to crush the panel and funnel glass separately. While crushing the CRT glass, inhalation of the generated dust should be avoided.

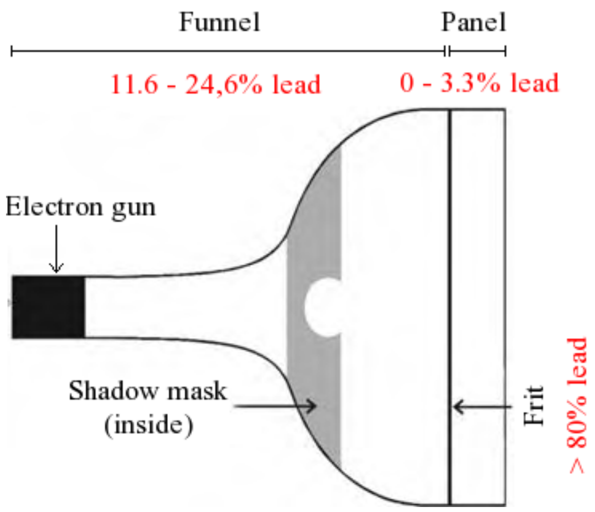
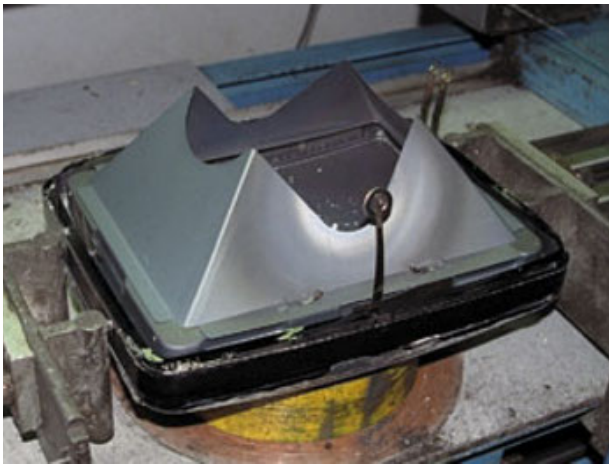


Figure 4. Lead contents in a CRT ([6], modified)

1 ⚠	Before starting to separate funnel and panel glass, make sure the CRT is **not under pressure anymore**. Place the CRT firmly in a clamp or a similar device. First, remove sticker and other adhesive residues from the tube with a putty knife.	 **[9]**
2 ⚠	The glasses are then separated along the frit by means of a hot wire or laser-cutter. If possible, avoid dust formation. Use a fume hood to minimize worker exposition.	**[3]** 

3	Store the funnel glass in a segregated box. Go on with [DS 27: CRT].	 **[4]**
4	Remove the shadow mask and place it aside separately together with the ferrous metals. Go on with [DS 19: Ferrous Metals].	 **[3]**
5	Carefully vacuum the phosphor layer on the inner face of the panel glass. Avoid dust formation!	 **[3]**

6	Store the phosphor layer or the vacuum cleaner bag containing it, respectively, separately in a bin with a cover. Go on with [DS 28: Phosphor Layer].	**[3]** 
7	Store the cleaned panel glass in a gaylord box. Go on with [DS 27: CRT].	 **[4]**

Health & Safety

Part 1

To dismantle a CRT monitor, personal protection equipment such as goggles, apron, closed shoes and gloves is crucial as some potentially harmful steps are involved (indicated in the description of the dismantling process).

Here the most critical points are replicated:

⚠ Equalize the pressure in the CRT glass body in the very beginning to prevent explosion.

⚠ Wear protective equipment to smash the magnetic deflector with a hammer as flying splints can injure personnel

⚠ CRTs must be handled carefully also after pressure equalizing to ensure that no substances of concern are released. CRT glass bodies should be further processed only in industrial channels with adequate facilities.

Part 2

The same protection measurements as for part 1 are also a precondition to perform part 2. The most crucial points are:

⚠ Make sure the CRT is not under pressure anymore.

⚠ Wear protective equipment during the CRT dismantling. In particular, dust exposition should be avoided/minimized. During the glass cutting, a fume hood with an air pollution control system has to ensure the removal of any toxic dust. Additionally, a constant provision with fresh air must guarantee good air quality in the facility.

⚠ The glass and the phosphor layer have to be stored adequately, preventing any release of contaminants.

Composition

A CRT monitor in average weighs 14 kg and takes approximately 30 minutes to dismantle. Figure 5 shows the share by weight of the recoverable material. Further information on the lead content of the CRT is provided in Figure 4.

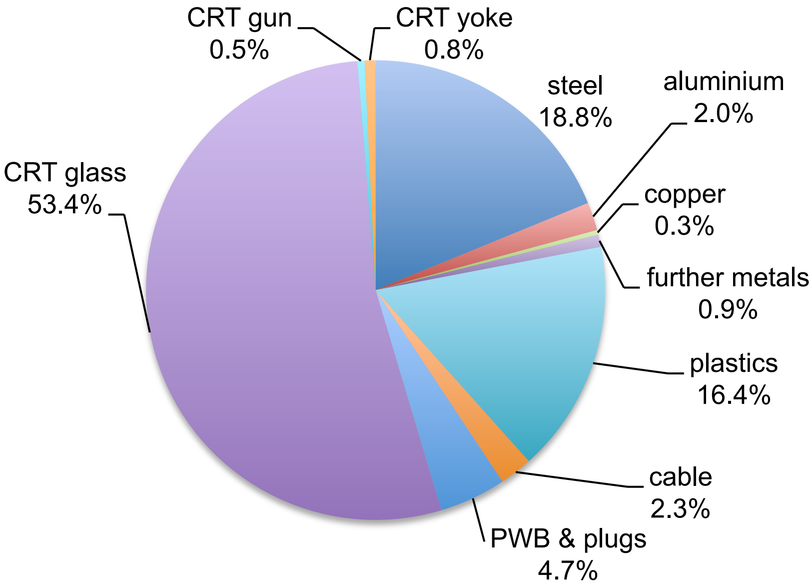


Figure 5. Composition of a CRT monitor (ecoinvent 2010).

Comments

Accounting for more than 50% of the complete material, the CRT tube (which contains lead oxide, see [DS 27: CRT]) is the biggest problem from an environmental and economic perspective. For adequate recycling it is indispensable to supply it to an appropriate treatment.

DS 5 Flat Screen

[1]

Previous dismantling steps:

DS 1

Following dismantling steps:

DS 12, DS 15

Material recovered:

Plastics (ABS/PC), Aluminium, Metal Mix, Mixed Scrap, Wiring and Cords, PWBs, liquid crystal layer

Hazardous material:

LCD backlights (CCFL)

Tools:

T1, T2, T4, T5, T6, T8, T9

Personal protection equipment:

P1, P4, P5

General Context

LCD screens are progressively replacing CRT screens on the market. Flat panel displays consist of a plastic case and a coat of liquid crystal contained between two glass panels and foils covered with conductive materials. Two different illuminants for LCDs exist: cold cathode fluorescent lamps (CCFL) and light emitting diodes (LED). Due to the toxic Hg-content, the CCFLs should be handled and treated with particular precaution.

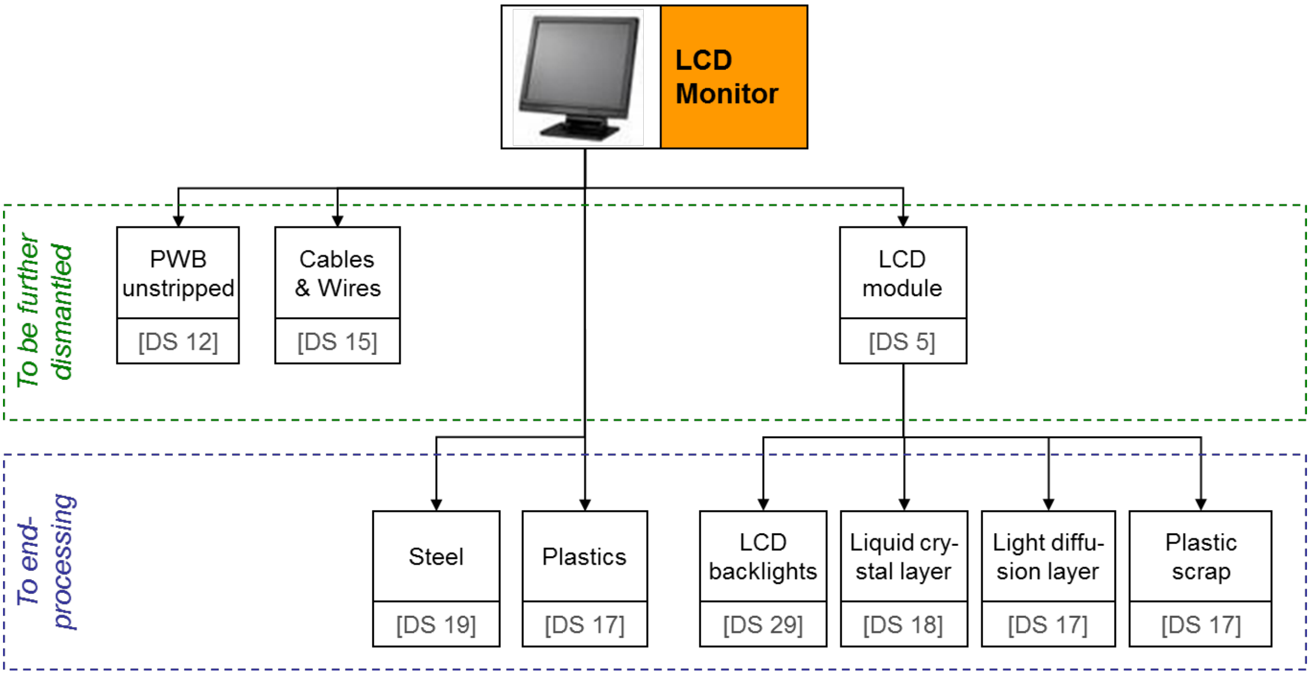
Recently, an increasing number of appliances use the OLED technology[2] (Organic Light Emitting Diode, Organic Light Emitting Diode). It is expected that OLED screens will replace the LCD technology in the coming years.

Material value Although many materials contained in LCD screens are of a high quality (e.g. electronics, highly transparent plastic within LCD module, etc.), there exist only few appropriate recovery technologies to further process them. Thus purchasers have to be selected carefully to be able to operate an economic viable dismantling process for flat screens.

[2] OLEDs are thin sheets of glass or plastic foils on which organic polymer compounds are printed by inkjet technology. OLEDs are stimulated by semiconductor elements to emit light. OLED displays are extremely thin, flexible, and therefore they can be applied in a wide range of applications. For smaller screen sizes and devices with a shorter period of use (e.g. mobile phones, laptops), OLED technology is already being applied successfully.

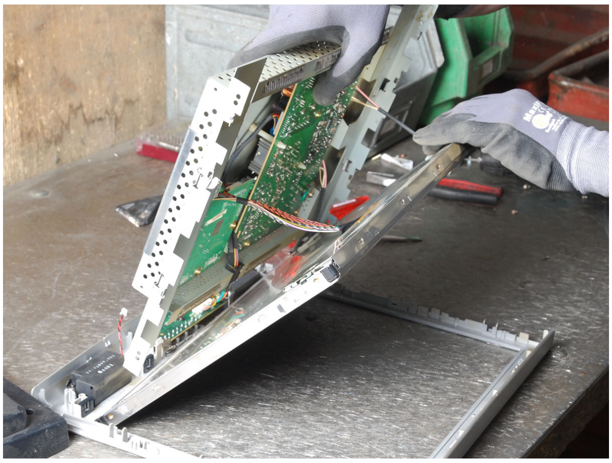
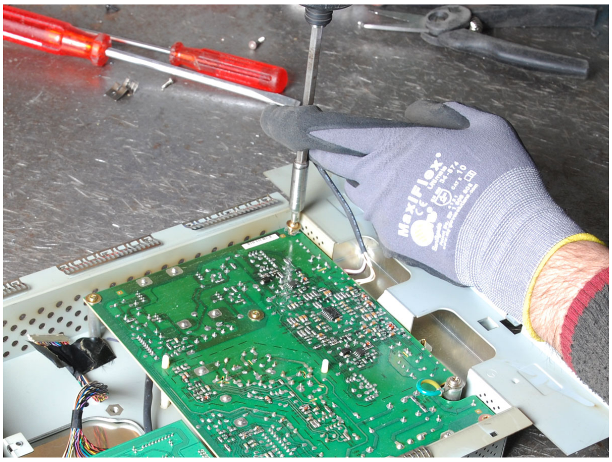
Flowchart

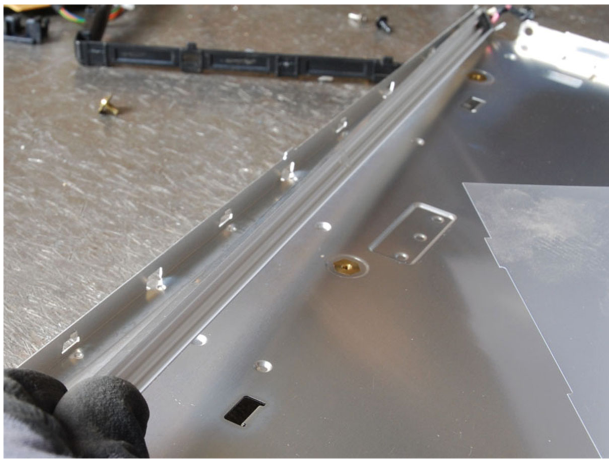
Dismantling a monitor along the principles introduced below takes **15 to 40 minutes**.

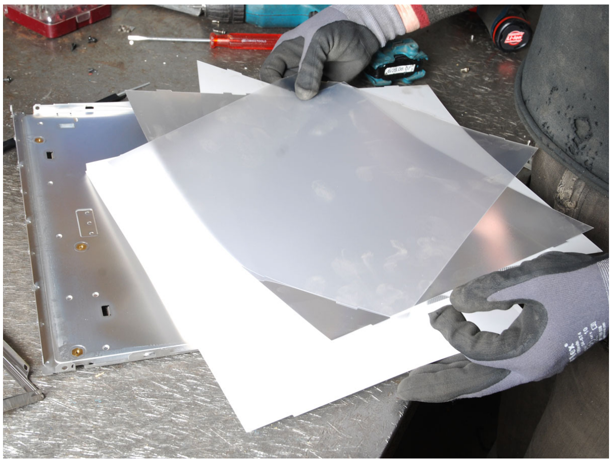


Dismantling Process

1	Before doing anything the monitor has to be placed face down to protect the monitor screen from breaking. Remove the monitor stand and dismantle it. It consists of some steel and plastic elements [DS 17: Plastics] and [DS 19: Ferrous Metals].	
2	Removing the back casing and clean the casing properly by removing all the foreign materials in the plastic such as labels, rubber mountains etc. and go on with [DS 17: Plastics]. LCD casings do not contain flame retardants and are thus adequate for plastic recycling.	

3	Remove the front frame, so that you can freely remove the wires and switches. Go on with [DS 15: Cables & Wires]. Remove the inner back casing by unscrewing all fixing screws to get access to the Printed Wiring Boards (PWBs). Go on with [DS 12: PWBs - Dismantling]. Also cut off all wires and go on with [DS 15: Cables & Wires].	 
4	Remove the steel cover protecting the layers by releasing it with a flat screwdriver (see picture). Check if the LCD is illuminated by CCFLs or by LEDs. • CCFLs => go on with step 5 • LEDs => go on with step 6	

5	The black connection at the bottom left and right indicate where the backlight lamps are attached. Carefully lift and remove the steel cover at this point to avoid the breakage of the lamps [DS 19: Ferrous Metals].	
	Remove the backlights carefully and place them aside [DS 29: CCFL]. Depending on the screen model, the backlights can be removed before or after taking apart the LCD module (see pictures).	
⚠	Avoid the breakage of the backlight as mercury vapour can be released. The lamps should be stored in a closed container which disposes of a mechanism preventing the release of air from the inside at the insertion of further lamps (see [DS 29: CCFL]). If a lamp is broken it should be placed immediately into the container.	

6	Remove the dark liquid crystal layer (foil) [DS 28: Liquid Crystal Layer] and other layers [DS 17: Plastics] to get access to the backlights (see below). Further information about the composition of the transparent light diffusion layer can be found in [DS 17: Plastics].	
7	Separate the remaining materials according to their type and go on with the appropriate data sheet (e.g. aluminium, ferrous metals, plastic, further PWBs, etc.). Make sure the plastic parts are completely free of metal pieces.	

Health & Safety

The critical step in demanufacturing a flat screen monitor is to remove the crystal liquid containing glass and the CCFLs. Often the backlight lamps are already broken due to transportation. As these lamps contain mercury, wearing an appropriate mask is essential.

Composition

A flat screen monitor weighs 6 to 18 kg and takes 15 to 40 minutes (depending on the size of the monitor and the amount of screws to remove) to dismantle. The following Figure 6 shows the share by weight of the recoverable material.

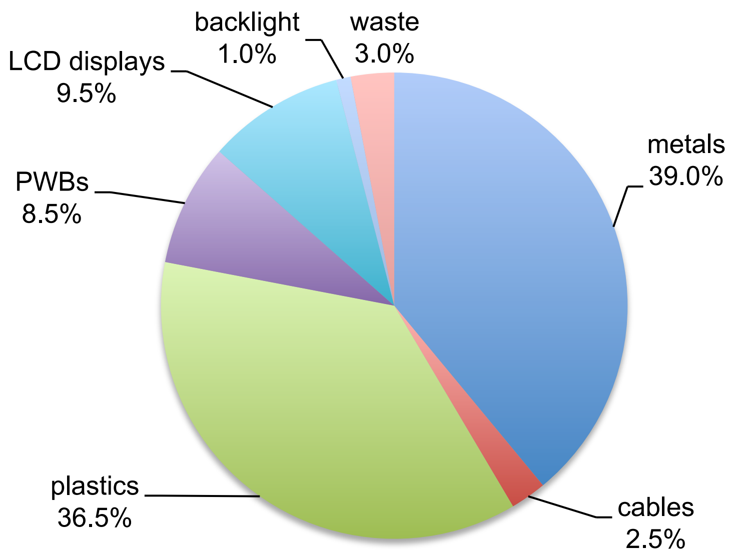


Figure 6. Composition of an LCD monitor (SWICO 2011).

DS 6 Keyboard

[1]

Previous dismantling steps:

DS 1, DS 2

Following dismantling steps:

DS 12, DS 15

Material recovered:

Plastics, Mixed Scrap, Cables and Wires, PWB

Hazardous materials:

Lead in PWB (old keyboards)

Tools:

T1, T2, T4, T5, T9

Personal protection equipment:

P1, P5

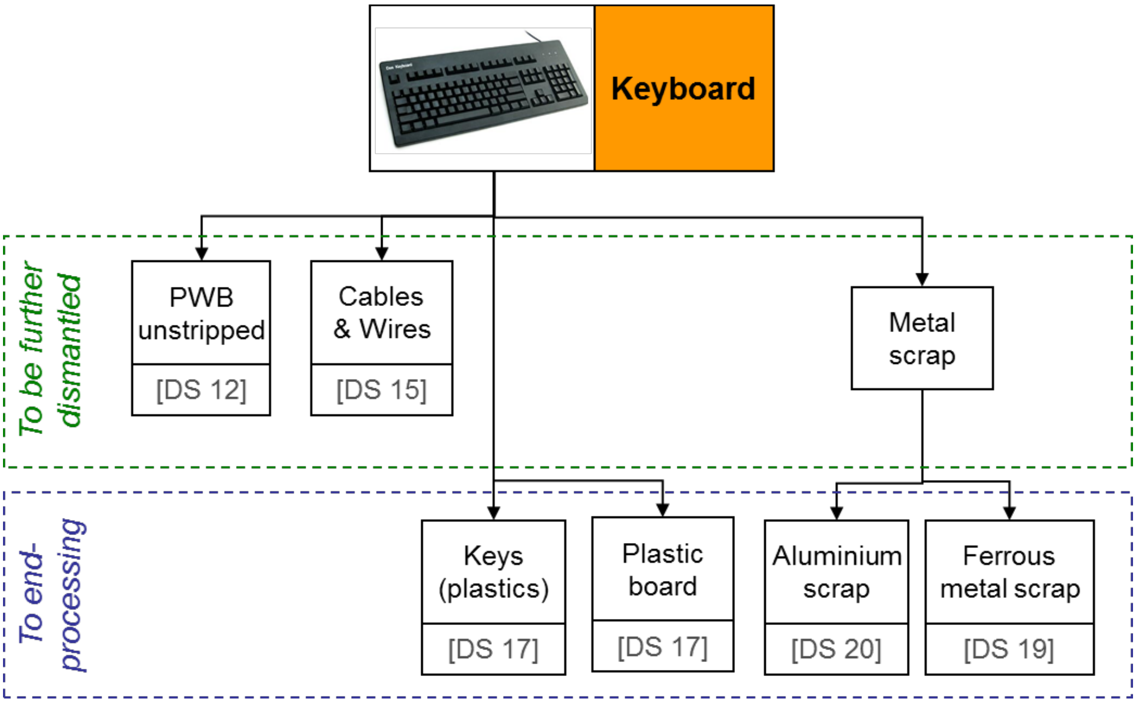
General Context

Keyboards have undergone a significant design development, accordingly their appearance varies a lot. Older keyboards contain a large amount of lead acting as conductor on printed wiring boards. More recent keyboards are much lighter as lead is substituted through lighter materials. They generally consist of a plastic frame and keys (ABS/PC), printed wiring boards (PWB), some cables, and metal scrap.

Keyboards from laptops can be treated the same way as common stand-alone keyboards.

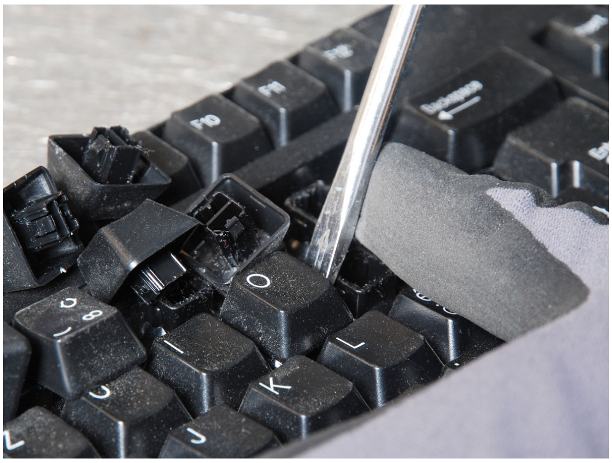
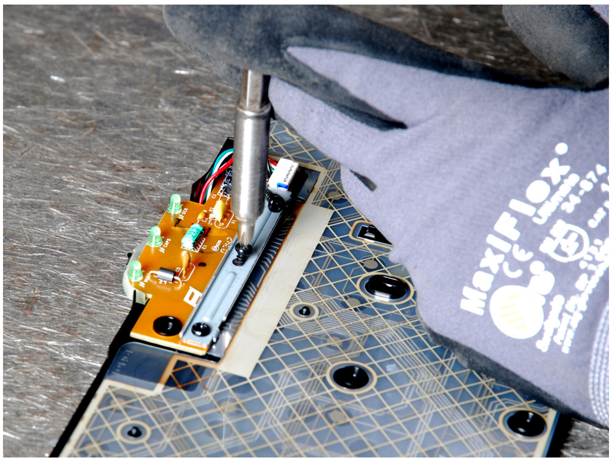
Flowchart

Dismantling a keyboard along the principles introduced below takes **approximately 5 minutes.**.



Dismantling Process

1	Dismantling a keyboard is relatively simple. Firstly, place the keyboard on the table and cut off the power cable if not already done. Go on with [DS 15 Cables & Wires].	

2	Pry the key caps out of their resting places using a small flat screwdriver. Get the screwdriver tip under the key cap first, then lower the handle onto the adjacent key cap so the screwdriver becomes a miniature prying lever. The key caps will snap out of their holders easily. For the plastic key caps, go on with [DS 17 Plastics].	
3 ⚠	Remove the front frame, so that you can freely remove the printed wiring boards [DS 16 PWBs]. Also remove all foreign materials such as labels, rubber mountains, etc. Sometimes steel wires are attached at the inside of the keys. Especially take care to remove all metal pieces as plastic should be perfectly clean for further recycling.	 

4	Separate all materials and introduce them into the adequate treatment. Go on with the appropriate data sheets. Make sure the plastic parts are completely free of metal pieces.	

Health & Safety

Dismantling keyboards is a simple task with no hazardous steps. Only very old keyboards have to be treated carefully as they contain a large amount of lead.

Composition

A **keyboard** weighs 1 to 3 kg and takes about 5 to 10 minutes to dismantle. The following graph shows the share by weight of the recoverable material.

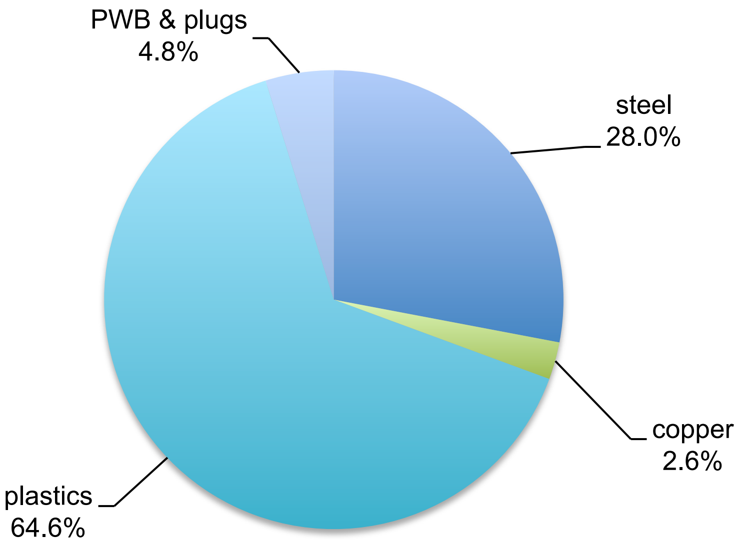


Figure 7. Composition of a keyboard (ecoinvent 2010).

DS 7 Mouse

[1]

Previous dismantling steps:

DS 1

Following dismantling steps:

DS 12, DS 15

Material recovered:

Plastics, Mixed Scrap, Cables and Wires, PWB

Hazardous materials:

-

Tools:

T1, T2, T4, T5, T9

Personal protection equipment:

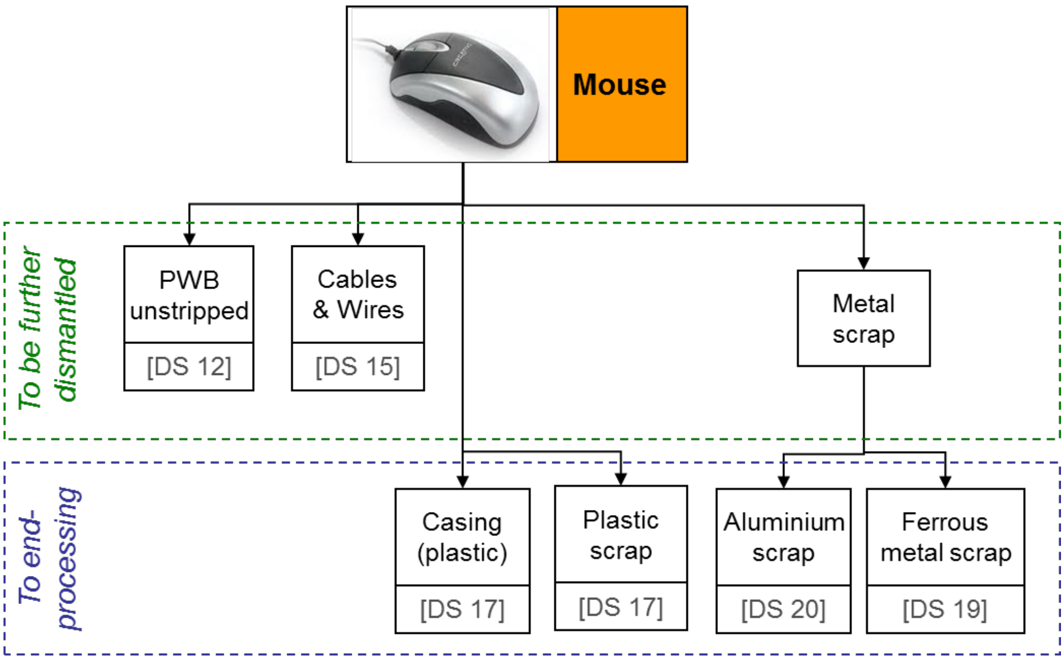
P1, P5

General Context

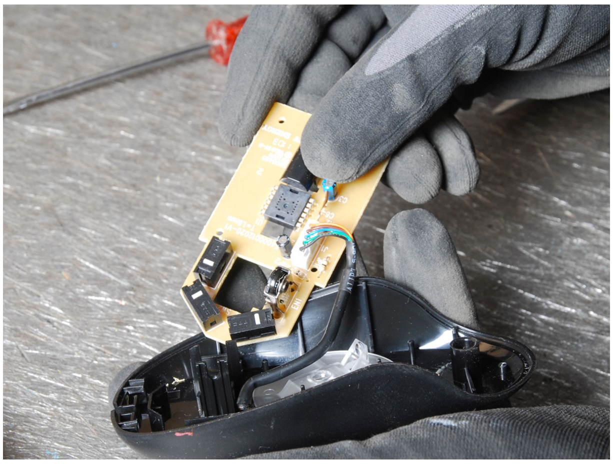
Many different mouse models exist, but commonly its composition is simple, consisting of a cable, a casing, a small PWB and some control elements.

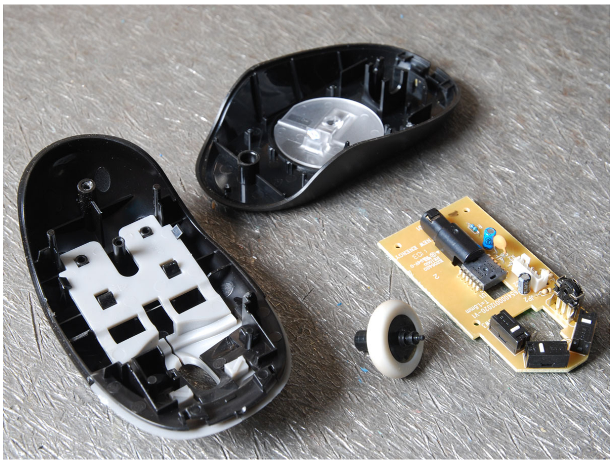
Flowchart

Dismantling a mouse along the principles introduced below takes **approximately 1-3 minutes.**.



Dismantling Process

1	Dismantling a mouse is relatively simple. Firstly, cut the cable off [Go on with DS 15: Cables & Wires]. If the mouse has screws, unscrew them and pry the mouse open (the screws are often located below pads on the bottom). If there are no screws, pry the casing open or break it apart [DS 17: Plastics].	 
2	Remove the printed wiring board and store it separately. Go on with [DS 12: PWBs – dismantling].	

3 ⚠	Separate all materials and introduce them into the adequate treatment. Especially take care to remove all metal pieces as plastic should be perfectly clean for further recycling.	

Health & Safety

Dismantling mice is a simple task with no hazardous steps.

Composition

A mouse generally weighs around 100 grams and takes only one to a few minutes to dismantle. A typical composition of a mouse is shown in Figure 8.

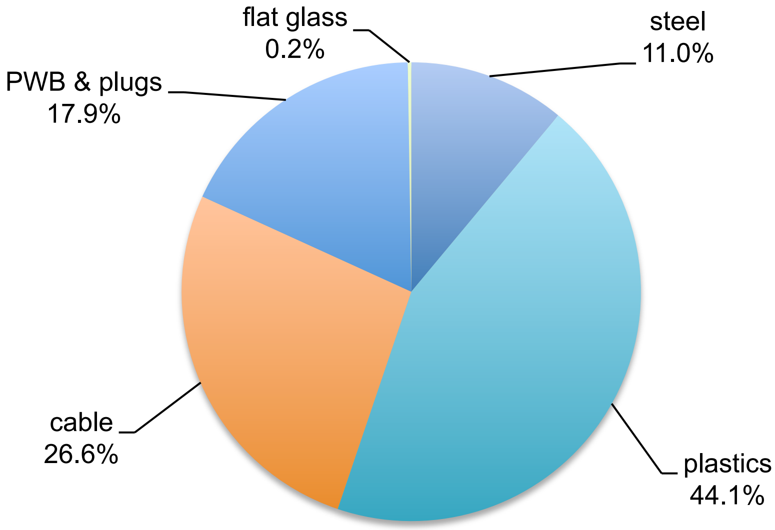


Figure 8. Composition of a mouse (ecoinvent 2010).

2.3 Subcomponents

DS 8 Power Supply

[1]

Previous dismantling steps:

DS 3

Following dismantling steps:

DS 12, DS 15

Material recovered:

Printed Wiring Board, Steel, Aluminium, Copper, Mixed Wiring

Hazardous material:

Capacitors

Tools:

T1, T4, T5, T8, T9

Personal protection equipment:

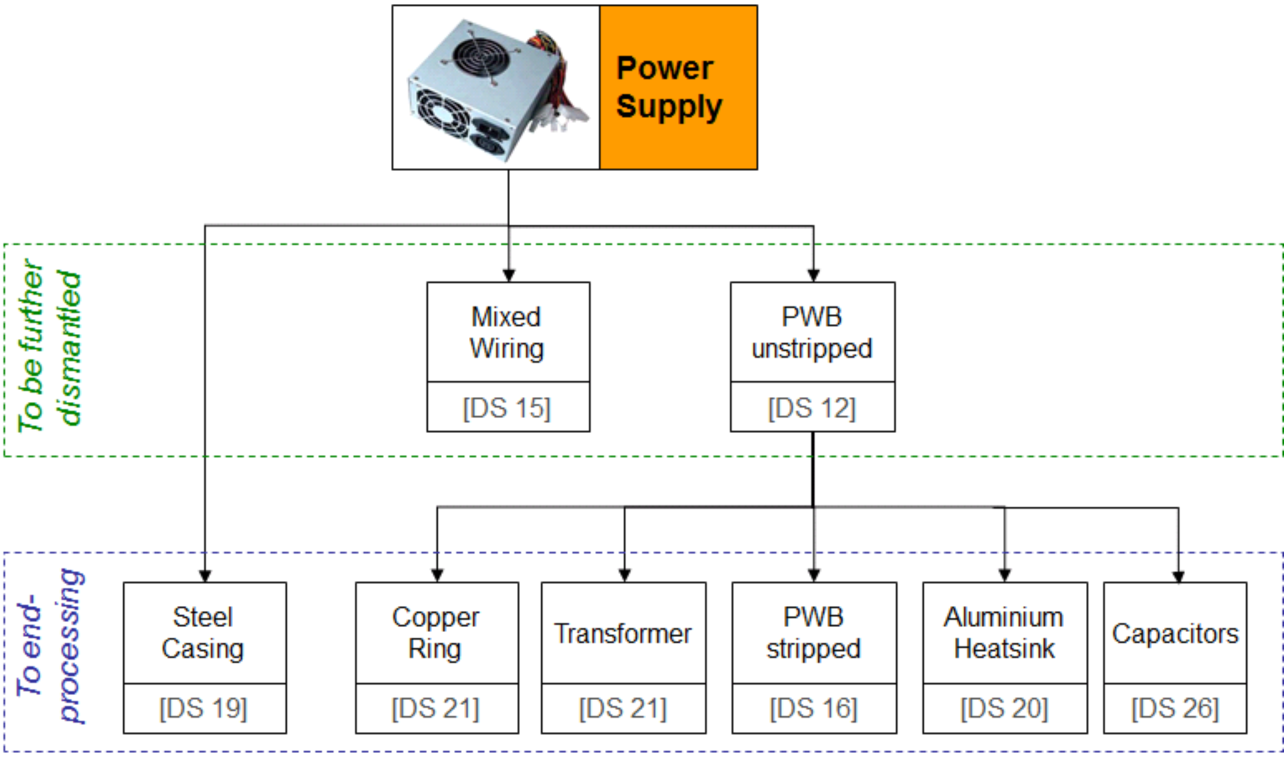
P1, P2, P4, P5

General Context

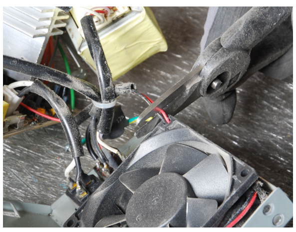
A power supply pack is derived from dismantling a central unit. It consists of a steel case, a printed wiring board (PWB), a fan, a radiator and cables. The dismantling process is relatively quick and

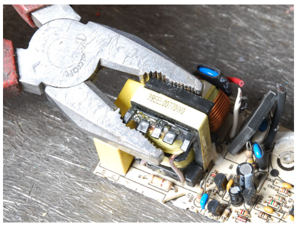
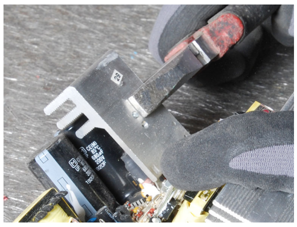
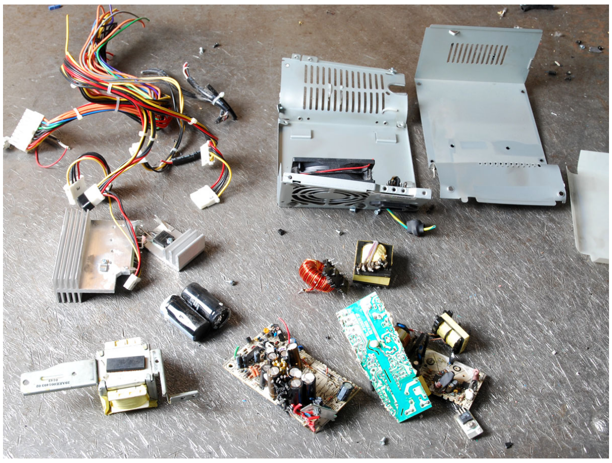
Flowchart

Dismantling a power supply pack along the introduced principles takes **approximately 5 minutes**.



Dismantling Process

1	Remove the steel casing, clean it and put it aside. Go on with [DS 19: Ferrous Metals].	
2	Remove all components like cooling fan, PWB, transformers, copper windings by cutting off cables and wires and place them aside. Go on with the appropriate data sheets. The PWB contains relatively large aluminium boards acting as heat sinks.	 

	Remove them and place them aside [DS 20: Aluminium]. Take care that aluminium is properly cleaned. Aluminium recyclers refuse impure parts.	 
3	Separate the remaining materials according to their type and go on with the appropriate data sheet (e.g. aluminium, ferrous metals, cables, plastic, further PWBs, capacitors etc.).	

Health & Safety

Dismantling a power supply doesn't include any harmful steps. Nonetheless workers should wear personal protection equipment like gloves, goggles, apron and robust shoes.

Composition

In average, a power supply weighs 1.3 kg and takes approximately **5 minutes** to dismantle. Figure 9 shows the share by weight of the recoverable material.

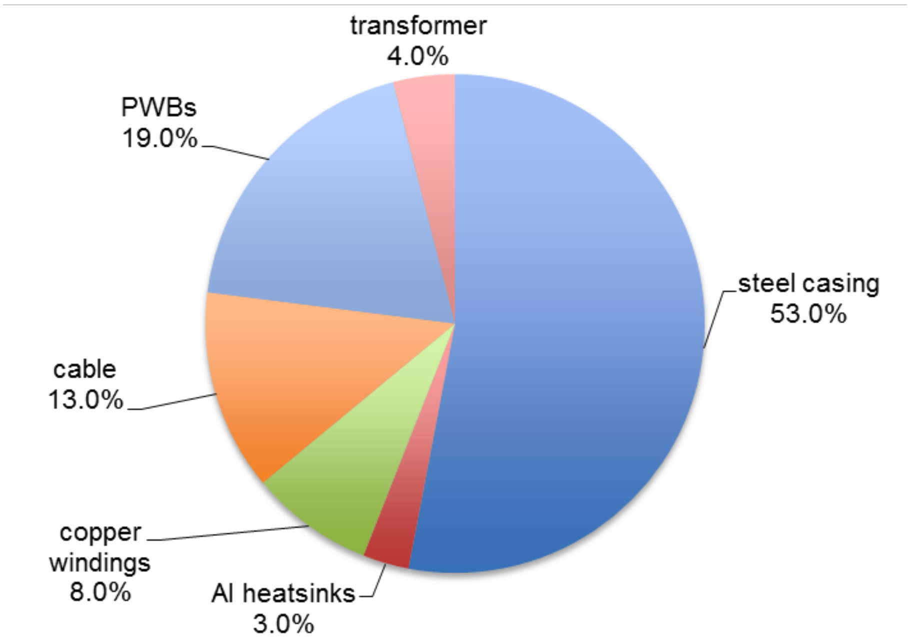


Figure 9. Composition of a power supply (ecoinvent 2010).

DS 9 Hard Disk Drive HDD

[1]

Previous dismantling steps:

DS 2, DS 3

Following dismantling steps:

--

Material recovered:

Printed Wiring Board, Mixed Metals, Aluminium, Copper, Mixed Wiring

Hazardous materials:

-

Tools:

T1, T5

Personal protection equipment:

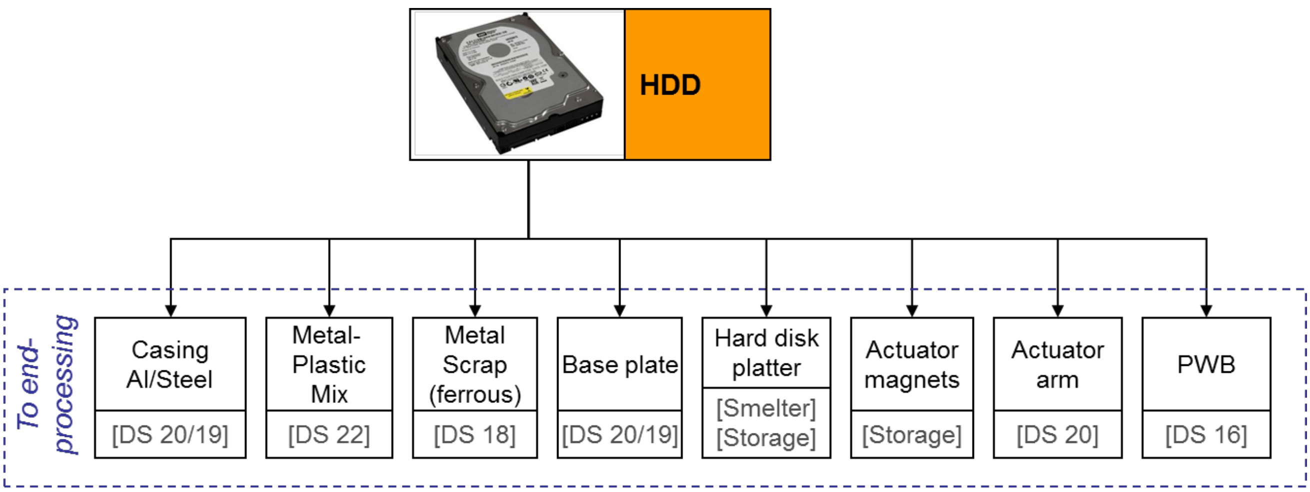
P1, P5

General Context

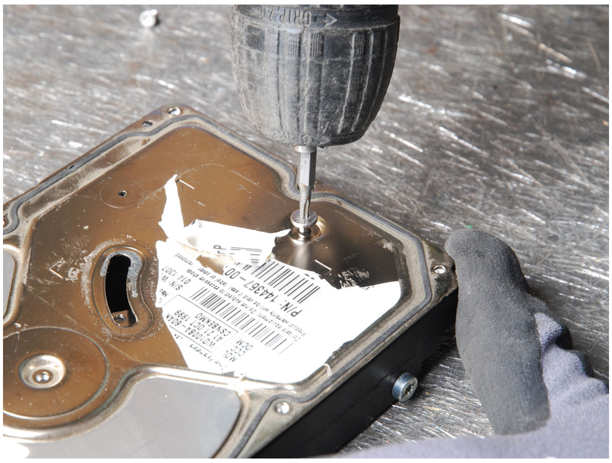
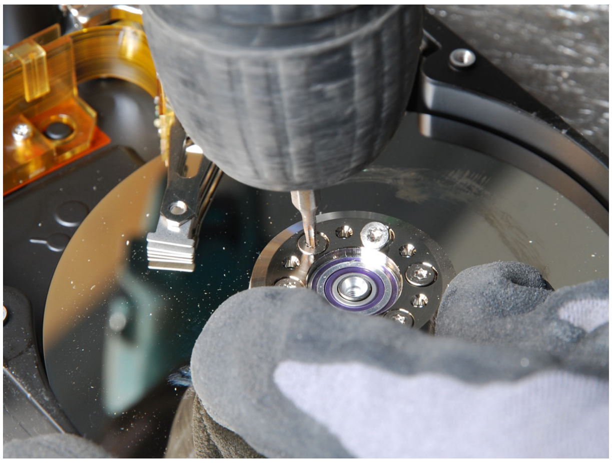
The hard disk drive is made up of a lid, a metal case, a data disk and a PWB. It is relatively rich in precious metals like Ag, Au and Pd. The location of the HDD will vary, usually attached to the computer case by 3-4 screws and connected to the motherboard with cables.

Flowchart

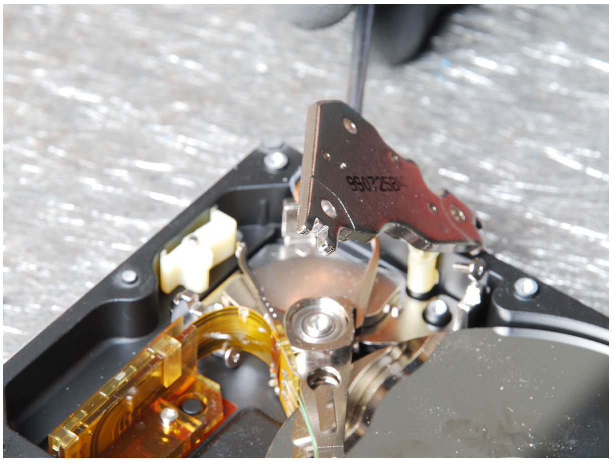
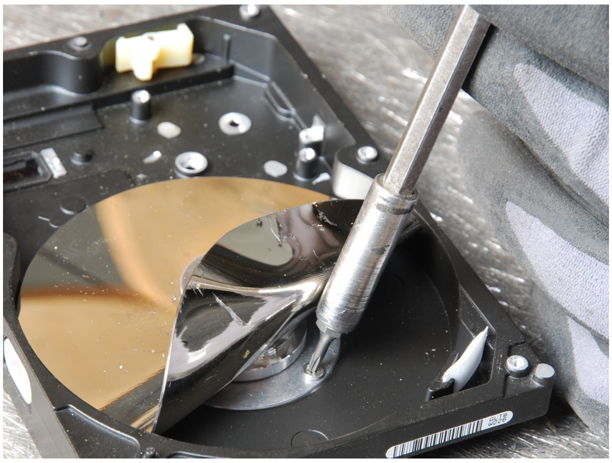
Dismantling the hard disk drive along the principles introduced below takes **approximately 5-10 minutes.**



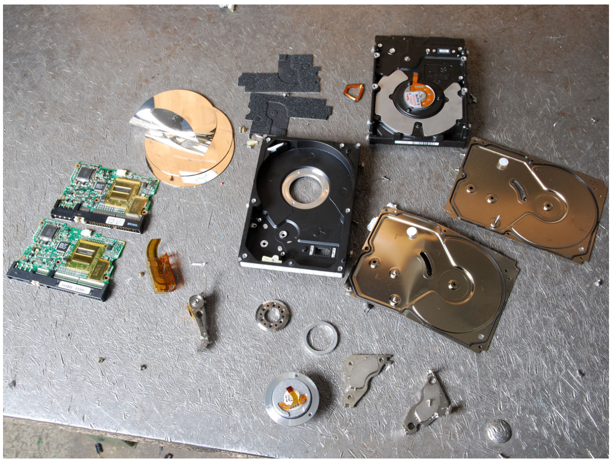
Dismantling Process

1	Put the HDD on the work bench upside down so that the PWB can be seen. Remove the screws fixing the PWB. In some cases the screws can be hex-headed or of unusual configuration. In this case simply drill the screws off. Go on with [DS 16: PWB – End-Processing]. ⚠ Wear goggles and gloves when drilling!	
2	Unscrew the top cover of the HDD. Some screws may be covered by stickers. Remove the top cover and go on with [DS 20: Aluminium] or the appropriate data sheet.	
3	Unscrew the semi-circular plate which holds the hard disk platters. Remove the plate ([DS 20: Aluminium] or [DS 19: Ferrous Metals]) and the hard disk platters [Storage/Integrated Metal Smelter]. *Due to their special metal content, it is recommended to supply the platters to an integrated metal smelter or to store them for a future recovery*[3].	

[3] A storage is recommended because future technological developments could enable the recovery of rare metals. A hard disk platter is typically made using an aluminium or glass and ceramic substrate and is coated by a complex layered structure consisting of various metallic (mostly non-magnetic) alloys (Wikipedia 2012b). The substrate and alloys may contain metals like Ruthenium (Ru), Platinum (Pt), Tantalum (Ta), Zirconium (Zr), Chromium (Cr), Nickel (Ni) and others (Nunney and Baily 2011).

4	Pry open the frame (actuator) which holds the pointer (actuator arm). Remove the actuator magnet and the actuator arm [DS 20: Aluminium]. If possible, store the magnets for a future rare metal recovery[4].	 
5	Unscrew the bottom circular plate with the motor. Go on with [DS 20: Aluminium] or the appropriate data sheet.	

[4] The magnets used in a HDD usually contain the rare metal Neodymium (Nd). Even though processes to recover Nd from obsolete devices are not yet available, a future recovery is likely. It is therefore recommended to store those magnets in order to avoid the loss of Nd and to enable its future recovery.

6	Separate the remaining parts according to their composition and go on with the respective data sheets.	

Health & Safety

Dismantling a hard disk drive doesn't include any harmful steps nor does the hard disk drive contain any hazardous materials. Nonetheless workers should wear personal protection equipment like gloves, goggles, apron and robust shoes.

Composition

A hard disk drive in average weighs 0.5 kg and takes approximately 5-10 minutes to dismantle. Figure 10 shows the share by weight of the recoverable material.

Remark: the strong magnet contained in the actuator consists of neodymium, amongst others. It is a rare earth element and could thus become an interesting material for recycling due to its scarcity.

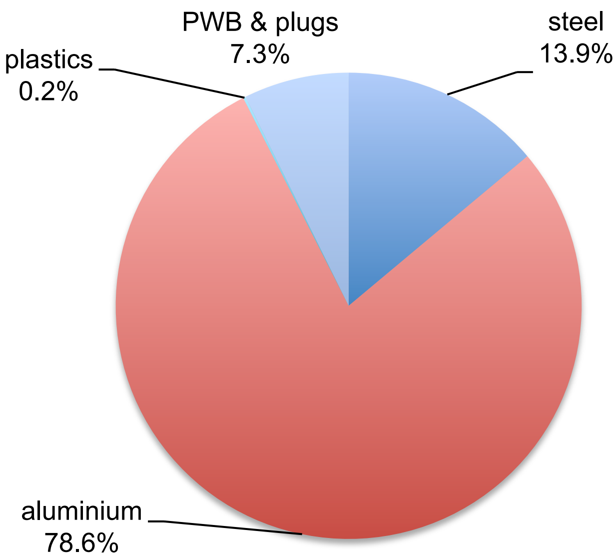


Figure 10. Composition of a sample HDD (Mohite 2005).

DS 10 Compact Disk Drive CDD


[7]

Previous dismantling steps:

DS 2, DS 3

Following dismantling steps:

--

Material recovered:

Printed Wiring Board, Mixed Metals, Aluminium, Copper, Mixed Wiring

Hazardous materials:

-

Tools:

T1, T5

Personal protection equipment:

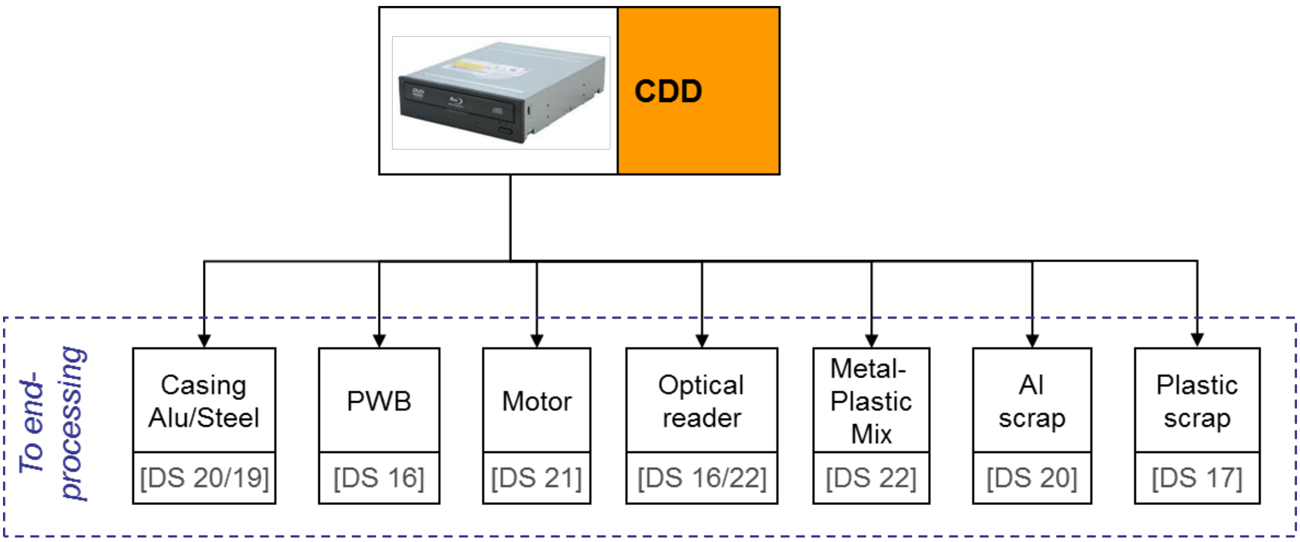
P1, P5

General Context

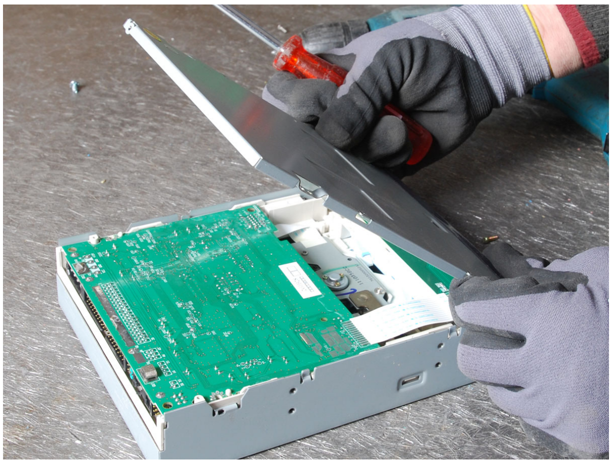
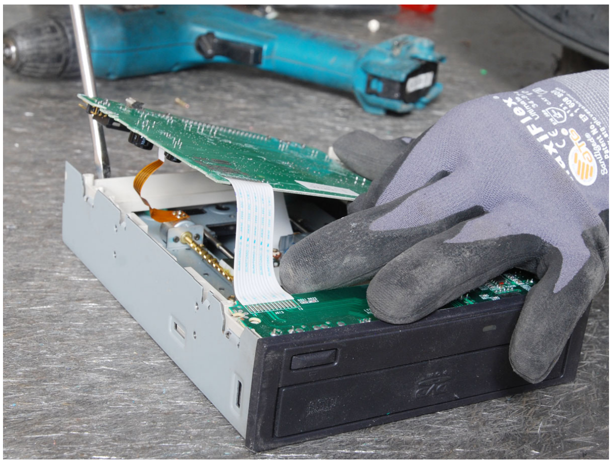
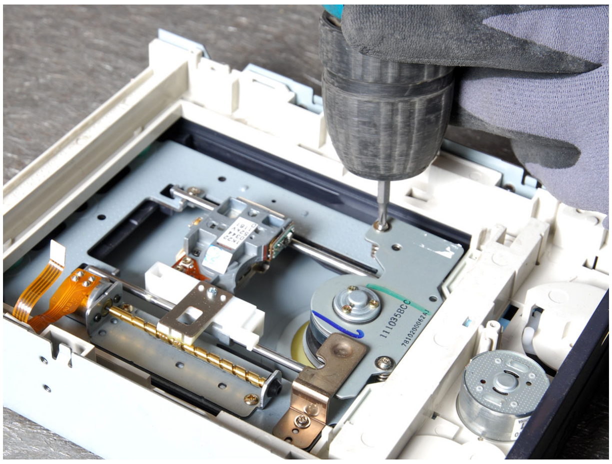
A compact disk drive consists of a casing, a CD tray, an optical reader and a PWB. The location will vary, usually attached to the computer case by 3-4 screws and connected to the motherboard with cables.

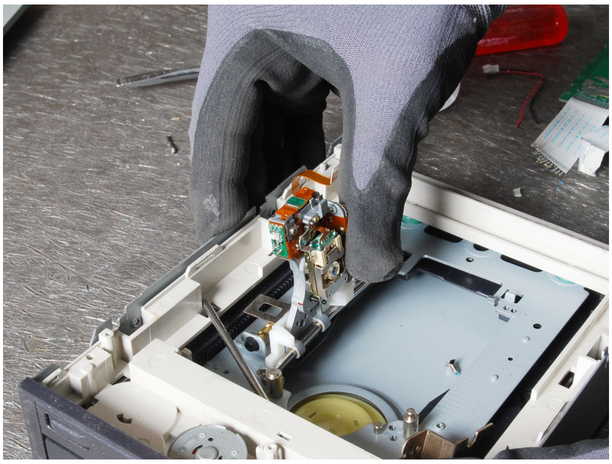
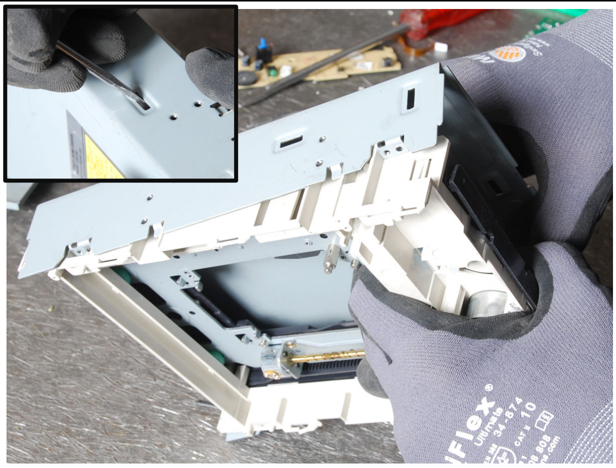
Flowchart:

Dismantling the compact disk drive along the principles introduced bellow takes **approximately 5-10 minutes.**



Dismantling Process

1	Unscrew and remove the bottom cover. Go on with the appropriate data sheet (usually [DS 20: Aluminium]).	
2	Unscrew and remove the PWB. Go on with [DS 16: PWB – End-Processing].	
3	Unscrew and remove the CD motor. Go on [DS 21: Copper]	

4	Remove the optical reader of the CDD. Go on with [DS 16: PWB] or [DS 22: Metal Plastic Mix][5]. Remove the CD motor base plate. Go on with the respective data sheet.	
5	Remove the front part of the casing, the CD tray and tray frame. Go on with the appropriate data sheet (usually [DS 20: Aluminium] and [DS 17: Plastics]). Use the clips indicated in the small pictures to separate the fractions.	 

[5] Depending on the quality of the material, the optical reader (which contains a small PWB) is accepted by an integrated metal smelter.

6	Remove and separate the remaining materials and put them to the adequate fractions. Make sure the plastic parts are completely free of metal pieces.	

Health & Safety

Dismantling a compact disk drive doesn't include any harmful steps nor does the compact disk drive contain any hazardous materials. Nonetheless workers should wear personal protection equipment like gloves, goggles, apron and robust shoes.

Composition

A compact disk drive in average weighs 1 kg and takes approximately 5-10 minutes to dismantle. Figure 11 shows the share by weight of the recoverable material.

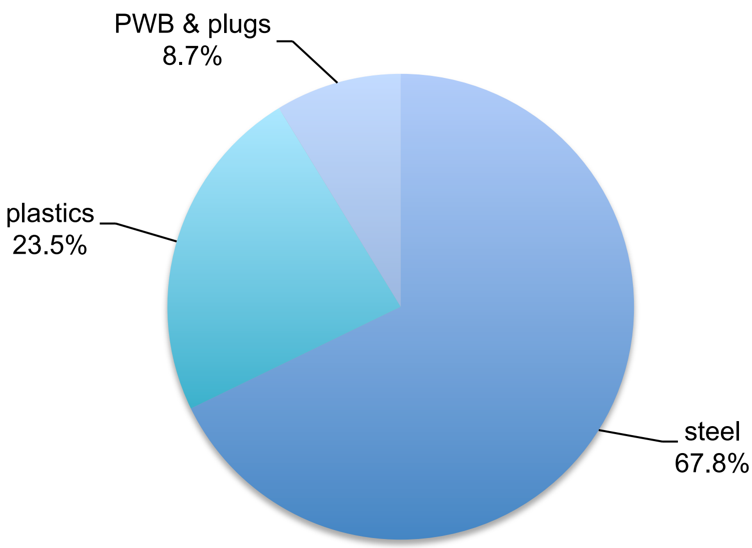


Figure 11. Composition of a sample CDD (Mohite 2005).

DS 11 Floppy Disk Drive FDD

[1]

Previous dismantling steps:

DS 2, DS 3

Following dismantling steps:

--

Material recovered:

Printed Wiring Board, Mixed Metals, Aluminium, Copper, Mixed Wiring

Hazardous Materials:

--

Tools:

T1, T5

Personal protection equipment:

P1, P5

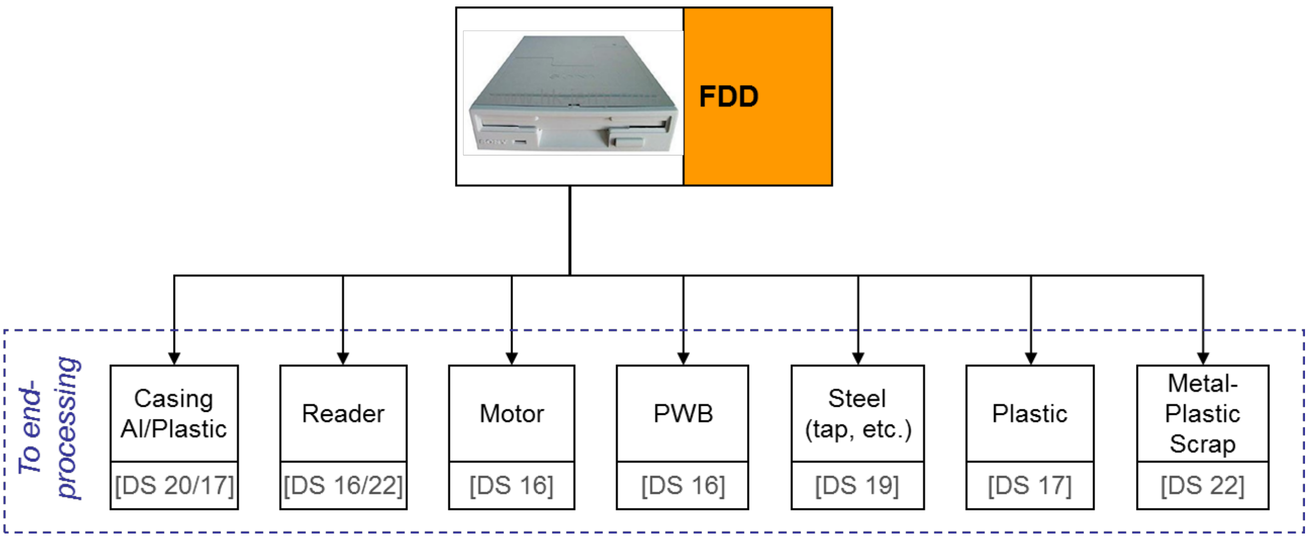
General Context

Floppy disk drives (FDD) are usually found in old computers, while newer computers do not dispose of FDDs anymore. A FDD consists of a casing, a PWB, a motor, a tray to receive the disk and a reader.

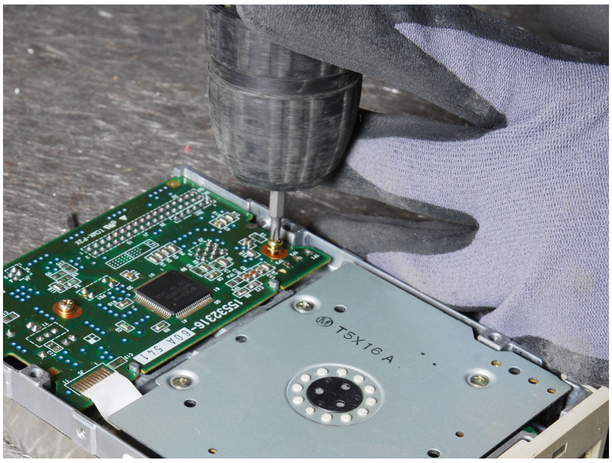
The location of the FDD will vary, usually attached to the computer case by 3-4 screws and connected to the motherboard with cables.

Flowchart:

Dismantling the floppy disk drive along the principles introduced bellow takes **approximately 5-10 minutes.**

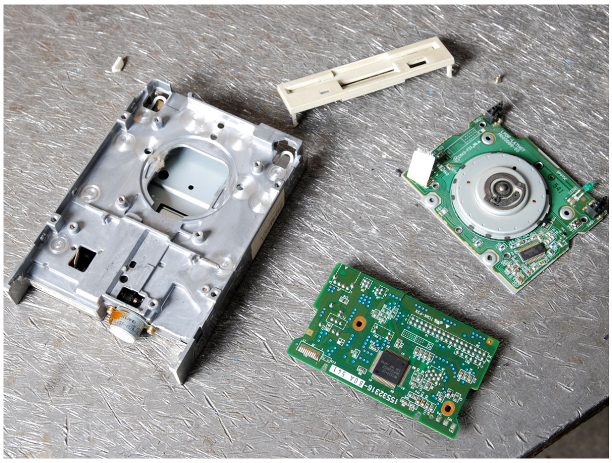


Dismantling Process

1	Open and remove the bottom and top cover (unscrew/pry open). It might be necessary to remove a small PWB to do so. Put the covers to the concerning material fraction and go on with the respective data sheet [DS 17: Plastics] or [DS 20: Aluminium]. *Two types of FDD casings exists: plastic or aluminium casings.*	
2	Unscrew the PWB cover and unscrew/remove the main PWB. Go on with [DS 16: PWB – End-Processing].	
3	Separate the remaining materials and components, amongst others the back cover, the motor[6] ([DS 16: PWB End-Processing]), the floppy disk reader[7] ([DS 16: PWB End-Processing] or [DS 22: Metal Plastic Mix]), the metal frame, etc. Assign them to the correct material fraction (e.g. aluminium, copper, ferrous metals, plastic, further PWBs, etc.). Make sure the plastic parts are completely free of metal pieces.	

[6] The motor of a FDD is normally mounted on a PWB. Copper and other metals of the PWB can be recovered in an integrated metal smelter.

[7] Depending on the quality of the material, the reader is accepted by an integrated metal smelter.

Health & Safety

Dismantling a floppy disk drive doesn't include any harmful steps nor does the floppy disk drive contain any hazardous materials. Nonetheless workers should wear personal protection equipment like gloves, goggles, apron and robust shoes.

Composition

A floppy disk drive in average weighs 0.5 kg and takes approximately 5-10 minutes to dismantle. Figure 12 shows the share by weight of the recoverable material.

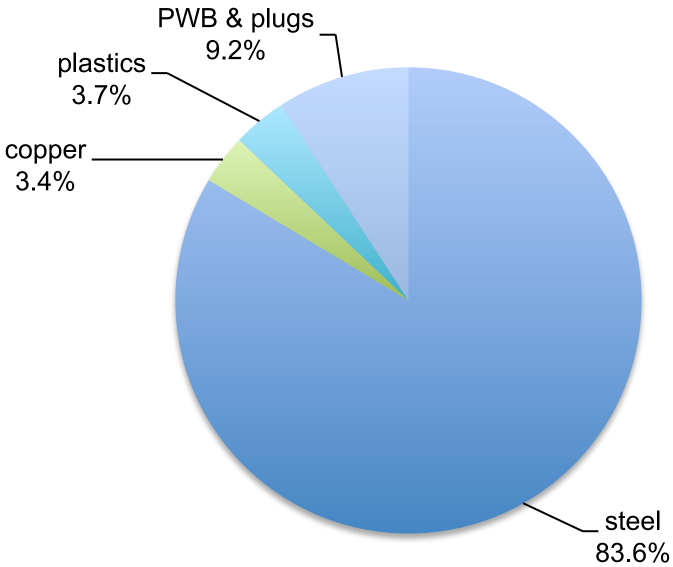


Figure 12. Composition of a sample FDD (Mohite 2005).

DS 12 Printed Wiring Board - Dismantling

Previous dismantling steps:

DS 2, DS 3, DS 4, DS 5, DS 6, DS 7, DS 8

Following dismantling steps:

--

Material recovered:

PWB, ferrous metals, copper, aluminium

Hazardous Materials:

Batteries, capacitors

Tools:

T1, T4, T5

Personal protection equipment:

P1, P2, P5

General Context

PWBs are omnipresent in a computer - almost every component of a computer contains one or several boards. For more details about PWBs see [DS 16 PWB – End-Processing].

The present data sheet focuses on the grading of a PWB (its quality) and how to dismantle each grading. As Table 2 shows, a PWB may be classified into different grades. The source of a PWB often indicates to which grade it is belonging to.

Table 2. Possible classification of board grades according to the gold content.

Grade	Au content [ppm]	Occurrence (not exhaustive, not definitive)
Ultra low grade	up to 20 ppm	Unprepared boards from CRT monitors (TV & PC), HiFi, power supplies, small domestic appliances, etc.
Very low grade	up to 50 ppm	Prepared* boards from CRT monitors (TV & PC), HiFi, power supplies, small domestic appliances, etc.
Low grade	up to 100 ppm	Leached IT boards (very low to low grade)
Medium grade	up to 200 ppm	IT boards (PC, server, printer), mixed connectors, LCD monitors, IT mother boards
High grade	up to 300 ppm	IT/telecom boards
Very high grade	above 300 ppm	Mobile phones, IT components (processors, etc.)

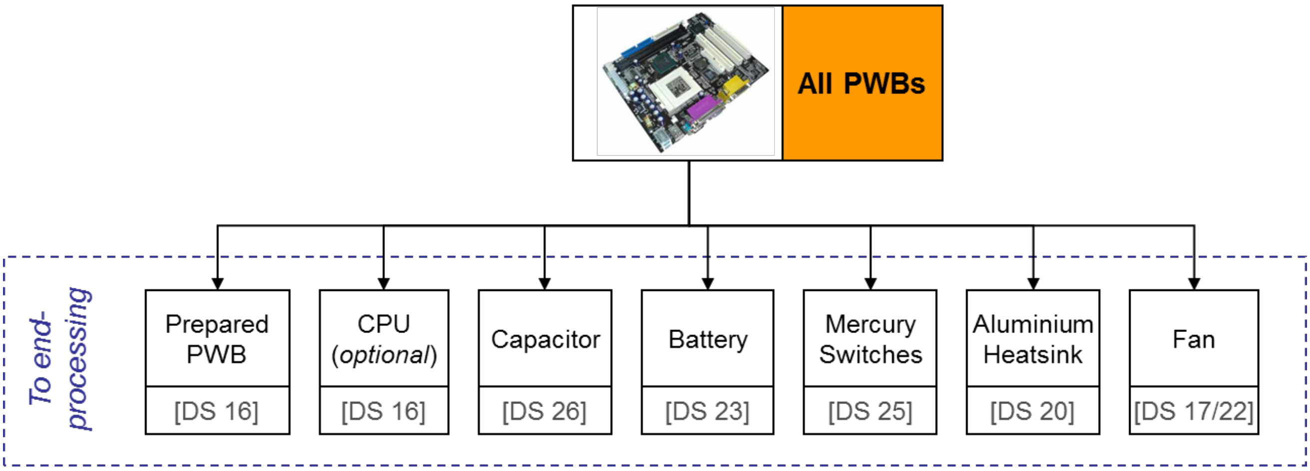
** prepared refers to the removal of heat sinks, Al frames, transformers, etc.*

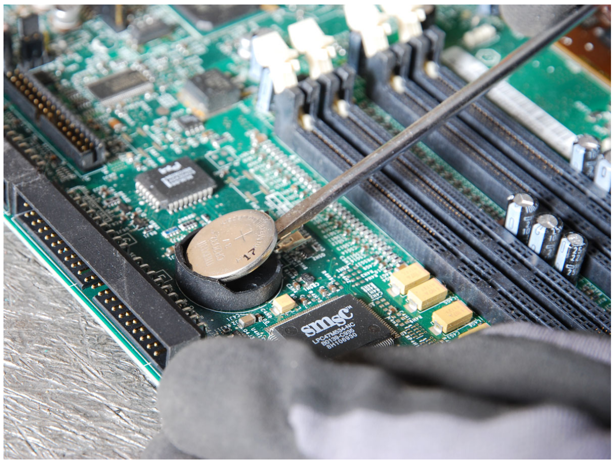
The dismantling depth of the boards will depend on the grade of the boards, as high grade boards need very little pre-processing and can be sold as such, while low grade boards need to be "up-graded" by removing the heavy parts.

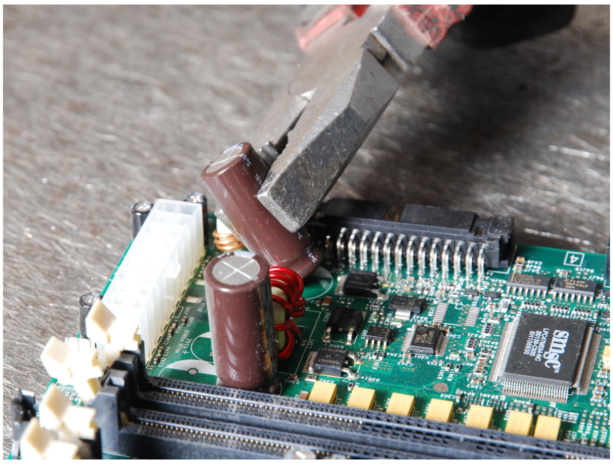
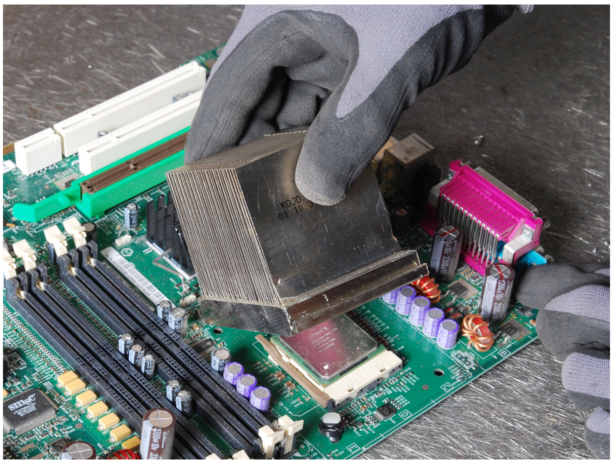
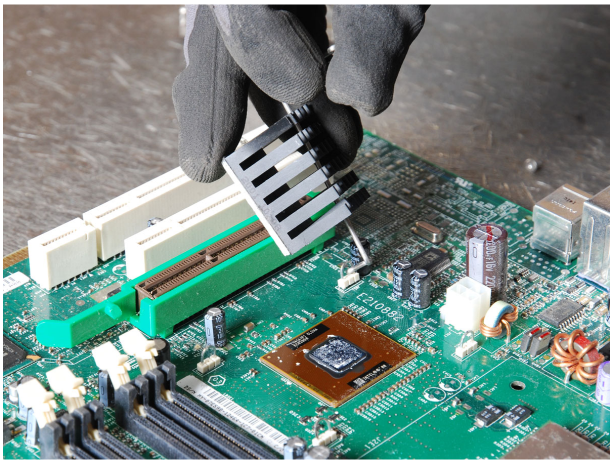
Dismantling Process for All PWBs

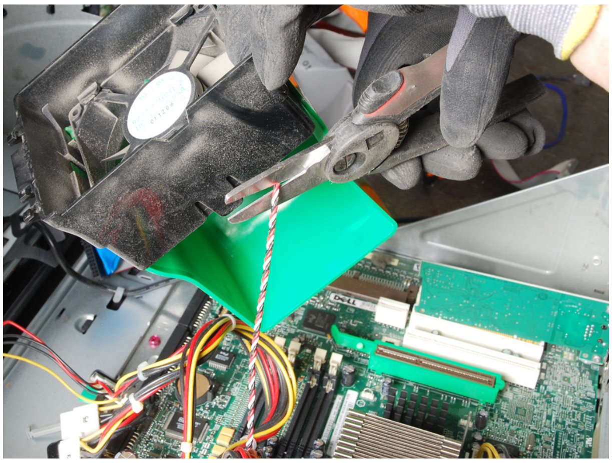
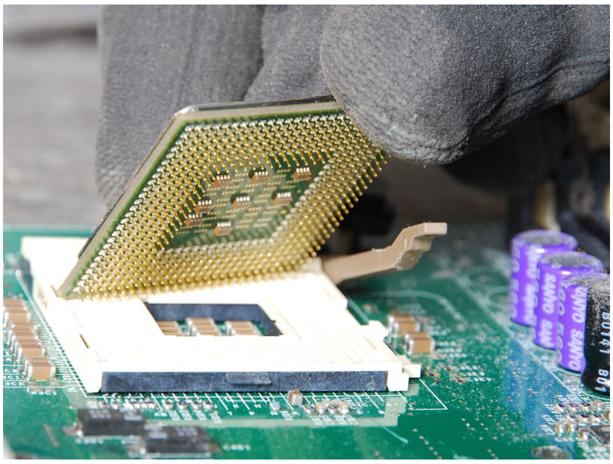
For all grade of boards, the first step is the **decontamination phase**, i.e. removing and storing securely components containing hazardous substances.

Flowchart All PWBs



1	Place the board on a table. Identify and remove the battery. Store the battery in a separate secure container a go on along instructions on [DS 23: Battery].	

2	Identify and remove large capacitors (diameter > 2 cm) and store in a separate secure container. Continue with the instructions on [DS 26: Capacitor]. Also screen the PWB for mercury switches and remove existing switches. Store them in a separate secure container a go on along instructions on [DS 29: CCFL].	
3	Unclip and remove the heat sinks (and the fan). Go along with [DS 20: Aluminium].	 

4	Remove the fan from the heat sink. Sometimes the fan is pasted and a screwdriver may be needed to separate it. Store the fan and continue [DS 22: Metal Plastic Mix]. Store the heat sink and continue according to [DS 20: Aluminium].	
5	*Optional step*[8]*:* If the central processing unit (CPU) can be saled separately, it might be economically viable to removed. The CPU is usually found on the motherboard, but may also exist on some video cards and on server boards. Release the locking lever and remove the CPU. Store separately and follow instructions in [DS 16: PWB End-Processing].	

No additional processing is required for **high-grade boards**, which may be stored separately and sold to a refinery (see [DS 16: PWB – End-Processing]).

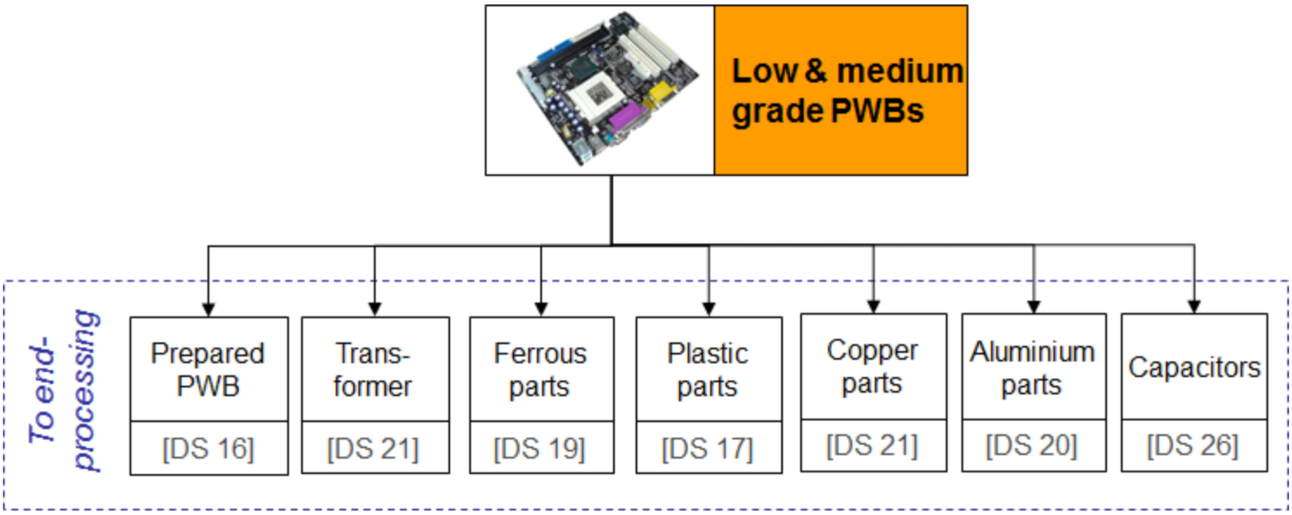
Further Dismantling for Low & Medium Grade Boards

Medium & low-grade boards need further processing and finer dismantling before being sold. The low amount of precious metals contained in these boards may cause the shipment prices to exceed the sales value of the boards. Therefore, it is necessary to concentrate the value on the boards by removing heavy parts made of homogeneous materials.

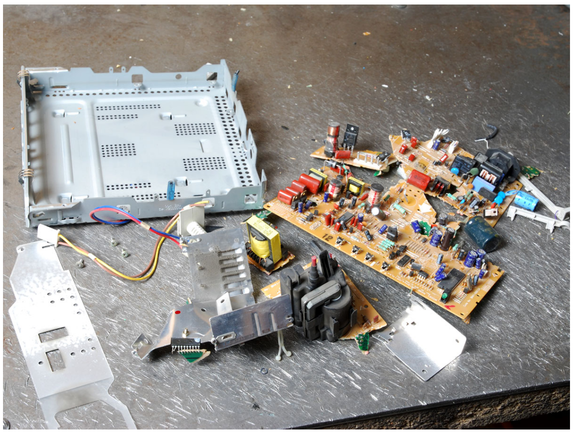
Dismantling the boards according to the flow chart below takes **approximately 10 minutes.**

[8] Depending on the receiving smelter, a separation of the CPU from the PWB might be economically advantageous.

Flowchart Low & Medium Grade PWBs



1	Remove the aluminium, the ferrous, the plastic and copper containing parts. If possible, unscrew and simply remove the components. If it is pasted, a hammer, tweezers and chisel may be needed. ⚠ Gloves and goggles are needed if parts are being broken off, as splinters could cause eye injuries or cuts. Store the different removed fractions separately (see [DS 17: Plastic; DS 19: Ferrous Metals; DS 20: Aluminium; DS 21: Copper; DS 22: Metal Plastic Mix; DS 26: Capacitors]).	 

2	Store the "stripped" PWB separately and go on along instructions on [DS 16: PWB – End-Processing].	

Best Practice (Do's and Don’ts)

- **Do not practice wet chemical leaching**: it may be tempting to extract precious metals such as gold or silver immediately with wet chemical processes. Such process include dissolving the metals in acids and precipitating them with cyanide salts or mercury. All these processes are highly hazardous and must be conducted by professionals in a laboratory. In addition, recent studies have shown that such processes are selective (they only act on 1 metal) and inefficient (they only allow to extract the apparent metals). The best alternative for recovering value from PWBs is to sell them to precious metal refineries and smelters (DS 16: PWB – End-Processing).
- Another potentially hazardous practice is to de-solder certain components on a PWB by heating the solder. If this process is not performed under controlled conditions (heat regulation), very hazardous substances are released (e.g. dioxins, gaseous lead).
- If possible, always remove parts by unscrewing or dislodging. Breaking off the parts should only be done when they are pasted or too difficult to remove. Wear goggles and gloves when components are broken off.
- Immediately store different fractions in their respective containers and work on one material at a time. For example, first remove all aluminium parts and store them in the aluminium container. In a second step remove all the ferrous parts and store them in the relevant container. And so on. Doing so will avoid mixing up materials and thus reducing their sales value.

Health & Safety

Handling PWBs doesn't present any particular direct danger due to the hazardous content of some components. The main exposure of the worker to hazardous substances comes from the dust that can be contaminated by several substances present inside the computer. Therefore, it is recommended that workers:

- fix the dust by spraying a little bit of water on the boards before handling them
- wash hands regularly
- heal injuries immediately (cuts)
- avoid breaking open batteries and capacitors.

3 Dismantling Printer Appliances

DS 13 Printer

[1]

Previous dismantling steps:

DS 1

Following dismantling steps:

DS 12, DS 15

Material recovered:

Plastics, ferrous metals, PWB, mixed wiring

Hazardous materials:

Cartridges and toners, photoconductive drums (laser printer)

Tools:

T1, T2, T4, T5, T6, T8, T9

Personal protection equipment:

P1, P2, P3, P4, P5

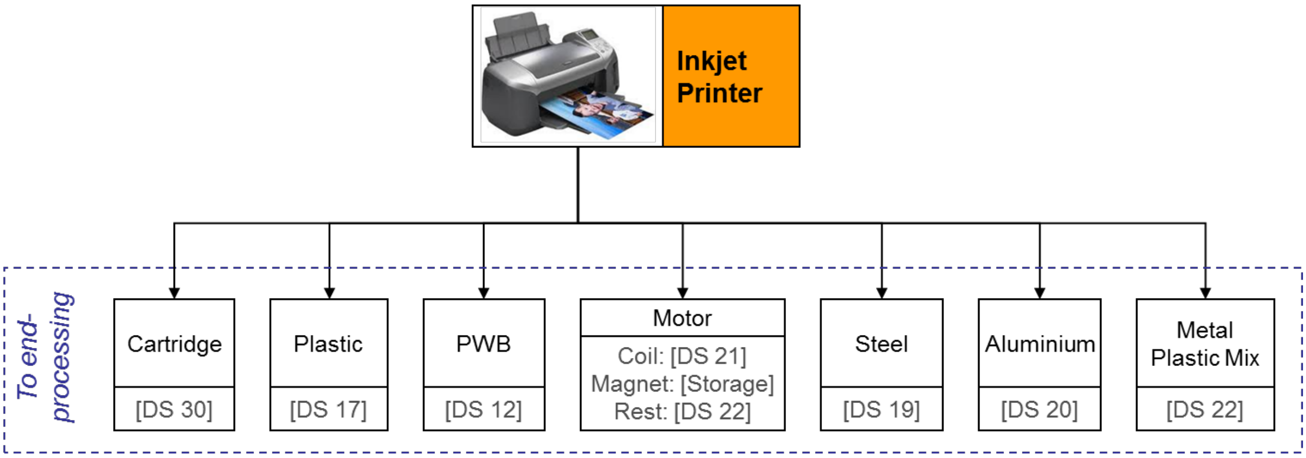
General Context

Mainly two types of printers are used: the **inkjet printer** and the **laser printer**. The definition of an average in terms of weight and composition is very difficult due to the wide range of equipment types present on the market. Elderly, large and heavy pieces may have higher, and therefore economically more viable value, because of their steel content, which could be sold to a scrap metal merchant for shredding after detoxification. However, more recent models are unlikely to yield any significant material revenue as their casing is predominantly made from plastics.

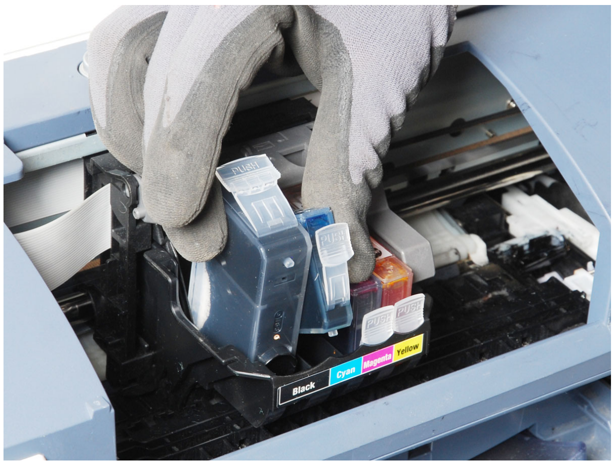
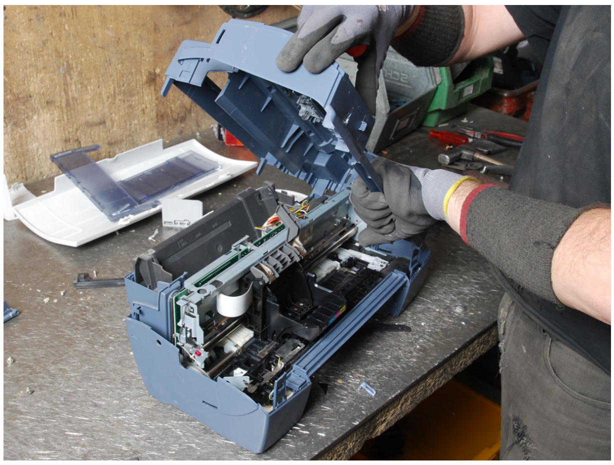
Dismantling Process

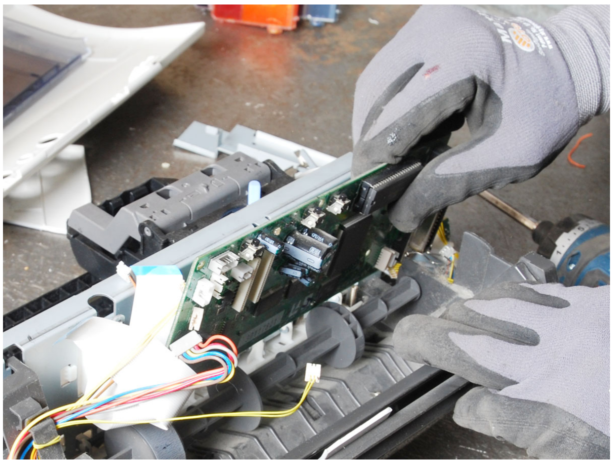
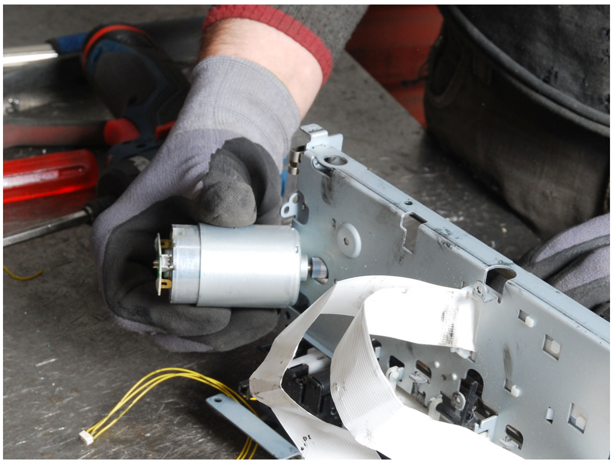
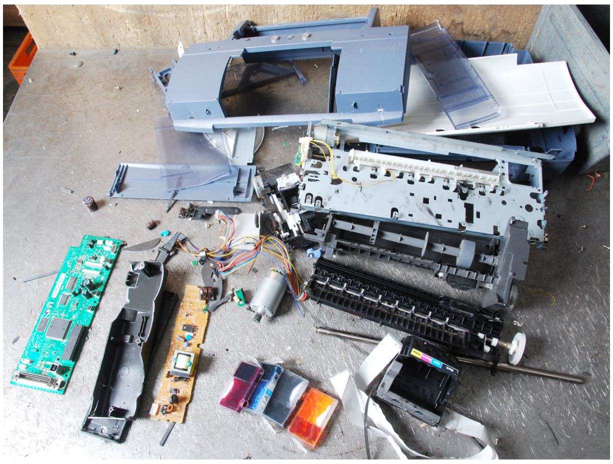
Due to the large variety of printers available on the market it is impossible to give a specific manual how to dismantle a printer. Therefore, the dismantling steps for inkjet and laser printers indicated below have to be adapted from case to case. No dismantling times and average weights can be indicated.

Flowchart Inkjet Printer



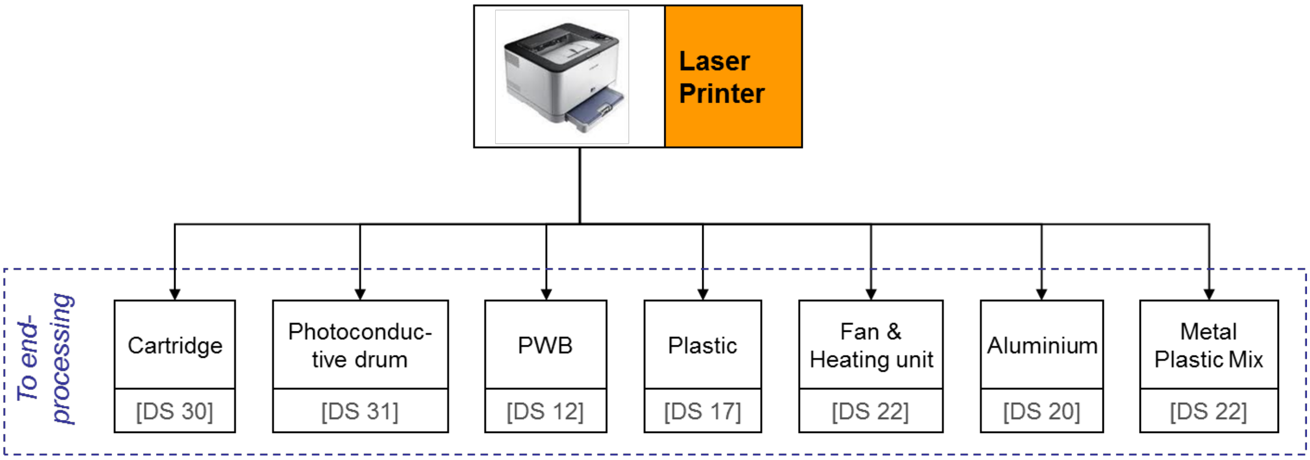
Inkjet Printer

1	Remove the ink cartridges and put them aside. Go on with [DS 30: Cartridges]. Cartridges can be refilled and reused! In case they are broken, they need to be disposed of as hazardous waste.	
2	Open the plastic casing by unscrewing all screws and removing clips. Clean the casing properly by removing all the foreign materials in the plastic such as labels, rubber mountains etc. and go on with [DS 17 Plastics]. Make sure the plastic parts are completely free of metal pieces.	

3	Unscrew and remove the PWB and go along with [DS 12: PWB – Dismantling].	
4	Remove the printer motor. If possible, separate the copper coil [DS 21: Copper] or the magnets insider the motor. The magnets should be stored separately[9]. For the remaining materials of the motor, go on with [DS 22: Metal Plastic Mix].	
5	Separate the remaining materials according to their type and go on with the appropriate data sheet (e.g. aluminium, ferrous metals, plastic, further PWBs, etc.). Make sure the plastic parts are completely free of metal pieces.	

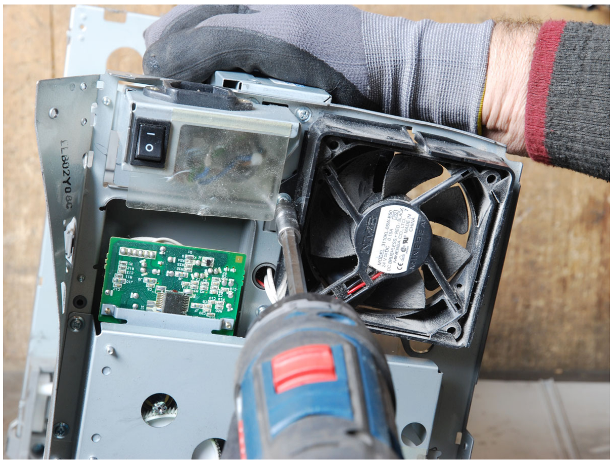
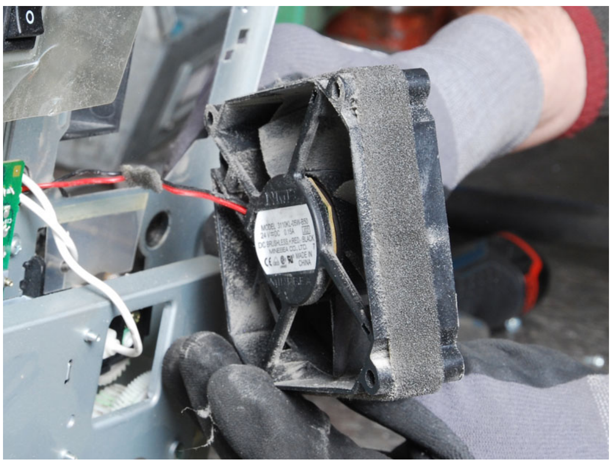
[9] The magnets may contain rare metals like Neodymium (Nd) or Samarium (Sm). Even though processes to recover those rare metals from end-of-life devices are not yet available, a future recovery is likely. It is therefore recommended to store those magnets in order to avoid the rare metal loss and to enable its future recovery.

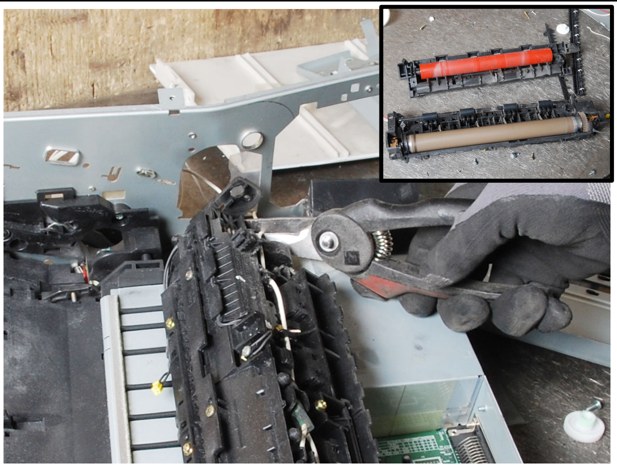
Flowchart Laser Printer



Laser Printer

1	Remove the toner cartridge. Go on with step 2 to segregate the photoconductive drum or put it aside and go on with [DS 30: Cartridges]. ⚠ Cartridges can be refilled and reused! In case they are broken, they need to be disposed of as hazardous waste.	
2	***Photoconductive drum*** The photoconductive drum is usually located within the cartridge. Drums from older copy and fax machines may be coated with the toxic substances cadmium-sulfid or selen and should therefore be segregated and supplied to an adequate treatment. Find more information about identification of those drums and about their further treatment on [DS 31: Photoconductive Drum]. To segregate the drum, remove the axis and store the photoconductive drum separately. Go along with [DS 31: Photoconductive Drum].	

⚠	Avoid exposure to the coatings of the Cd- and Se-drums! Selenium-coated drums should be stored without exposure to light (barrel with cover)!	 
3	Open the plastic casing by unscrewing all screws and removing clips. Clean the casing properly by removing all the foreign materials in the plastic such as labels, rubber mountains etc. and go on with [DS 17 Plastics]. Make sure the plastic parts are completely free of metal pieces.	
4	Remove all screws and segregate the PWBs. Go along with [DS 12: PWB – Dismantling].	
5	Remove the fan and go along with [DS 22: Metal Plastic Mix].	

6	Cut off and remove the heating unit (including (brown) heated roller, see small picture). Go along with [DS 22: Metal Plastic Mix].	
7	Separate the remaining materials according to their type and go on with the appropriate data sheet (e.g. aluminium, ferrous metals, plastic, further PWBs, etc.). Make sure the plastic parts are completely free of metal pieces.	

Health & Safety

Toner and cartridges are to be classified as special waste. However, on dismantling toner cartridges and treating toner powder, dust protection measures are necessary to protect the air passage and to minimize occupational health hazards for concerned workers. If not handled by a certified enterprise, toner cartridges and powders have to be disposed of in hazardous landfill disposal sites.

Composition

The definition of an average weight or an average composition cannot be given due to the wide range of equipment types present on the market. Figure 13 shows the share by weight of the recoverable material of a laser printer. Notice that the material share between different types of printers varies considerable, too.

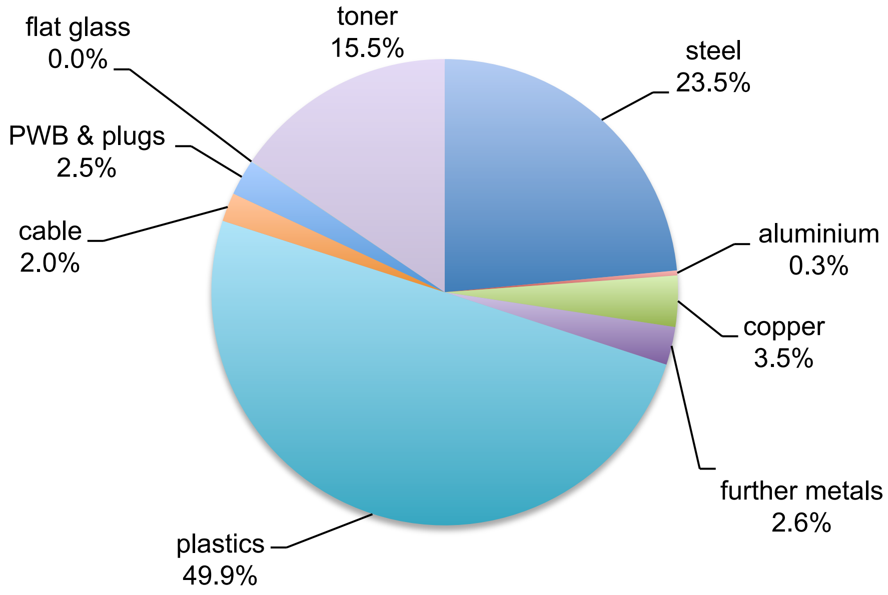


Figure 13. Composition of a laser printer (ecoinvent 2010).

Comments

Due to a large variety of appliances, different technologies, types, models and sizes present on the market, there is a big variance in the average cost and disassembly time figures. A sensitivity analysis would therefore not yield any viable results. Very old, large and heavy pieces may have a higher value because of their steel content. The casing design of new equipment is predominantly made of plastic which yields only very little material recovery value.

It can be concluded, that disassembly of printers is not likely to be financially interesting in most cases. The first aim of the manual disassembly is hence decontamination by removing the ink cartridge and toner as well as the photoconductive drum.

4 Dismantling Mobile Phones

DS 14 Mobile Phone

[5]

Following dismantling steps:

--

Materials recovered:

PWB, plastics, steel, aluminium, liquid crystal display

Hazardous materials:

Battery

Tools:

T1, T2

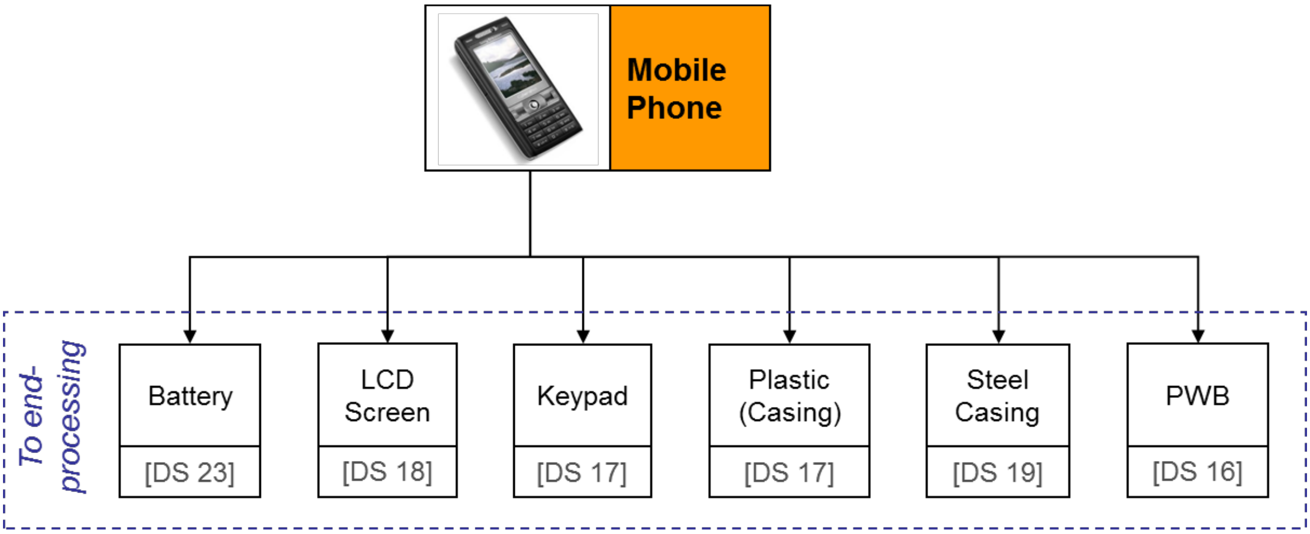
Personal protection equipment:

P1, P2, P5

General Context

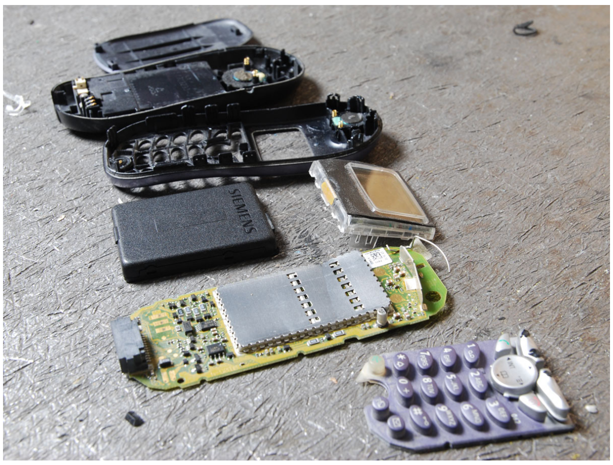
The technology of mobile phones has evolved rapidly during recent years and consequently the models differ a lot in function and shape. Nevertheless, the disassembly of a mobile phone has generally remained quite simple: remove the battery and casing and supply the rest to an integrated metal smelter which treats PWBs. PWBs in mobile phones are commonly high-grade quality and can – if supplied to the adequate downstream processor – generate a high revenue.

Flowchart



Dismantling Process

Depending on the requirements of the downstream processor, it is sufficient to remove the battery from the mobile phone and omit the further dismantling steps described below.

1	Remove the battery first. Generally, the battery is located under the back cover. In some cases, there is no quick access to the battery, thus the casing must be pried open. Go on along instructions on [DS 23: Battery].	
2	Remove the casing and keypad from the inner parts (unscrew, pry open, etc.) and go on with instructions on [DS 17: Plastics] or the respective fraction data sheet.	
3	The remaining parts – mainly PWB and LCD – can be further treated as described in [DS 16: PWB – End-Processing]. PWBs from mobile phones are usually high-grade board quality (see Table 2). If easily detachable, it might be wise to separate further materials like plastics, steel, aluminium, etc.	

Health & Safety

No steps are involved that present a risk to human health or to the environment. Nevertheless, workers should wear basic protection equipment like gloves, apron and goggles.

Composition

The weight of a mobile phone varies according to its age and the model. A typical mobile phone weighs about 100 grams and it takes 1-5 minutes to dismantle it.

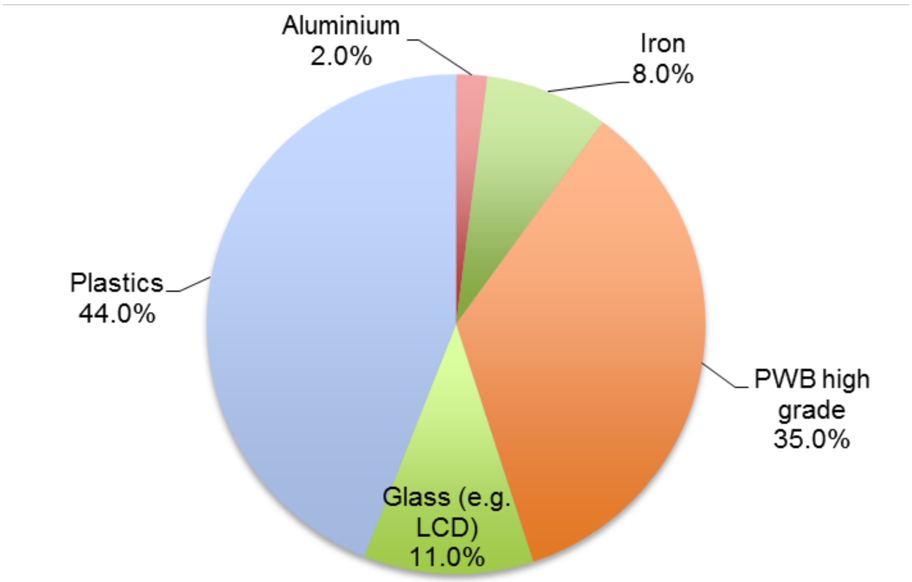


Figure 14. Composition of a mobile phone (Empa).

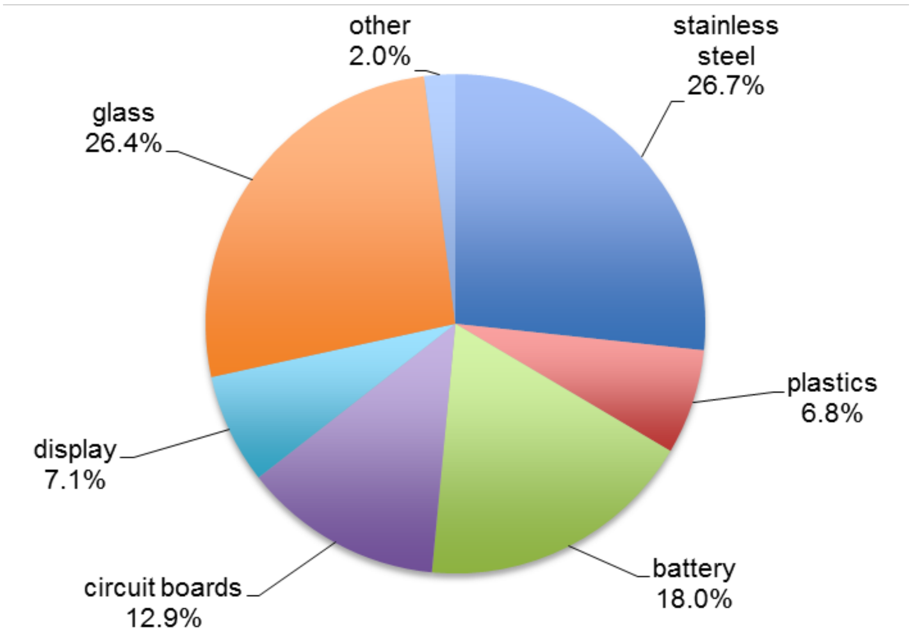
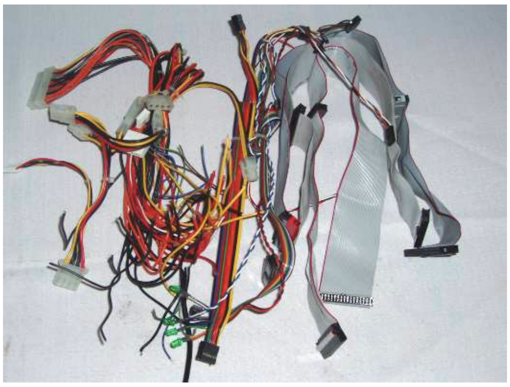


Figure 15. Composition of a smartphone (Apple 2011; Apple 2009).

5 Stripping Cables & Wires

DS 15 Cables & Wires



Previous dismantling steps:

DS 1, DS 2, DS 3, DS 4, DS 5, DS 6, DS 7, DS 8, DS 13

Following dismantling steps:

--

Material recovered:

Plastic (low density), scrap, copper, other metals

Tools:

T4, T5, T6

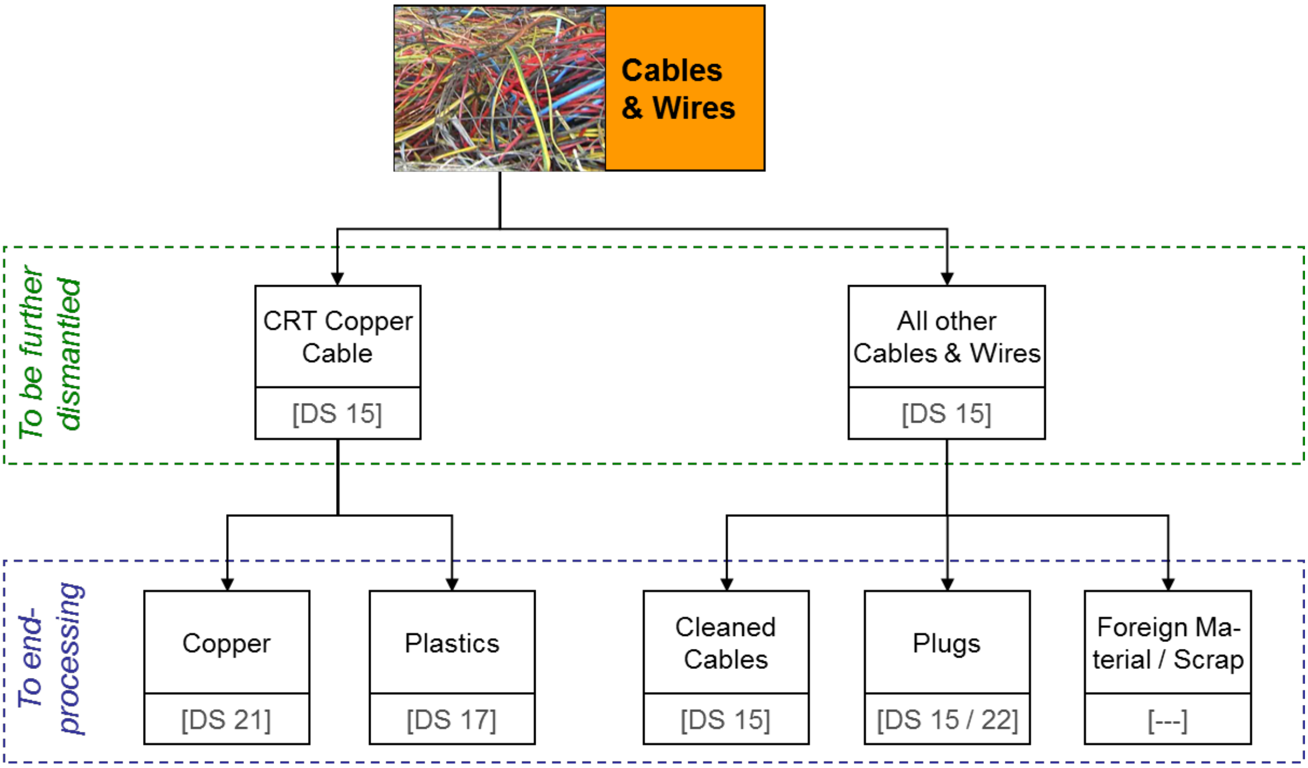
Personal protection equipment:

P1, P5

General Context

Cables and wires are found in all IT devices and there exist a lot of different types of them. Basically there are 3 types: thick black cables, flat cables and coloured wires. Cables are recycled to recover **copper**. Refineries granulate cables to extract the metals from the surrounding isolation plastic automatically. Depending on the recycler's demand, the cables should be stripped and cleaned accordingly. Some recyclers e.g. do use the flat grey plugs for recycling purposes, others don't. Below the further processing of cables is demonstrated in a general way.

Flowchart



Dismantling Process

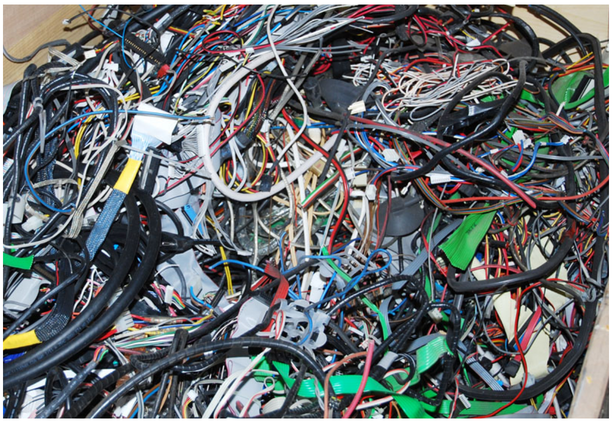
Depending on the type of cable a different way of dismantling must be performed. The process described first refers to CRT copper cables (A) and the process described below refers to all other cables, which are processed mechanically (B).

Part A: CRT Copper Cable

1	Only the black copper cable embracing the CRT glass body can be stripped manually using a knife or side cutter. All other cables must be processed mechanically (see Part B).	

2	When the whole black copper cable is cut open, the copper wiring can be pulled out of the insulation. Store the materials separately. Go on with [DS 17: Plastics] and [DS 21: Copper].	

Part B: Other Cables

1	Clean the cables by removing all foreign materials and plugs. Because cables will be mechanically granulated, all brackets or similar components must be removed to prevent the damage of the granulators. Some plugs can be reused (mainly the bigger flat ones). Clarify this with the local cable recycler/granulator.	 
2	Place the cleaned wires aside for further processing at a cable granulator.	

Health & Safety

⚠ **Burning cables to remove metals is very hazardous and must be avoided.**

⚠ Personal protection equipment like goggles and gloves should be worn as splints can snap around while using a side cutter.

Composition

Cables' composition varies strongly according to its type. Most cables contain **copper**, others **aluminium** as conductor. Also the surrounding plastic type varies. Many cable insulations are made of PVC, which releases very hazardous substances if burnt[10].

Comments

Depending on labour costs and accessible infrastructure, it may be economically advantageous to segregate the cables from their insulation (manually or mechanically).

[10] Burning PVC insulation releases hydrogen chloride gas, which on inhalation mixes with water in the lungs to form hydrochloric acid; PCB (polychlorinated biphenyls) can be generated during burning as well.

PART C – DOWNSTREAM PROCESSES

6 Markets and Treatment Alternatives for Recyclable Materials

Depending on the input and the chosen dismantling concept, the output of a dismantling plant for e-waste can comprise up to 30 different fractions. Dismantling scenarios concentrating on depollution and gaining high valuable fractions only (such as PWBs) lead to a high content of mixed fractions (mixed scrap, power supplies, etc.) that have to be further separated by means of mechanical separation processes. Dismantling scenarios trying to gain as many pure materials as possible produce more pure metals destined directly to metal recovery processes (smelters, refineries, etc.).

However, any manual dismantling process for e-waste is the first treatment step within the e-waste recycling chain to gain secondary raw materials. The recovery of secondary raw materials requires mechanical and/or sophisticated chemical-physical processes that cannot be provided by a dismantling plant. In any case, manual dismantling has to follow international quality standards. Substandard practices like burning of cables or leaching PWBs have to strictly be avoided due to serious environmental pollution and health problems caused by these practices.

Normally a lot of the produced output fractions like ferrous metals can be commercialised on the local market. Some of them like printed wired boards (PWBs) have to be destined to sophisticated recycling plants, that are located only in a few countries over the world. This is the same to some of the hazardous fractions, that have to be further treated and disposed under controlled environmental sound conditions, that are not available in every country. Commercialisation of recycling fractions normally lead to positive financial revenues. For the disposal of hazardous fractions disposal costs have to be considered.

Therefore investigation and choice of appropriate purchasers for the different output fractions is indispensable to set up a financial sustainable and environmental sound e-waste recycling business. A lot of fractions normally can be destined directly to subsequent recycling or recovery plant, some of them might have to be commercialised via intermediaries. In any way achievable sales prices often depend on global price indices as a lot of the recycling fractions are traded on the global market, even if they are sold to local purchasers. Unfortunately this is a quite volatile market; prices can rise or drop often more than 30% of the original value within one year. Initial indications about current prices values for certain material can be gained via internet platforms, such as

- www.metalprices.com
- www.lme.com
- www.kitco.com
- www.recycle.net

The following chapters contain information about how the certain fractions should be handled and stored and to which kind of further processing they should be destined. Concerning hazardous fractions necessary health & safety precautions are indicated and potential risks are described.

DS 16 Printed Wiring Board – End-Processing

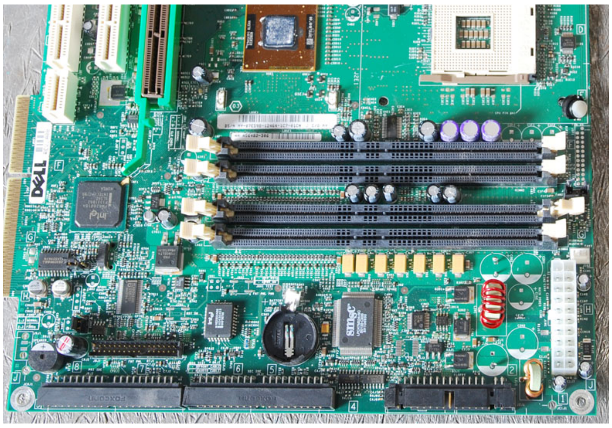


Figure 16. Motherboard (high grade PWB) [2].

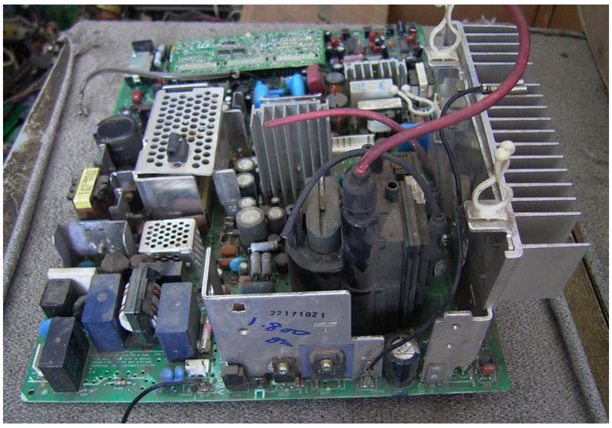


Figure 17. Low grade PWB of a CRT monitor [2]

General description

From dismantling an endo-life-computer the printed wiring boards (PWB) represent the most valuable fraction. They contain several base, precious and special metals, that can be recovered by specialized metal refineries. With regard to their content of precious metals, different qualities of PWBs exist. A possible way to determine their grade (quality) is the gold content. Table 3 gives a potential classification of the board grades and corresponding PWB examples.

On the other hand, PWBs also contain several toxic substances like heavy metals or flame retardants. A major release of hazardous substances can be caused by an inappropriate treatment of the PWBs, e.g. uncontrolled wet chemical processes, incineration, etc. Such processes present a high risk of losing value and usually imply harms to human health and the environment. Thus these processes have to be avoided. In general, PWBs are preferably sold to refineries having high recovery rates and paying the best price for the material.

Table 3. Possible classification of board grades according to the gold content.

Grade	Au content [ppm]	Occurrence (not exhaustive, not definitive)
Ultra low grade	up to 20 ppm	Unprepared boards from CRT monitors (TV & PC), HiFi, power supplies, small domestic appliances, etc.
Very low grade	up to 50 ppm	Prepared* boards from CRT monitors (TV & PC), HiFi, power supplies, small domestic appliances, etc.
Low grade	up to 100 ppm	Leached IT boards (very low to low grade)
Medium grade	up to 200 ppm	IT boards (PC, server, printer), mixed connectors, LCD monitors, IT mother boards
High grade	up to 300 ppm	IT/telecom boards
Very high grade	above 300 ppm	Mobile phones, IT components (processors, etc.)

* prepared refers to the removal of heat sinks, Al frames, transformers, etc.

Pre-processing

For an appropriate manual pre-processing of the PWBs, refer to the data sheet [DS 12: PWB – Dismantling]. Before a pre-processing is performed, it is helpful to check the precise conditions of acceptance of the purchaser. Often it is reasonable to sort the PWBs according to the different grades (qualities). To supply the boards to an integrated metal smelter, do not perform any further processes than described in [DS 12: PWB – Dismantling]. Especially an inaccurate crushing/shredding of the PWBs usually leads to a significant loss of precious metals and thus reduces the value of the fraction.

As described in [DS 12: PWB – Dismantling], depending on the receiving smelter, a separation of the CPU from the PWB might be economically advantageous. Due to its high content of gold and silver, CPUs are well paid on the market.

Markets and Prices

Due to the complex composition of PWBs, high recovery rates of the metals contained therein can only be met by an appropriate treatment in specialized plants. Different technologies like pyrometallurgy, hydrometallurgy, electrometallurgy and a combination of those can be applied to recover the metals. Schluep et al. (2009) describes the different existing technologies and reasons why only **integrated copper and precious metal smelter-refinery operations**[11] – which combine different of the above mentioned technologies – are able to cope with requirements like environmentally sound treatment, high recovery rates, industrial scale of application, etc. The main advantages of such combined plants are:

- Recovery of multiple metals (in contrast to e.g. a treatment solely based on hydrometallurgical steps) allowing for a higher material revenue.
- High efficiency (recovery rates) for the different metals, resulting in a higher material revenue.
- Controlled processes which allow for a treatment under environmentally sound conditions (off-gas cleaning system, waste water treatment, etc.) and for safe conditions for workpeople.

Here, it is therefore recommended to supply PWBs to integrated metal smelters on the global markets. As mentioned before, those facilities demand certain requisites for PWB supplies (grade quality, minimum lot, board upgrading, etc.). Due to requisites like minimum lot shipment, it might be necessary to supply lower volumes of PWB to an intermediary. However, it should be ensured that PWBs do not end up in an inappropriate treatment.

[11] Or in short: integrated metal smelter

Integrated metal smelters determine the price of the PWBs mainly by their concentration of gold (Au), palladium (Pd), silver (Ag) and copper (Cu). Data about the concentration of Ag, Au, Pd and platinum (Pt) for PWBs originating from different appliances are given in Table 4. The concentration of Cu in a PWB is commonly around 15-20 w%. Table 3 gives a possible classification of board grades by an integrated metal smelter.

Table 4. Average concentration of precious metals in printed wiring boards from different equipment types (literature review in Chancerel et al. 2009)

Equipment type (origin of the printed circuit board)	*Silver (g/t)*	*Gold (g/t)*	*Palladium (g/t)*	*Platinum (g/t)*
Audio and video equipment	674	31		
Radio set	520	68	8	
DVD player	700	100	21	
Personal computer	905	81		
Personal computer	1000	250	110	
Personal computer	1000	230	90	
Personal computer	775	156	99	
Personal computer	600	300		
Personal computer	700	600	100	40
Computer keyboard and mouse	700	70	30	0
Computer CRT Monitor	150	9	3	
Computer LCD Monitor	1300	490	99	
Printer	350	47	9	
Telephone	2244	50	241	
Mobile telephone	3573	368	287	
Mobile telephone	5540	980	285	7
Small IT and telecommunication equipment	5700	1300	470	
TV set—CRT-Monitor	280	17	10	
TV set—CRT-Monitor	1600	110	41	
TV set—LCD-Monitor	250	60	19	

Special fractions

The following fractions contain either PWBs or special metals and can therefore be supplied to integrated metal smelters, too (to be clarified with the respective smelter):

- Optical reader of FDD
- Floppy disk reader

- Hard disk platters of HDD (storage for future recovery or supply to integrated metal smelter)

DS 17 Plastics

Figure 18. Plastic keys and keyboard [2].

Figure 19. Plastic casing of a CRT monitor [2].

General description

Nowadays plastics are found in almost every electronic appliance. They have replaced traditional materials over time, such as metal, wood or glass for many applications. They are usually found in casings, frames, covers and small parts of electronic appliances. Various types of plastic exist, of which ABS (acrylonitrile butadiene styrene), PS (polystyrene) and PP (polypropylene) are usually used in computer manufacturing. In addition, many other types are used depending on their characteristics, as well as plastic compounds.

When plastics are recycled the quality of the material often decreases (*downcycling*). If several plastic types are recycled mixed together, this degradation is even stronger. As a consequence, one of the main purposes of pre-processing plastics is their separation according to their plastic types and to cleanse the plastics from foreign material.

Pre-processing

Depending on the final treatment of plastics, different pre-processing steps can be performed:

(1) In any case plastics should be cleansed from all foreign material. Especially steel parts are unwanted in the plastic mix as they can destroy recycling machines. Unclean plastic therefore has less value and some recyclers don't even take it.

(2) To add a maximum value to the recycling process, plastics should be segregated by type (ABS, PP, PS, HIPS, etc.) and by content of BFRs. Depending on the requirements of the plastic processor, the segregation is realized at the dismantling facility or at the processor's plant. In most cases, plastic types apt for recycling can be classified by the plastic recycling code (PIC – see Table 5). A bigger challenge is the identification of BFRs within plastic (see below, *Flame retardants*).

(3) To transport plastics efficiently, it is reasonable to reduce the particle size of plastic by shredding it mechanically. This is sometimes required from the plastic processor, too. When shredding, several aspects should be taken into account:

- Only pure plastic fractions should be shredded; avoid the presence of other materials in the plastic fraction.
- Ensure a good maintenance of the shredder.
- In the shredder high temperatures can occur. At temperatures above 300 °C, the generation of dioxins from BFRs is likely to happen. But if a proper maintenance of the shredder is ensured, those temperatures are not reached when shredding pure plastic fraction. At the absence of direct temperature gauging, blue colour changes of metal parts of the shredder are a clear warning signal that temperatures have reached a level where dioxins can be generated (> 300 – 350 °C). In that case the shredder should be stopped and (a) bearings and movable parts of the shredder should be cleaned (i.e. from stuck plastic), (b) the hammers and/or blades of the shredder should be grinded.

Table 5. Symbols of the plastic recycling code (Wikipedia 2011).

Symbol	Code	Description
01 PET	#1 PET(E)	Polyethylene terephthalate
02 PE-HD	#2 PEHD or HDPE	High-density polyethylene
03 PVC	#3 PVC	Polyvinyl chloride
04 PE-LD	#4 PELD or LDPE	Low-density polyethylene
05 PP	#5 PP	Polypropylene
06 PS	#6 PS	Polystyrene
07 O	#7 O(ther)	All other plastics
	#9 or #ABS	Acrylonitrile butadiene styrene

Valuable LCD layers

The light-conducting and -diffusion layer in an LCD or LED monitor is made of high-quality plastic which can possibly be commercialized separately from common plastics. If relevant amounts of this material can be gathered, a potential way to sell it are online recycling markets.

As Figure 20 shows, the layer is a thicker layer which is highly transparent. It is directly connected to the light source (backlight of LCD).

The further layers (except the polarizer/liquid crystal-"sandwich", see [DS 18: Liquid Crystal Layer]) of the LCD module are high-quality, and thus valuable, too.

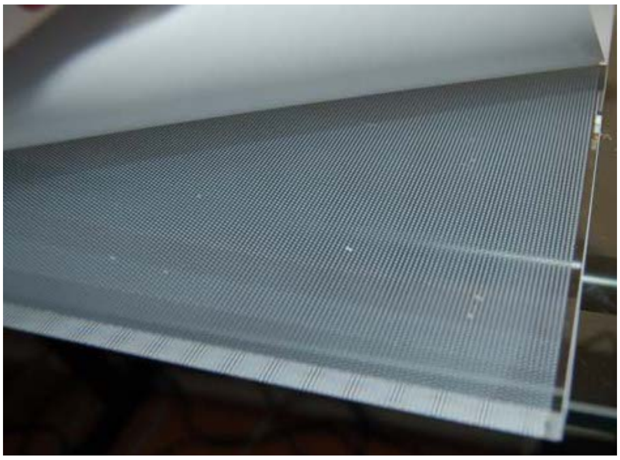


Figure 20. Light-conducting and -diffusion layer of an LCD monitor [8]**.**

Flame retardants

Some plastics contain brominated flame retardants (BFR), which are hazardous substances introduced to reduce the flammability of plastic parts. Theses plastics are found in many parts of electronic appliances and must be treated as hazardous materials.

A study by Waeger, Schluep, and Mueller (2010) on toxic substances in mixed WEEE-plastic indicates that ICT equipment (excluding monitors) generally contains brominated flame retardants at concentrations close to or above the European Maximal Critical Value (MCV)[12]. However, the concentration of BFR in similar devices vary significantly; While i.e. CRT casings contain relatively high concentrations of BFR, no BFRs could be found in flat screen casings.

In practice, it is difficult to identify which plastic parts contain BFR and which do not if no special analytical equipment is available[13].

[12] Restriction of Hazardous Substances in electrical and electronic equipment Directive or RoHS-Directive (2002/95/EC) by the European Union (http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:037:0019:0023:en:PDF).

[13] A potential way to determine whether plastics contain halogens (incl. BFRs) or not is the well-known *Beilstein test*: (1) A copper wire is cleaned and heated in a flame, (2) the plastic part is touched with the heated copper wire, (3) hold the wire into the flame again and observe the colour of the flame: if it turns green to blue, the plastic contains halogens (Br, Cl, etc.) and thus probably BFRs. Due to the likely generation of dioxins, only small pieces should be tested (burnt) and a sufficient ventilation must be provided.

The heating of plastics containing brominated flame retardants (> 300°C) can cause the formation of brominated dioxins and furans, which are highly toxic. This has to be considered especially when shredding plastic fractions.

Markets

Plastics are made of natural hydrocarbons such as oil, gas or carbon. Depending on the technique applied, homogeneous plastics can be valorised as plastics or fuel. This is more difficult for plastic compounds, which can be valorised thermally, i.e. by burning them appropriately in an incinerator.

At present, treatments exist which allow for the separation of different plastic types, including the separation of plastics with and without BFRs, respectively. The existing treatment alternatives for plastics are summarized in Table 6.

Treatment

Table 6. Treatments for plastics (adopted from MAVDT 2010).

Treatment	Description
Mechanical recycling (plastics in general)	Shredding of plastics and subsequent heating for pelletizing.
Chemical or tertiary recycling (plastics in general)	Waste plastics are treated by physicochemical processes in which the plastic molecules are broken in order to get monomers or other useful/valuable products for the petrochemical industry and convert into raw materials again. Chemical recycling can take place by different processes: pyrolysis, hydrogenation, gasification, degradative extrusion and methanolysis. A big advantage of some chemical recycling processes such as pyrolysis is that no previous separation by plastic resin type is required, which allows for the recycling of mixed plastic waste. Among the chemical processes used for the recycling of plastics is also the methanolysis (depolymerization process) which decomposes the plastic to its original components by applying heat and pressure in the presence of methanol. This combination not only causes the decomposition of the polymer chain (leaving only monomers which are purified and re-polymerized to a new resin), but enables the destruction of contaminants.
Incineration with energy recovery (plastics in general)	By a controlled combustion, this process takes advantage of the high energy content of plastic waste as alternative fuel. Although some plastics can be recycled with benefits to the environment, there may be remaining plastics from the recycling process that cannot be recycled. In case a mechanical or chemical recycling cannot be justified, energy recovery may be an effective way to recover the intrinsic value of plastic waste.
Incineration	In developed countries, plastics have to be incinerated. An incineration of plastics containing brominated flame retardants is reasonable if some specifications are considered. To avoid the generation of dioxins or furans, a controlled combustion in excess of 600 ° C must be ensured. Moreover, the incinerator must have appropriate filters and equipment in their furnaces to control pollution, emission of metals, VOCs and dioxins (off-gas control).

DS 18 Liquid Crystal Layer

Figure 21. Components of an LCD module [2]**.**

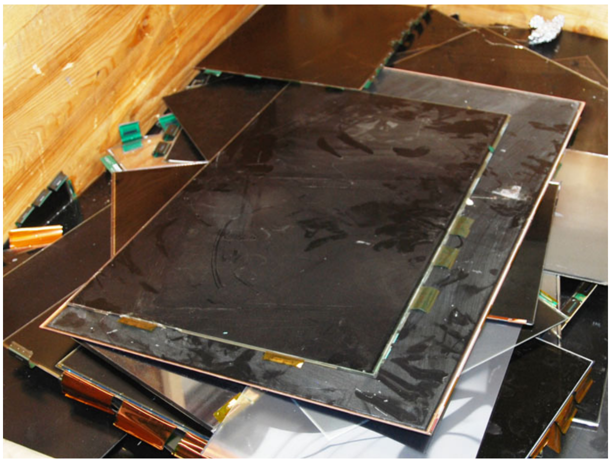


Figure 22. Liquid crystal layers [2]**.**

General description

Liquid crystals find wide use in liquid crystal displays, which rely on the light modulating properties of certain liquid crystalline substances.

The optical properties of the liquid crystal layer are modified by applying an electric field to it. Liquid crystals do not emit light directly and are therefore dependent on a light source (in general cold cathode fluorescent lamps or LEDs). The CCFLs are hazardous and must therefore be treated cautiously (see [DS 29: CCFL]).

Liquid crystal layers contain indium, which is a valuable rare metal.

Localisation in appliances and distinctive signs

Large liquid crystal layers are mainly used in computer and TV monitors. Smaller liquid crystal layers are also found in displays of printers, fixed line telephones, photo cameras, etc. The liquid crystal layer is located between two (dark) polarizers (see Figure 22 and Figure 23), which is enclosed by several other, usually white or transparent plastic layers (see Figure 21).

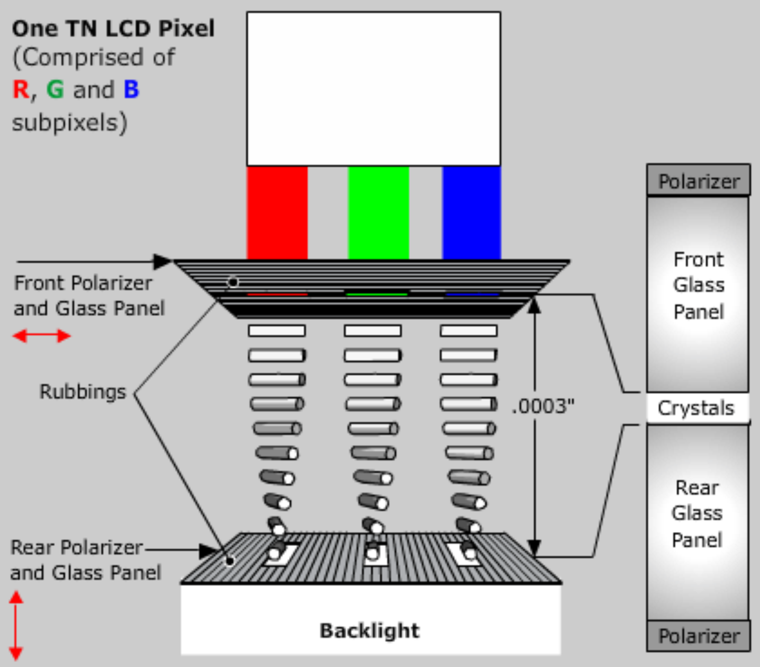


Figure 23. Scheme of a liquid crystal layer [10]**.**

Caution during storage

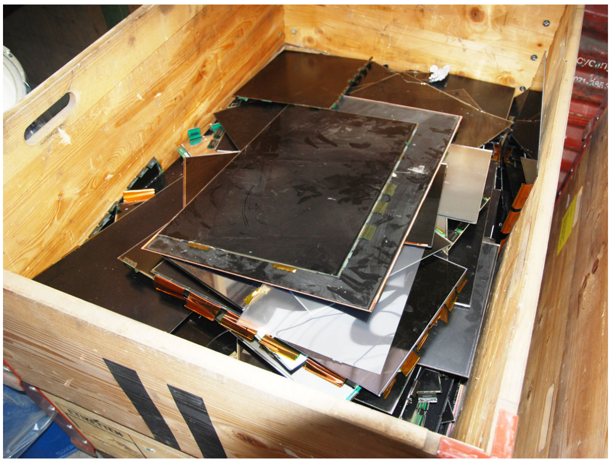


Figure 24. Storage of LCD layers (without backlight).

Store the LCD layers in a recipient. If possible, avoid breakage of the layers.

Collection and treatment facility

In the ITO (indium tin oxide) electrodes of the liquid crystal module, small amounts of indium (In) can be found. Indium is a rare metal which is increasingly in short supply. Due to the small volume of the liquid crystal layer and the potentially rising price of indium, it is recommended to **store them for future indium recovery**.

Another option is the disposal of the liquid crystal module (without CCFL, see [DS 29: CCFL]) in a **landfill** (see 7.1) or its **controlled incineration** (see 7.2).

DS 19 Ferrous Metals

Figure 25. Stainless steel [2].

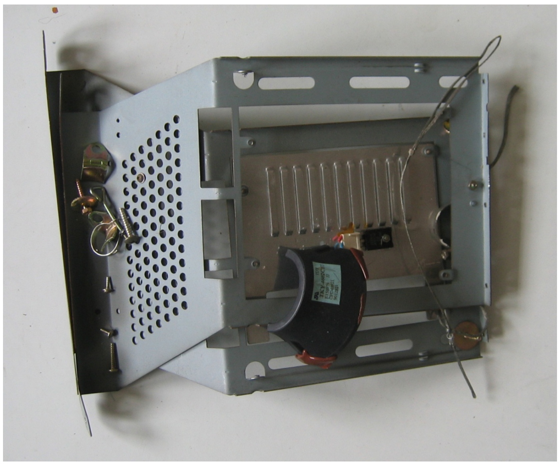


Figure 26. Steel scrap [2].

General description

Ferrous metals comprise the different grades of steel parts, including chrome steel, chrome-nickel steel and stainless steel. It is often difficult to differentiate the different types of steel, so that they are usually stored together. Knowing which type of steel is found in which component makes the segregation easier. Chrome steel and chrome-nickel steel are usually not painted, shiny and without rust. Stainless steel, an alloy of iron and chromium, should be stored separately and not be mixed with ferrous scrap.

In a computer ferrous metals of different types are generally found in protective tower, casings of the various drives, casings of the power supply and the loudspeakers. Some frame parts are also contained in other components.

Pre-processing

Steel should be cleaned up to a degree where it is still viable. Steel with some plastic content is also accepted as plastic can act as a burning facilitator.

Markets

Ferrous metals can be sold to scrap metal merchants. Like other commodity prices, ferrous metals prices are fluctuating considerably.

DS 20 Aluminium

Figure 27. Aluminium scrap [2].

Figure 28. Cleaned Aluminium [2].

General description

Nearly all electronic goods using electric power higher than a few watts contain aluminium plates. They generally act as heat sinks and therefore are found in the power supply pack in greater quantities. Also HDD and FDD housings as well as motherboards contain aluminium components. As shown in the figure above they are found in different shapes.

Pre-processing

Aluminium can easily be distinguished from other metals as it is clearer and not magnetic. To clean recovered aluminium components, all foreign material, such as screws, rubber, plastic etc. should be removed. Take care that aluminium is properly cleaned as aluminium recyclers refuse impure parts.

Markets

Aluminium scrap can be sold to scrap metal merchants. Like other non-ferrous metals, aluminium prices are fluctuating considerably. Prices depend on the aluminium quality (grade). Table 7 shows how strong the prices for different scrap aluminium types may vary.

Table 7. Exemplary aluminium scrap prices 2009 (Recycle.net 2009).

Aluminium Scrap	**Spot Market Price** ***[USD/KG]***
Primary Aluminium	*1.40*
Old Mixed Aluminium	0.37
Utensil Aluminium	0.49
Aluminium Turnings	0.18
Aluminium Extrusions	1.04

Low Copper Aluminium	1.01
Clean Painted Aluminium	0.29
Painted Aluminium Insulated	0.11
Used Beverage Cans (UBC loose)	0.37
Insulated Aluminium Wire	0.37
Bare Aluminium Wire	0.97
Aluminium Foil	0.44

DS 21 Copper

Figure 29. Recovered copper from a CRT monitor [2].

Figure 30. Copper coils [2].

General description

Copper is implemented in all electronic devices. It's incorporated in cables and wires, in magnetic deflectors, coils and conductors. A considerably large amount of copper is found in CRT monitors respective in the magnetic deflector and the surrounding wire. It is comparably easy to access and can be recycled to a great value after cleaning. Other components like copper coils are harder to clean and therefore are of lower value (see copper scrap table below).

The composition of a transformer is given in Figure 31.

Pre-processing

Copper should be cleaned before further processing. Therefore all foreign materials like screws, rubber and plastic should be removed. This is not viable with all components, e.g. copper coils, as it is too labour intensive. Wires and cables can be granulated to remove copper (see data sheet wires and cables).

Markets

Copper scrap can be sold to a scrap metal merchant. As other non-ferrous metals, copper prices are fluctuating considerably. Scrap copper prices depend on the copper quality (grade).

Table 8. Exemplary copper scrap prices, 2009 (Recycle.net 2009).

Copper Scrap	Spot Market Price [USD/kg]
Copper Grade A	*4.30*
Heavy Scrap Copper	3.92
Scrap Copper	3.44

Light Scrap Copper	2.98
Copper Turnings	2.98
Copper Wire Scrap	3.81
Insulated Copper Wire	1.81

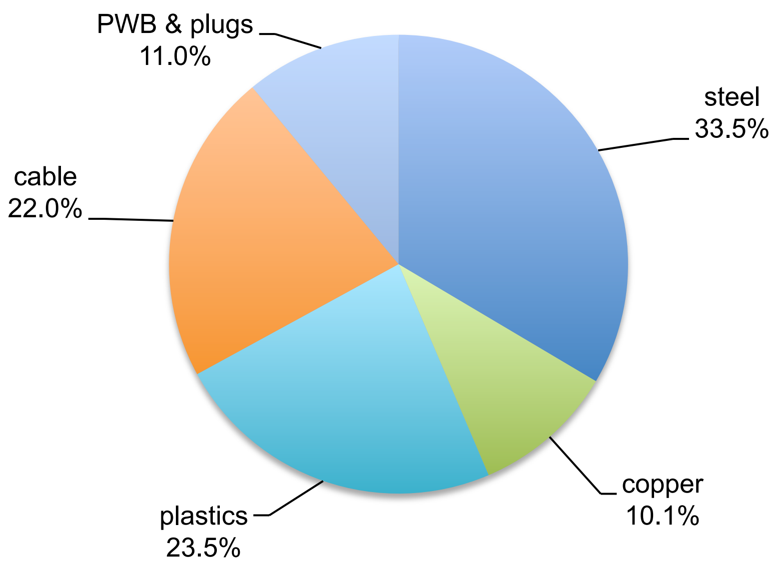


Figure 31. Composition of a transformer (ecoinvent 2010).

DS 22 Metal Plastic Mix

Figure 32. Mix of different components containing plastic and metals [2]

Figure 33. Loudspeakers and fans [2].

General description

Metal plastic mixed components are mostly found on printed wiring boards. Among them are cooling fans, loudspeaker, electrolytic capacitors, coils, transformers, connectors, transistors etc. Cables and wires, also consisting of a metal plastic mix, are treated separately (see [DS 15: Cables & Wires]).

Pre-processing

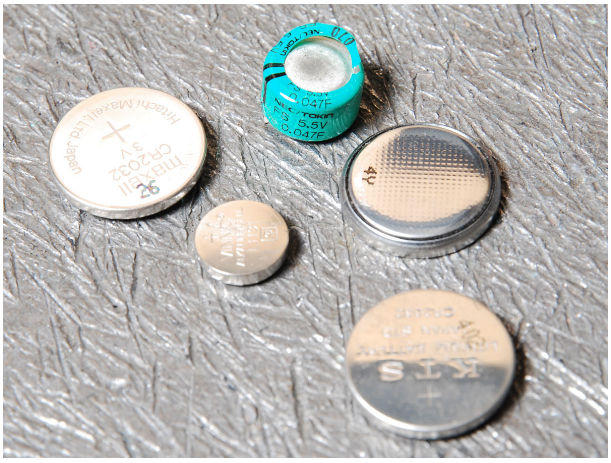
In most cases it is not viable to dismantle or clean plastic metal mixed components. It would just be too laborious to separate it manually. In many countries there exist mechanical recycling plants that are able to separate mixed scrap containing Fe- and NE-metals and plastics into more or less pure materials by means of shredding, magnetic separation, sensor based separation and so on.

Markets and prices

The value of mixed metal-plastic scrap depends on the composition. A higher content of copper in the material increases, high content of plastics decreases the value of te concerning fraction. Some scrap metal merchants take metal components even with a high fraction of plastic as plastic sometimes is used as a burning facilitator in the melting process.

7 Hazardous Fractions: Characterization & Treatment Alternatives

DS 23 Battery



Button cells batteries [2]

Laptop Li-ion battery [2]

Application and function

Many different types and shapes of batteries can occur in IT appliances. Small batteries (i.e. button cells) are used to cover the permanent low energy supply for alarm and computer system (clock, memory backup, etc.). In contrast, bigger batteries (e.g. laptop batteries) allow to run the whole device. Most modern devices do not need the small batteries anymore because the permanent energy demand for the system is reduced on the one hand. On the other hand the remaining energy demand can be covered by the capacitors.

Localisation in appliances and distinctive signs

Batteries are very diverse in terms of characteristics, composition, form, size, colour, etc. Almost every IT-equipment contain at least one battery. Rechargeable accumulators can be found in mobile phones, laptops, toothbrush or electrical razors. Appliances like torches, portable CD players, etc. can be operated using rechargeable and non-rechargeable batteries. Small (button) cell batteries are often used as a backup battery to the main battery; it provides an independent energy supply for processors, timers, security backup, etc. in computers. It is commonly located on the PWB.

The following inscriptions can help to identify batteries and to distinguish from others components (capacitors, resistances). Inscription: **+ / -**, **Li-ion**, **NiCd**, **NiMH** (nickel metal hybrid battery), **alkaline** (Zn/MnO_2), "**RAM**", "**Dallas**", "**Symphony**", **"Danger do not open"**, "**Do not dispose in fire**", "**Timekeeper**". Rectangle batteries are often disposed near the bios system of the motherboard, with the sign of a **clock**, or a **dog**.

Hazardous substances

Heavy metals such as cadmium (Cd), nickel, (Ni), and to some extent zinc (Zn). Organic solvents, etc.

Health and environmental threat

Cadmium (Cd) is extremely toxic even at low concentration. Breathing large levels of Cd severely damage the lungs and can cause death. Water contaminated with Cd severely irritates the stomach, leading to vomiting, and diarrhoea. Cd stays in the body for a long time and can build up in kidney, or lead to lung damage and fragile bones. It is a probable carcinogen. Cd is also used in silver solders or as stabilizer for plastics as well as in phosphorescent coatings in some CRT.

The most common harmful effect of **nickel** is an allergic reaction (skin rash, asthma) for people sensitive to it (10-20 % of the population). People working in nickel-processing plants have experienced chronic bronchitis and reduced lung function. Long use of drinking water contaminated with high concentration of nickel may lead to stomach ache and adverse effects to blood and kidneys. Ni compounds are known as carcinogens for human.

Zinc is an essential element in human diet. Zn deficiency results from inadequate intake of Zn and can cause problem (hair loss, diarrhoea, brain development retardation of foetus and young children). However, large doses are harmful which can cause stomach cramps, nausea, vomiting. Intake over a longer period can cause anaemia. Free Zn ion (Zn^{2+}) in solution is highly toxic to plants, invertebrate and some fish.

Mercury: see [DS 25: Mercury switch]

Caution during dismantling

Never crush or open a battery!

There is usually no difficulty or risk to separate the batteries from their support if they are in good condition. Use gloves, and wash hands and throw the gloves away after contact with substances from defective and leaking batteries.

Caution during storage

Figure 34. Safe battery storage in a barrel [2].

Avoid long time storing. Batteries are subject to corrosion and cell rupture, which could release reactive hazardous substances (heavy metal oxide, organic solvents, sulphuric acid).

Lithium-ion batteries can easily rupture, ignite, or explode when exposed to high temperatures, or direct sunlight.

Avoid fire risk and contact with heat sources. All batteries be stored acid-resistant barrels. They should be stored in a dry and sheltered place.

Collection and treatment facility

Batteries should be treated in an adequate plant. In any case, they should not be incinerated in an open fire or with municipal waste.

Table 9. Average composition of rechargeable batteries in laptops (Meskers, Hagelueken, and Van Damme 2009)

(in weight %)	NiMH	Li-ion	Li-polymer
Mixed metal	5.3	-	-
Electrolyte	10	-	-
Steel or Fe	25	35**	1
Plastic	8	10-20	3
Nickel	21.8*	1-2	2
Copper	-	7-8	16
LiCoO2	-	25-27	35
Carbon	-	10	15
Aluminum	-	35**	15
Others	17.4	12-18	23

** in NiOOH   ** depending on use of Al or Fe can*

DS 24 Lead-acid Battery

Figure 35. Selection of lead-acid batteries [1]**.**

Application and function

Lead-acid batteries are one of the most commonly used independent and rechargeable energy supplies for automotives (cars, motorcycles starter, truck, etc.), for big appliances (e.g. off-grid household electric power system, portable TV).) as well as for torches, laptops, telephones, etc. They are also contained in UPS appliances (uninterruptable power supply).

Localisation in appliances and distinctive signs

Usually, a UPS is an easily identifiable separate unit, that is connected to the appliance by two wires. The following inscriptions can help to identify lead-acid batteries and to distinguish them from others batteries:

+ / **-** (for all batteries in general), **lead**, **Pb**, **dry**, **SLA** (Sealed Lead Acid battery), **VRLA** (Valve Regulated Lead Acid battery).

UPSs are usually easy to reach and disconnect from the appliance.

Hazardous substances

- Lead (Pb),
- Lead oxide and
- Sulphuric acid

Health and environmental threat

Lead is a global environmental contaminant. It is a threat for human being, animals and plants. It can be spread through air or water and can be accumulated in the ground. It is a poisonous metal that can damage the nervous system, especially in young children, causing mental retardation, memory and learning difficulties as well as behavioural problems. Pregnant woman should avoid contact with Pb. Basically; lead can affect almost every organ and system in body. According to the EPA (US Environmental Protection Agency), lead is a probable human carcinogen.

Sulphuric acid can be extremely corrosive.

Caution during dismantling

Never open a battery!

Usually they are not dangerous to handle when in undamaged condition, but be careful in handling when leakage due to mechanical damage can be observed.

Discharging them by short-circuiting (direct electrical connection between + and -) may rapidly increase heat and might lead to explosion. Especially large batteries can cause an electrical shock.

Caution during storage

Avoid long time storing. Batteries are subject to corrosion and cell rupture, which could release reactive hazardous substances (lead, sulphuric acid).

Avoid fire risk and contact with heat sources. All batteries should be stored in acid-resistant barrels.

They should be stored in a dry and sheltered place.

Collection and treatment facility

Batteries should be treated in an adequate plant. In any case, they should not be burned in an open fire or with municipal waste.

DS 25 Mercury Switch

Figure 36. Selection of mercury switches [1]**.**

Application and function

The electrical switch function is to interrupt an electrical flow in an electrical circuit (on/off function). Mercury switches have been commonly used in bimetal thermostats (coffee machines, etc.).

Mercury switches are mainly found in large household appliances (EU-WEEE category 1) and only to a very limited extent in ITC appliances (EU-WEEE category 3). Because of the presence of the poisonous mercury, these switches have been eliminated from most application. They are still used in vending machines with "tilt alarms".

Localisation in appliances and distinctive signs

Mercury is encapsulated in a sealed glass capsule, which might be protected by a case. It has the aspect of a big drop of silvery moving liquid.

Hazardous substances

Mercury (Hg), also called quicksilver is a shiny, silver-white, odourless liquid at room temperature. If heated, it is a colourless, odourless gas. It can also be solid (white powder salt or crystals) when mixed with other compounds (chlorine, sulphur, oxygen). Liquid metal mercury vaporises easily. In a gaseous state it is absorbed by the lungs. Its toxicity is caused by its effects on enzymes and proteins.

Health and environmental threat

Mercury can enter the body through the lungs, through the skin, and via the digestive system. The nervous system is very sensitive to all forms of mercury. Hg vapour increases significantly the exposure and affects directly the brain. Short-term exposure to high level of Hg vapours may cause lung damage, nausea, vomiting, diarrhoea, skin rashes, and eye irritation. Exposure to high levels of Hg can permanently damage the brain, kidneys and developing foetus. Effect on brain results in irritability, shyness, tremors, change in vision, hearing and memory problems.

Some forms of Hg are possible human carcinogens.

Caution during dismantling

Never break the sealed envelope!!!

Caution during storage

Store separately to avoid shock with hard and heavy objects. Keep it in a sealed recipient, and keep it in a cool place away from any heat sources (e.g. direct sunlight).

Collection and treatment facility

The switches have to be sent to a proper recycler without breaking them.

DS 26 Capacitor

Figure 37. **Selection of capacitors** [2].

Figure 38. Capacitor [2].

Application and function

Also called condensers (old fashioned term). They have many uses in electronic and electrical systems: energy storage, rectification of power energy supply and electrical signals, filter for electrical "noise", motor starting energy capacitor, signal processing, selection of information in frequency bands (tune for radio stations).

Localisation in appliances and distinctive signs

Capacitors are present in any electrical and electronic appliances and their appearance is very diverse. Some are similar to alkaline batteries, but wear a ruff on the upper part. Inscription: **nF**, **μF**, **mF** (for nano-, micro- and millifarads).

Critical capacitors (with PCBs, see below) are large (same size or larger than a thumb) and produced before 1987. Therefore, old appliances (HiFis, refrigerator, TV, electrical ovens, vacuum cleaners, etc.) should be depolluted with caution.

Hazardous substances

Old large capacitors are very likely to contain **polychlorinated biphenyls** (**PCBs**) as dielectric fluids. New electrical components are no longer produced with PCBs. As a rule all capacitor with a **diameter larger than 2 cm** (**same size or larger than a thumb**) and found in appliance **made before 1986-87** should be handled with extreme caution. PCBs is a family of more than 200 different chlorinated organic molecules. They are either liquids or solids, colourless or light yellow. Besides capacitors, products made before 1987 with PCBs are fluorescent lighting fixtures, hydraulic oils, etc. They have been used as coolants and lubricants in electrical equipment because they don't burn easily and are good insulators.

Capacitors may also contain harmful **organic acids** as electrolytic solution.

There exists a certain concern about large capacitors from microwaves (magnetron) as they may contain beryllium in the ceramic material around the filament. **Beryllium** (Be) and its salts are toxic substances and potentially carcinogenic. It may cause acute beryllium disease, a form of pneumonia. Beryllium dust production and inhalation should be avoided, as they may provoke lung cancer. People working with beryllium may become sensitive to it and develop an inflammatory reaction called chronic beryllium disease (CBD) that occurs within a few months or many years after exposure. The symptoms are fatigue, weakness, night sweat, difficulty in breathing, persistent dry cough. It can result anorexia, heart disease, and lung inflammation. CBD is treatable but nit curable.

Health and environmental threat

Capacitors may retain a charge long after power is removed from circuit; this charge can cause dangerous electrical shocks. Those used in camera flash can be extremely harmful and dangerous.

Exposure to PCBs may lead to skin diseases (chloracne, rashes), liver damage, alteration of estrogens formation (reproduction problems). PCBs are very probably carcinogens.

PCBs are very stable compounds remaining in the environment for a very long period. They can travel easily into air or into water with organic particles and bind strongly in the soil. PCBs accumulate easily in animals, and can reach significant concentrations in fish and marine mammals.

Caution during dismantling

Capacitors, especially large ones, may give an **electrical shock** that can be harmful and dangerous. The best way to avoid it is to leave the appliances disconnected from any energy sources during a few days. Therefore, WEEE should not be connected to the electrical network before dismantling. Never test an appliance before opening it!

Concerning depollution of PCBs containing capacitors, the following criteria allows to identify the critical capacitors: **diameter larger than 2 cm** (**same size or larger than a thumb**), produced **before 1986-87**. If such capacitors are found, any contact with the content should be absolutely avoided. Thus, such capacitors should be handled with tools to avoid hand contact. They can be separated from the support by a gentle 1/4-rotation with a pair of pliers. Use gloves and wash hands. Throw the gloves away if they get contaminated by liquid from capacitors, as the gloves can be a source of contamination. Do not crush or open capacitors!

Capacitors that do not match these characteristics can be processed with metal scraps.

Caution during storage

Avoid fire risk and contact with heat sources. Capacitors could be stored in a metal barrel.

They should be stored in a dry and sheltered place.

Figure 39. Storage of capacitors in a barrel [2]**.**

Collection and treatment facility

PCBs is known as dioxin precursor when it is burnt at too low temperature and with lack of oxygen. Therefore, capacitors that match the depollution recommendation should not undergo a thermic process at any case.

DS 27 Cathode Ray Tube CRT

Figure 40. CRTs stored in a container [2].

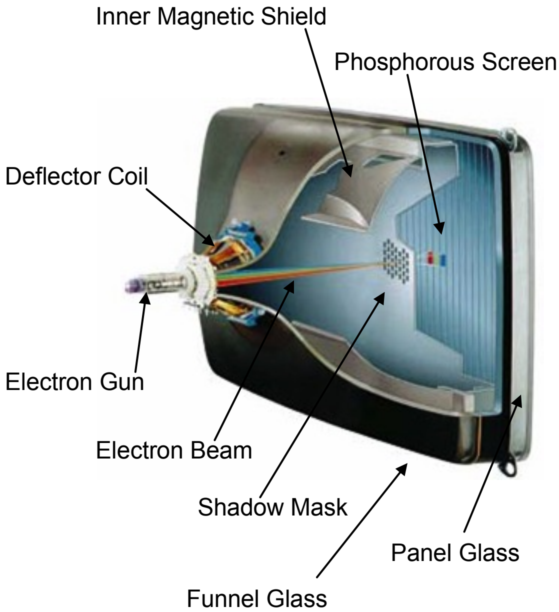


Figure 41. Schematic view of a CRT [1].

Application and function

The Cathode Ray Tube (CRT) is a vacuum tube containing an electron gun (a source of electrons) and a fluorescent screen used to create images in the form of light emitted from the fluorescent screen. CRTs contain a large amount of hazardous substances such as lead and barium oxide and therefore must be treated carefully in an adequate plant to avoid personal injury.

Localisation in appliances

Cathode Ray Tubes (CRTs) are the main component in CRT monitors and CRT TV-sets.

Hazardous substances

CRTs consist of different parts containing hazardous substances. The chemical composition of the panel and funnel glass is different because of the different technical requirements. Whereas in funnel glass lead oxide is used as an additive (in average 15%) for absorption of the high energetic radiation, the panel glass contains barium oxide or strontium oxide (in average 13%) (Gabriel 2001). The phosphor layer contains zinc sulphide, cadmium sulphide, yttrium, and europium.

During CRT manufacturing a phosphor layer is spread on the inner surface of the panel glass, whereas for the colours red, blue and green **zinc sulphide, cadmium sulphide, yttrium- and europium** are used. In black and white CRTs, a high fraction of **cadmium sulphide** is found in the phosphor layer. These monitor layers are applied in very thin coating and weigh 5 to 7 g per monitor. Further information about the phosphor layer is found on [DS 28: Phosphor Layer].

Getter platelets (remainder from the electron gun) are containing **barium** as well as barium containing compounds. For further treatment see [DS 19: Electron Gun & Getter Platelet].

Health and environmental threat

Lead and lead containing compounds are classified as cancer-causing. Uptake of lead can lead to acute and chronic poisoning. In the environment lead accumulates in aquatic and biological chains. In CRTs lead is embedded in the glass matrix and does not cause direct danger. However, during grinding of the glass fractions, lead can be laid open, eluted and transported by air. If there isn't any flue gas purification equipment, it can lead to higher emissions of lead and consequently to a distribution in the environment.

Mainly **cadmium and cadmium containing compounds** contained in the phosphor layer are classified as toxic and cancer causing. They accumulate in kidneys and lever and can cause acute and chronic poisonings.

Barium oxide deriving from electron guns is classified as harmful.

Caution during dismantling

To reduce the impact of the hazardous substances in CRTs on the environment, CRTs must be de-manufactured under controlled conditions.

A **vacuum** is applied to the interior of all CRT monitors. The monitors may implode if the outer glass envelope is damaged. Due to the power of the implosion, fractions may bounce and explode outwards with splints travelling at potentially fatal velocities. To avoid personal injury it is therefore crucial to equalise the pressure before any further treatment (see [DS 4: CRT Monitor]).

If the **electron gun** is still attached to the CRT, it should be removed. Attached to the electron gun may be a so called getter platelet. In some cases the getter platelet is attached at the top of the CRT itself. For further treatment see [DS 19: Electron Gun & Getter Platelet].

Using specially designed processes and machinery, the CRT glass body can be separated into panel glass, funnel glass, shadow mask and phosphor coatings. During this process all CRT coatings such as graphite and silicate conductive coating, iron oxide, aluminium oxide, and some other substances are removed. The exact composition of the coatings depends on who the original CRT manufacturer was.

In [DS 4: CRT Monitor] a method to separate panel and funnel glass of CRTs by hot wire cutting is described. Another method to separate the different glass fractions is to crash the CRT glass body as a whole. An especially developed technology then allows separating the grinded glass splints by the application of X-ray. X-ray detects lead containing glass splints and subtracts them from the pure glass fraction. Other toxic substances are washed out under controlled conditions.

After demanufacturing the CRTs, the cleaned glass fractions should be recycled. Figure 43 shows a selection of recycling options and interim solutions of which the ones indicated with a thick arrow should be preferred. Dashed lines mean that the option should not be considered as far as possible.

Caution during storage

Figure 42. Storage of cathode ray tubes (CRT) [2]**.**

The cleaned CRTs can be stored in open containers. To prevent leakage the container should not be exposed to the weather. If CRTs or parts of it are exposed to rain, the above mentioned hazardous substances can elude and drain into the lithosphere!

Once the CRT is further treated, e.g. panel is separated from funnel glass, all hazardous materials should be isolated immediately.

Collection and treatment facility

As CRT de-manufacturing requires well developed infrastructure to prevent damage to the health and environment, different approaches depending on the locally available technology should be chosen (see Figure 43).

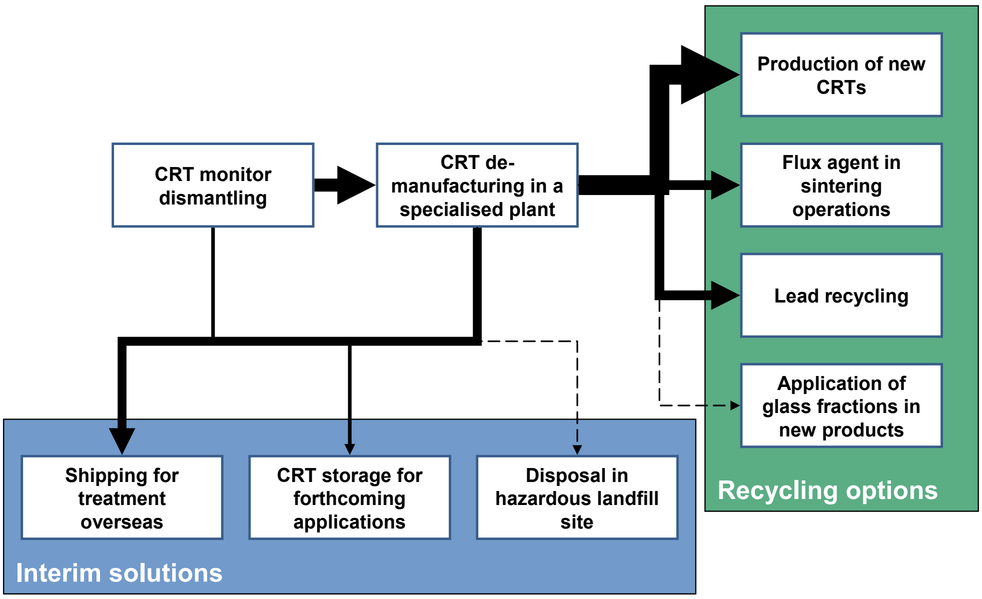


Figure 43. Recycling options and interim solutions for CRTs. Recycling paths to be preferred are highlighted with bold arrows. Dashed arrows indicate ultimate solutions, which should be avoided.

Table 10. Treatment alternatives for CRTs.

Treatment	Description
CRT glass to CRT glass	The reproduction of CRT glass offers the highest environmental outcome and is currently the best way to recycle CRTs as primary raw material is substituted. In addition to removing lead from the municipal waste stream, CRT recycling avoids the environmental impacts associated with mining and processing raw lead from ore, by supplying lead in the form of CRT glass, for CRT glass manufacturing. It also provides significant savings in energy and saves resources such as water and other raw material inputs for the CRT manufacturer. The introduction of new technologies like HDTV and the preference of consumers for flat panel displays accelerate the rate of obsolescence and replacement of conventional CRT sets. As Liquid Cristal Displays (LCD) are more and more replacing CRT monitors, CRT recycling may be faced out in the long term. To cope with these changes, development of new applications for used CRT glass is required.
CRT glass to flux agent in sintering operations	If recycling to CRT glass is not viable, CRT panel glass can be applied as a slag former in sintering processes. Used in small amounts (up to 5% in weight), it can replace conventional flux agents improving the densification process and the mechanical properties (Andreola et al. 2008).
CRT glass to lead recycling	"CRT glass to lead recycling" is a recycling process, where metallic lead (Pb) is recovered and separated from the CRT glass through a smelting process, where CRT glass acts as a fluxing agent in the smelting process. This process is a more automated process compared to "CRT glass to CRT glass recycling" and might be more cost-effective. It also provides safer working conditions because workers are protected from lead dust because of the automated process and an emission control system. The CRT glass to lead recycling process has a high overall throughput. However, this process reduces the value of high-quality glass (Kang and Schoenung 2005).
CRT glass to new products	To add heavy metals from CRTs to building materials or to give it to processes in the ceramic industry is critical because hazardous substances are diffusively distributed in the environment. This can lead to elution of these compounds by acid water. Nonetheless there are attempts to use CRT screen glass in the bricks and tiles production, as flux in brick and ceramic manufacture, in ceramic glaze, and in foam glass.

DS 28 Phosphor Layer

Figure 44. Phosphor layer [2]**.**

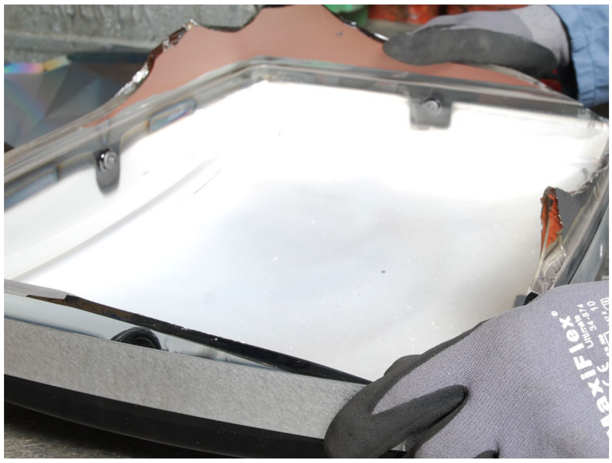


Figure 45. Interior view of the panel glass with phosphor layer [2]**.**

Application and function

Phosphors are substances that exhibit luminescence and are often transition metal compounds or rare earth compounds of various types (not to be mistaken for the chemical element phosphorus P). They are used in CRTs, fluorescent lamps (FL), compact fluorescent lamps (CFL), cold cathode fluorescent lamps (see [DS 29: CCFL]), light emitting diodes (LED) and other devices.

The phosphor layer in a CRT monitor is very thin (few nanometres), thus only small amounts are used per monitor (ca. 5-7 g). It is a white powder that is coated on the inner surface of the panel glass. When electrons (e.g. from the electron gun, see Figure 41) strike the phosphor, it emits light. Depending on its composition, the light appears in different colours. To generate the colours red, green and blue, the panel glass is coated with three different phosphors, that contain e.g. zinc sulphide, cadmium sulphide, compounds of yttrium and europium. The powder consists of a large variety of elements, among them also hazardous ones (see Table 11). In black/white CRTs, the phosphor layer contains significant amounts of toxic cadmium (Cd).

Localisation in appliances and distinctive signs

The phosphor layer in a TV or computer CRT can be easily located on the inner surface of the panel glass (see Figure 45).

Hazardous substances

- Yttrium Y (see[DS 27: CRT])
- Cadmium Cd (see [DS 23: Battery])
- Barium Ba (see[DS 27: CRT])
- Lead Pb (see DS 24: Lead-acid battery)

Table 11. Chemical composition of the powder from a CRT in weight-% (Resende and Morais 2010).

Y	In	Ce	Nd	Sm	Eu	Al	Si	S	K
17%	0.49%	0.02%	0.01%	0.02%	0.76%	4.55%	10.44%	17.38%	2.36%
Ca	**Mn**	**Fe**	**Zn**	**Sr**	**Zr**	**Ir**	**Pd**	**Ba**	**Pb**
0.80%	0.39%	0.54%	31.4%	0.82%	0.15%	0.42%	0.07%	2.15%	7.53%

Caution during dismantling

The generation of phosphor dust should be avoided during dismantling. It is recommended to wear a dust mask. To protect the worker, the air around the workplace should be aspirated by a fume hood.

Caution during storage

Figure 46. Recipient for phosphor powder [3]**.**

The phosphor layer has to be stored in a closed recipient (cover!) which prevents its release (Figure 46).

Collection and treatment facility

Phosphors contain both valuable and hazardous elements. There are two alternatives for their treatment:

- **Storage**: If possible, the elements contained in the phophors should be recovered. Due to the lack of adequate technologies, this is not viable for many elements contained in phosphors at present. But given the content of valuable elements and the rising prices for rare metals, it might be not only environmentally, but also economically advantageous to store the phosphors until appropriate technologies are available.
- **Disposal in a HW landfill**: It should be ensured that the phosphors are disposed in a safe landfill which prevents the release of the hazardous substances (e.g. leachate) into the environment (see also chapter 7.1). By landfilling phosphors, a potential recovery of the contained valuable elements is impeded.

DS 29 Cold Cathode Fluorescent Lamp CCFL

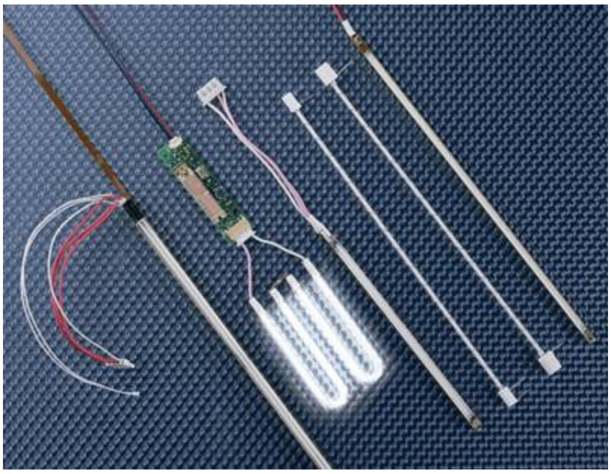


Figure 47. Selection of LCD backlights [1]**.**

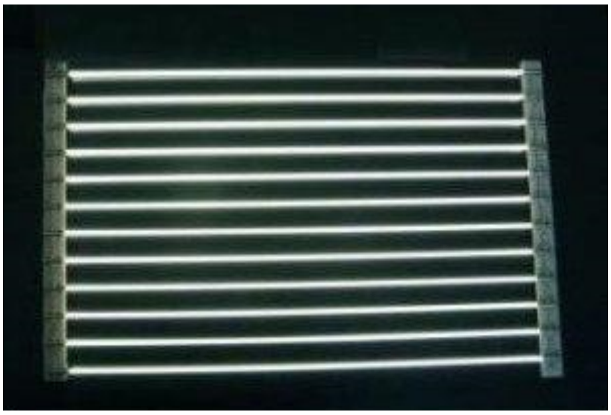


Figure 48. CCFL of a TV monitor [1]**.**

Application and function

The most common way to illuminate the liquid crystal layer is to use a cold cathode fluorescent lamp (CCFL). They increase the luminosity of the screen. They are found in laptops, TVs, and other devices with LCDs (photocopy machine display, mobile phones, etc.). CCFLs are classified hazardous due to their mercury (Hg) content and the phosphor layer (see [DS 28: Phosphor Layer]). The mercury is applied to the fluorescent tubes in a gaseous form. If it is ionised by electricity, it emits UV light, which in turn is transformed by the phosphor layer into visible light.

Localisation in appliances and distinctive signs

Figure 49. CCFL in a computer LCD screen [2]**.**

Two CCFLs are to be found inside the display frame, usually on the upper and bottom parts.

Hazardous substances

Mercury (Hg)

Phosphor layer (see [DS 28: Phosphor Layer]).

Health and environmental threat

Mercury (Hg), also called quicksilver, is a shiny, silver-white, odourless liquid at room temperature. If heated, it is a colourless, odourless gas. It can also be solid (white powder salt or crystals) when mixed with other compounds (chlorine, sulphur, oxygen). Liquid mercury vaporises easily. In a gaseous state it is absorbed by the lungs. Its toxicity is caused by its effects on enzymes and proteins.

Caution during dismantling

Depollution should be done in a fume hood with an air pollution control system to avoid mercury vapour exposure to the workers when a backlight accidentally breaks.

The fluorescent tubes are very thin and fragile, and should not break during dismantling. Access to them is possible only through careful manual dismantling of the frame. Once it is located, the fluorescent tube can be disconnected easily by cutting the alimentation wires. Be careful, as some fluorescent tubes are, in addition, stuck to the support.

Usually, backlights from TV monitors are more difficult to remove than those in computer monitors, as they are larger. In case of breaking, they should quickly be put into a closed box or barrel (see Figure 51).

Collection and treatment facility

Figure 51. Barrel with a special cover to store broken fluorescent tubes in a safe way [2]**.**

Figure 50. Safe storage in a box (with cover) for undamaged fluorescent tube [2]**.**

Fluorescent tubes should be stored very carefully in boxes that prevent the release of Hg-vapour in case of breaking (see Figure 51). However, if possible the breaking of the fluorescent tubes should be avoided.

DS 30 Cartridge

Figure 52. Toner Cartridge with photo-conductive drum (green) [2].

Figure 53. Ink Cartridges [2].

Application and function

An **ink cartridge** is a replaceable component of an ink jet printer. It contains liquid ink which consists of various pigments or colours for the coloration of a surface to create images and texts. Some ink cartridge manufacturers also add electronic contacts and a chip that communicates with the printer.

Toner cartridges contain fine dry ink (toner) particles, normally black coloured, which adheres to the paper electrostatically and is fixed by heating.

Localisation in appliances and distinctive signs

Toner and ink cartridges of different sizes are found in

- photocopiers
- fax machines
- printers

Hazardous substances

Beside toner particles, toner material contains very small amounts of potentially toxic compounds. Among them are Volatile Organic Hydrocarbons ('Volatile Organic Compounds', VOC), such as Styrol, Toluol, Ethylbenzol, Xylols, Phenols, Aldehyds and Ketons as well as various carbonic acids. In exceptional cases also carcinogen Benzol has been found in toner material.

Fluid and pasty toners can contain solvents declared as hazardous waste. Moreover colouring toners can contain heavy metals. Black powder toners normally don't contain toxic components.

Caution during dismantling

Toner and ink cartridges must be manually separated from the rest of the printer by all means. Otherwise hazardous substances contained in the toner material would be released during possible further mechanical treatment and seriously pollute recycling material.

Different toner and ink cartridges should be captured separately. Otherwise the quality of the collected material is degraded.

Caution during storage

Toner cartridges should be collected and stored in a way that prevents the release of any toner material.

Collection and treatment facility

As far as possible toner cartridges should be refilled and reused.

Toner cartridges filled with black powder can be emptied. The emptied plastic cartridges can be supplied to plastic recycling.

Toner cartridges containing fluid or pasty toners, colouring toners or toners of which the substances of content are unknown, should be disposed as hazardous waste.

DS 31 Photoconductive Drum

Figure 54. Organic photoconductive (OPC) drum without hazardous substances [2].

Figure 55. Selen-containing photoconductive drum [5].

Application and function

Photoconductive drums are used in laser printers and photocopiers to fuse the dry ink (toner) to the paper. According to the image to be printed, the electrical charge on the drum is specifically removed by a laser beam. The photoconductivity of the drum allows charge to leak away from the areas exposed to light. Dry ink adheres electrostatically to the charged areas of the drum that have not been exposed to light. Subsequently, the drum fuses the dry ink to the paper by direct contact and heat.

Localisation in appliances and distinctive signs

Photoconductive drums are found in laser printers, photocopiers and fax machines.

Drums in modern appliances commonly use non-hazardous organic photoconductors as a drum coating (OPC – organic photoconductor). OPC-drums can be identified by their coloured glimmer (see Figure 54 and Figure 56).

Modern high-performance printers work with drums based on amorphous silicon. These are distinguished by their greyish-blue and metallic appearance, its surface is hard and scratch-resistant.

However, drums from older appliances were often coated with toxic selenium (Se) or cadmium (Cd). Cadmium-sulfid-layered photoconductor drums are yellowish painted, while selen-layered photoconductor drums are characterised by their silver-gray surface, a larger diameter and a cylindricity that is open to the front side (see Figure 55).

Hazardous substances

- Selen
- Cadmium-sulfid

Health and environmental threat

Selen (Se) is a substantial trace element, high concentrations of selen can have toxic effects on human bodies and can cause acute and chronic poisoning.

Cadmium (Cd) is a heavy metal, which is toxic and cancer causing (see also [DS 23: Battery]).

Caution during dismantling

Photoconductive drums containing cadmium-sulfid and selen should be **captured separately**, otherwise the quality of the collected material is degraded. At latest during the mechanical treatment of the appliances, the coatings and hazardous substances in it are released.

In order to recover the containing aluminium, all photoconductive drums can be captured separately. However, to remove their coating they must then be supplied to an appropriate pre-treatment (i.e. blast cleaning, incl. special disposal of abraded Se/Cd-coating).

Caution during storage

Figure 56. Storage of non-hazardous organic photoconductive drums (OPC).

OPC drums and drums made of amorphous silicon can be stored in an open recipient.

Cadmium-sulfid- and selen-layered drums should be stored in a dry and closed recipient that prevents any release of substances. Do not expose selen-coated drums to light (store in a dark recipient, e.g. a covered barrel), because the coating starts to fall off under prolonged light exposure.

Collection and treatment facility

Cadmium-sulfid- and selen-layered drums (or their abraded layers) should be disposed of as hazardous waste. The drum itself can be recovered in the appropriate metal smelter.

DS 32 Electron Gun & Getter Platelet

Each CRT contains an electron gun and at least one getter. It is a small, circular troughs attached by a metallic stripe to the electron gun and filled with an earth metal, barium (Ba) being the most common. Barium is used to remove last traces of oxygen in the CRT. It is very reactive with air and water where it forms barium oxide. Ba is poisonous when dissolved in water. Therefore the getter platelet should not be touched during dismantling of CRTs.

Figure 22. Electron gun & getter platelet [2]**.**

According to Pramreiter et al (2007) the getter platelet has to be separated from the electro gun. The getter platelet has to be stored in drums protected against ingress and disposed as hazardous waste.

The electro gun consists of a high-alloyed nickel steel and can be commercialised as a recycling fraction.

Hazardous Waste Treatment Facilities

7.1 HW Landfill

Landfilling is one of the most widely used methods of waste disposal. However, it is common knowledge that all landfills leak. The leachate often contains heavy metals and other toxic substances which can contaminate ground and water resources. Even state-of-the-art landfills which are sealed to prevent toxins from entering the ground are not completely tight in the long-term. Older landfill sites and uncontrolled dumps pose a much greater danger of releasing hazardous emissions.

Mercury (see also [DS 25 – Mercury switch]), Cadmium (see also [DS 23 – Battery]) and Lead (see also [DS 24 – Lead-acid battery]) are amongst the most toxic leachates. Mercury, for example, will leach when certain electronic devices such as circuit breakers are destroyed. Lead has been found to leach from broken lead-containing glass, such as the cone glass of cathode ray tubes from TVs and monitors. When polybrominated flame retarded (PBDE) plastics or plastics containing cadmium are landfilled, both PBDE and cadmium may leach into soil and groundwater. Similarly, landfilled condersers emit hazardous PCB's.

Besides leaching, vaporisation is also of concern in landfills. For example, volatile compounds such as mercury or a frequent modification of it, dimethylene mercury can be released. In addition, landfills are also prone to uncontrolled fires which can release toxic fumes.

Significant impacts from landfilling could be avoided by conditioning hazardous materials from e-waste separately and by landfilling only those fractions for which there are no further recycling possibilities and ensure that they are in state-of-the-art landfills that respect environmentally sound technical standards.

7.2 HW Incineration

Incineration is the process of destroying waste through burning. Because of the variety of substances found in e-waste, incineration is associated with a major risk of generating and dispersing contaminants and toxic substances. The gases released during the burning and the residue ash is often toxic. This is especially true for incineration or co-incineration of e-waste with neither prior treatment nor sophisticated flue gas purification. Studies of municipal solid waste incineration plants have shown that copper, which is present in printed wiring boards and cables, acts a catalyst for dioxin formation when flame-retardants are incinerated. These brominated flame retardants when exposed to low temperature (600-800°C) can lead to the generation of extremely toxic polybrominated dioxins (PBDDs) and furans (PBDFs). PVC, which can be found in e-waste in significant amounts, is highly corrosive when burnt and also induces the formation of dioxins.

Incineration also leads to the loss valuable of trace elements which could have been recovered had they been sorted and processed separately.

7.2.1 Open Burning

Since open fires burn at relatively low temperatures, they release many more pollutants than in a controlled incineration process at an MSWI-plant. Inhalation of open fire emissions can trigger asthma attacks, respiratory infections, and cause other problems such as coughing, wheezing, chest pain, and eye irritation. Chronic exposure to open fire emissions may lead to diseases such as emphysema and cancer. For example, burning PVC releases hydrogen chloride, which on inhalation mixes with water in the lungs to form hydrochloric acid. This can lead to corrosion of the lung tissues, and several respiratory complications. Often open fires burn with a lack of oxygen, forming carbon monoxide, which poisons the blood when inhaled. The residual particulate matter in the form of ash is prone to fly around in the vicinity and can also be dangerous when inhaled.

7.3 HW Treatment Plant

The hazardous waste treatment plant generally comprises **three steps**:

1. Detoxication

The first step in the recycling process is the removal of critical components from the e-waste in order to avoid dilution of and / or contamination with toxic substances during the downstream processes. Critical components include, e.g., lead glass from CRT screens, CFC gases from refrigerators, light bulbs and batteries.

2. Shredding

Mechanical processing is the next step in e-waste treatment, normally an industrial large scale operation to obtain concentrates of recyclable materials in a dedicated fraction and also to further separate hazardous materials. Typical components of a mechanical processing plant are crushing units, shredders, magnetic- and eddy-current- and air-separators. The gas emissions are filtered and effluents are treated to minimize environmental impact.

3. Refining / Redeployment

The third step of e-waste recycling is refining. Refining of resources in e-waste is possible and the technical solutions exist to get back raw with minimal environmental impact. Most of the fractions need to be refined or conditioned in order to be sold as secondary raw materials or to be disposed of in a final disposal site, respectively. During the refining process, to three flows of materials is paid attention: Metals, plastics and glass.

Secondary raw material can also be redeployed directly in new products. E.g. plastics can be implemented in a whole range of new products, such as roof tiles, fence poles, insulation material etc. Crucial before redeploying secondary raw material is to clarify the composition of hazardous substances and to know potential environmental impacts.

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