# FUNDAMENTALS OF E-WASTE RECYCLING

**As basis for the following chapters, it is essential to understand the fundamental issues underlying e-waste recycling. These are independent of the recycled material, the device and the recycling location or region and address the:**

- ✓ **Significance of e-waste for resource management and toxic control,**
- ✓ **General structure, main steps and interfaces of the recycling chain,**
- ✓ **Objectives to achieve,**
- ✓ **General frame conditions which impact process selection.**

## SIGNIFICANCE OF E-WASTE RECYCLING

**E-waste is usually regarded as a waste problem, which can cause environmental damage if not dealt with in an appropriate way. However, the enormous resource impact of electrical and electronic equipment (EEE) is widely overlooked. Summarizing the lack of closing the loop for electronic and electrical devices leads not only to significant environmental problems but also to systematic depletion of the resource base in secondary materials.**

**Modern electronics can contain up to 60 different elements; many are valuable, some are hazardous and some are both. The most complex mix of substances is usually present in the printed wiring boards (PWBs). In its entity electrical and electronic equipment is a major consumer of many precious and special metals and therefore an important contributor to the world's demand for metals. Despite all legislative efforts to establish a circular flow economy in the developed countries/EU, the majority of valuable resources today are lost. Several causes can be identified: firstly, insufficient collection efforts; secondly, partly inappropriate recycling technologies; thirdly, and above all large and often illegal exports streams of E-waste into regions with no or inappropriate recycling infrastructures in place. Large emissions of hazardous substances are associated with this. Unfortunately, these regions with inappropriate recycling infrastructure are often located in developing and transition countries. At the moment the developing and transition countries are striving to implement technologies to deal with the recycling of e-waste and to establish circular flow economies.**

**Besides the direct impact of effective recycling on the resource base of the recycled metals, state of the art recycling operations 2 also considerably contribute to reducing greenhouse gas emissions. Primary production, i.e. mining, concentrating, smelting and refining, especially of precious and special metals has a significant carbon dioxide (CO2) impact due to the low concentration of these metals in the ores and often difficult mining conditions. "Mining" our old computers to recover the contained metals – if done in an environmentally sound or correct manner – needs only a fraction of energy compared to mining ores in nature.**

**Furthermore, the environmentally sound management of refrigerators, air-conditioners and similar equipment is significant in mitigating the climate change impact at end-of-life. The ozone depleting substances in these devices, such as CFC and HCFCs, have a very high global warming potential (GWP) and effective recycling will ensure these substances are not released into the environment. In that sense there is still a lot to win.**

**Essentially, the environmental footprint of a fridge, a computer and other electronic devices could be significantly reduced if treated in environmentally sound managed recycling operations, which prevent hazardous emissions and ensure that a large part of the contained metals are finally recovered for a new life in a new (electronic) device.**

## IMPACT ON METAL RESOURCES

**A wide range of components made of metals, plastics and other substances are contained in electrical and electronic equipment. For example, a mobile phone can contain over 40 elements from the periodic table including base metals like copper (Cu) and tin (Sn), special metals such as cobalt (Co), indium (In) and antimony (Sb), and precious metals including silver (Ag), gold (Au) and palladium (Pd), as shown in Figure 1. Metals represent on average 23% of the weight of a phone, the majority being copper, while the remainder is plastic and ceramic material. Looking at one ton of phone handsets (without battery) this would be 3.5 kg Ag, 340 g Au, 140 g Pd as well as 130 kg Cu. For a single unit the precious metal content is in the order of milligrams only: 250 mg Ag, 24 mg Au, 9 mg Pd while 9 g Cu is present on average. Furthermore, the Li-ion battery of a phone contains about 3.5 g Co.**

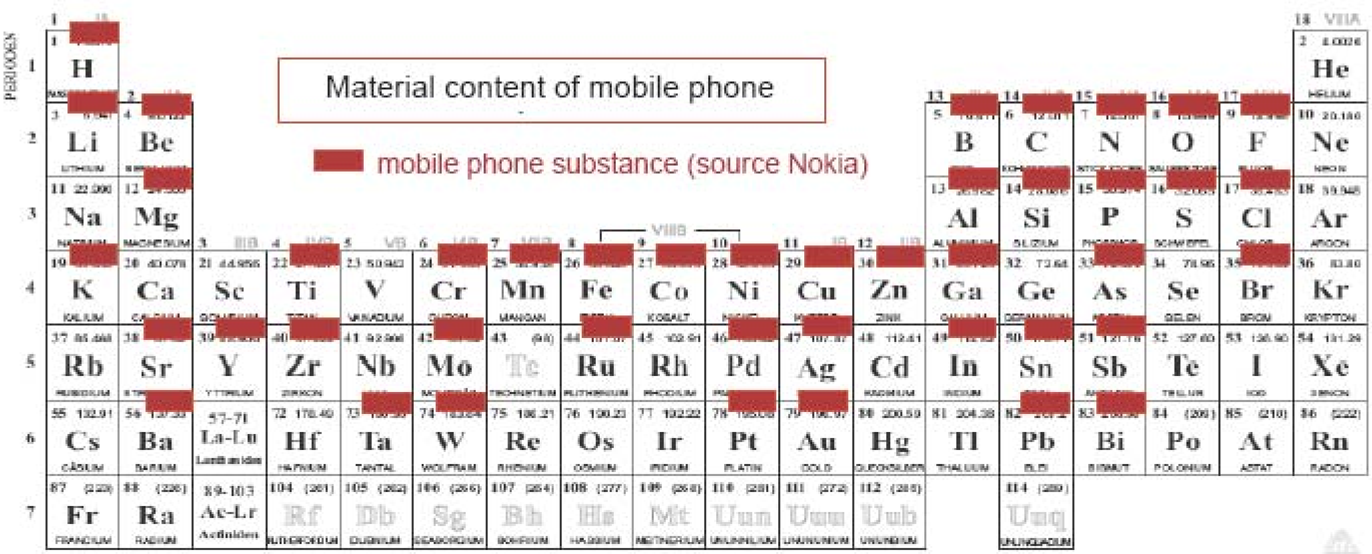



Figure 1: Material content mobile phone [Source Umicore 2008]

**a) Mobile phones:**
1200 Million units
x 250 mg Ag ≈ 300 t Ag
x 24 mg Au ≈ 29 t Au
x 9 mg Pd ≈ 11 t Pd
x 9 g Cu ≈ 11,000 t Cu
1200 M x 20 g/battery*
x 3.8 g Co ≈ 4500 t Co
* Li-Ion type

**b) PC & laptops:**
255 Million units
x 1000 mg Ag ≈ 255 t Ag
x 220 mg Au ≈ 56 t Au
x 80 mg Pd ≈ 20 t Pd
x ≈ 500 g Cu ≈ 128,000 t Cu
≈100 M laptop batteries*
x 65 g Co ≈ 6500 t Co
* Li-Ion type is > 90% used in modern laptops

| World Mine Production | | a+b share |
|---|---|---|
| Ag: 20,000 | t/y ▶ | 3% |
| Au: 2,500 | t/y ▶ | 3% |
| Pd: 230 | t/y ▶ | 13% |
| Cu: 16 | Mt/y ▶ | 1% |
| Co: 60,000 | t/y ▶ | 15% |

Figure 2: Impact of phones and PCs on metals demand, based on global sales 2007 [Source Umicore 2008]

**At first sight this appears to be very little, but taking into account the leverage of 1.2 billion mobile phones sold globally in 2007, this leads to a significant metal demand in total. When looking at PCs and laptops, numbers in a similar order of magnitude are found (Figure 2). Also, the use of more common metals such as iron in electronics is**

**considerable: about 6 kg iron/steel for a desktop PC means 930,000 tons are used to manufacture the PCs sold in 2007. The combined 2007 unit sales of mobile phones and personal computers already add up to 3% of the world mine supply of Au and Ag, to 13% of Pd and to 15% of Co**

**(Figure 2).**

**Taking into account the highly dynamic growth rates of all the other electronic devices such as liquid crystal display (LCD)-TVs and monitors, MP3 players, electronic toys and digital cameras, it becomes clear that electrical and electronic equipment is a major driver for the development of demand and prices for a number of metals as shown in Table 1. In particular the booming demand for precious and special metals is linked to increasing functionality of the products and the specific metal properties needed to achieve these. For example, electronics make up for almost 80% of the world's demand of indium (transparent conductive layers in LCD glass), over 80% of ruthenium (magnetic properties in hard disks (HD)) and 50% of antimony (flame retardants). Some of these metals are also important for renewable energy generation: selenium (Se), tellurium (Te) and indium (In) are used in thin film photovoltaic panels; platinum (Pt) and ruthenium (Ru) are used for proton exchange membrane (PEM) fuel cells3. Some metal price increases, which we have observed over the last years are directly connected to the developments in the electronic industry. The monetary value of the annual use of important "electrical and electronic equipment metals" represents USD 45.4 billion at 2007 price levels.**

**The metal resources used yearly for electrical and electronic equipment are added to the existing metal resources in society of the devices in use. These metal resources become available again at final end-of-life of the devices. As mentioned earlier this is a potential material resource of 40 million tons each year. Effective recycling of the metals/materials is crucial to keep them available for the manufacture of new products, be it electronics, renewable energy applications or applications not invented yet. In this manner primary metal and energy resources can be conserved for future generations.**

| Metal | Primary production* | By-product from | Demand for EEE | Demand/ production | Price** | Value in EEE** | Main applications |
|---|---|---|---|---|---|---|---|
| | t/y | | t/y | % | USD/ kg | $10^6$ USD | |
| Ag | 20 000 | (Pb, Zn) | 6 000 | 30 | 430 | 2.6 | Contacts, switches, solders… |
| Au | 2 500 | (Cu) | 300 | 12 | 22 280 | 6.7 | Bonding wire, contacts, integrated circuits… |
| Pd | 230 | PGM | 33 | 14 | 11 413 | 0.4 | Multilayer capacitors, connectors |
| Pt | 210 | PGM | 13 | 6 | 41 957 | 0.5 | Hard disk, thermocouple, fuel cell |

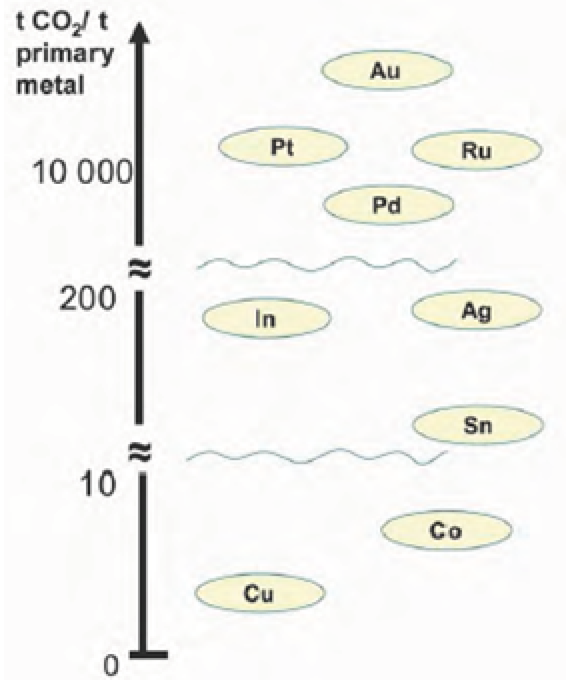
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Ru** | 32 | PGM | 27 | 84 | 18 647 | 0.5 | Hard disk, plasma displays |
| **Cu** | 15 000 000 | | 4 500 000 | 30 | 7 | 32.1 | Cable, wire, connector… |
| **Sn** | 275 000 | | 90 000 | 33 | 15 | 1.3 | Solders |
| **Sb** | 130 000 | | 65 000 | 50 | 6 | 0.4 | Flame retardant, CRT glass |
| **Co** | 58 000 | (Ni, Cu) | 11 000 | 19 | 62 | 0.7 | Rechargeable batteries |
| **Bi** | 5 600 | Pb, W, Zn | 900 | 16 | 31 | 0.03 | Solders, capacitor, heat sink… |
| **Se** | 1 400 | Cu | 240 | 17 | 72 | 0.02 | Electro-optic, copier, solar cell |
| **In** | 480 | Zn, Pb | 380 | 79 | 682 | 0.3 | LCD glass, solder, semiconductor |
| **Total** | | | **4 670 000** | | | **45.4** | |

* Rounded from [9], [10], [11]. ** Using the average price in 2007.

**Table 1: Important metals used for electric and electronic equipment (based on demand in 2006)**

**IMPACT ON THE ENVIRONMENT**

**Primary production (mining) plays the most important role in the supply of metals for electrical and electronic equipment applications since secondary metals (recycling) are only available in limited quantities so far. The environmental impact/footprint of the primary metal production is significant, especially for precious and special metals which are mined from ores in which the precious and special metal concentration is low. Considerable amounts of land are used for mining, waste water and sulfur dioxide (SO2) is created and the energy consumption and CO2 emissions are large. For example, to produce 1 ton of gold, palladium or platinum, CO2 emissions of about 10,000 tons are generated. Conversely the production of copper has only an emission of 3.4 t CO2 per ton metal (Figure 3). Combining these numbers with the metal usage in electrical and electronic equipment (given in Table 1) enables calculation of the CO2 emissions associated with the primary production of the metals as shown in the table of Figure 3. For example, the annual demand for gold in EEE is some 300 t at average primary generation of almost 17,000 tons CO2 per ton of gold mined, which leads to gold induced emissions of 5.1 million tons in total. In the case of copper, the specific primary emissions are with 3.4 t/t relatively low, but the high annual total demand in EEE leads to 15.3 million tons of CO2 emissions. As shown in Figure 3 (table) the cumulated values of the metals listed account for an annual CO2 emission level of 23.4 million tons, almost 1/1000 of the world's CO2 emissions. This includes neither CO2 emissions from other metals used in electrical and electronic equipment like steel, nickel or aluminium, nor other CO2 emissions associated with the manufacturing or use of electrical and electronic equipment.**




| Important EEE metals | demand for EEE t/a (2006) | data for primary production [t $CO_2$/t metal] | $CO_2$ emis-sions [Mt] |
|---|---|---|---|
| Copper | 4 500 000 | 3.4 | 15.30 |
| Cobalt | 11 000 | 7.6 | 0.08 |
| Tin | 90 000 | 16.1 | 1.45 |
| Indium | 380 | 142 | 0.05 |
| Silver | 6 000 | 144 | 0.86 |
| Gold | 300 | 16 991 | 5.10 |
| Palladium | 32 | 9 380 | 0.30 |
| Platinum | 13 | 13 954 | 0.18 |
| Ruthenium | 6 | *13 954* | 0.08 |
| **$CO_2$ total [t]** | | | **23.4** |

Figure 3: $CO_2$ emissions of primary metal production calculated using the EcoInvent 2.0 database

**Recovering metals from state-of-the art recycling processes generates only a fraction of these CO2 emissions and also has significant benefits compared to mining in terms of land use and hazardous emissions. For example, production of 1 kg aluminium by recycling uses only 1/10 or less of the energy required for primary production, and prevents the creation of 1.3 kg of bauxite residue, 2 kg of CO2 emissions and 0.011 kg of SO2 emissions as well as the impacts and emissions associated with the production of the alloying elements used in aluminium. Furthermore, the salt slag created during the recycling process is treated to recover salt flux for the recycling industry, inert oxides for cement industry and aluminium metal. For precious metals the specific emissions saved by state-of-the-art recycling are even higher.**

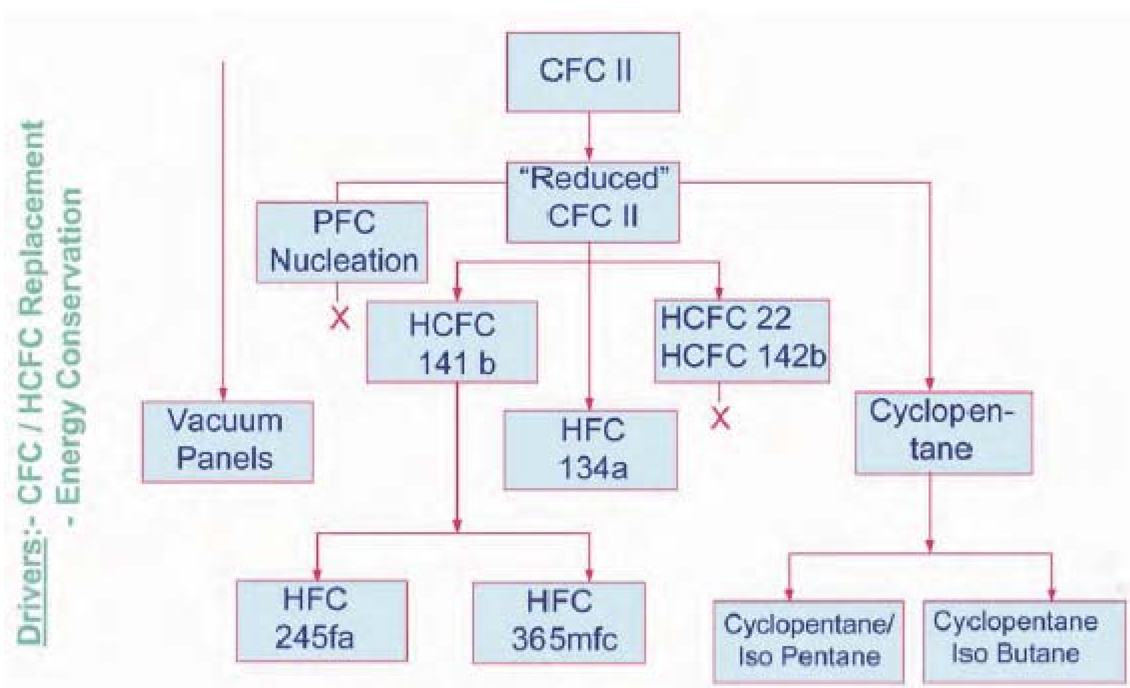


Figure 4: Use of ODS in cooling and freezing appliances over the years

**The substances contained in the devices can also have an impact on the environment. Cooling and freezing equipment for example, employ ozone depleting substances (ODS) in the refrigeration system. These substances, such as CFCs and HCFCs, have a huge global warming potential, as shown in Table 2. It must be mentioned that particularly the older devices are those which contain ODS with a high global warming impact; the newer devices use alternative substances. As a consequence it is important to ensure accidental release to the atmosphere because of damages during collection or improper recycling treatment is not taking place. It is in this manner that high environmental impact during end-of-life can be avoided.**

| Substances | GWP | | |
|---|---|---|---|
| CFC-12 | 10 720 | ± | 3 750 |
| CFC-114 | 9 880 | ± | 3 460 |
| CFC-115 | 7 250 | ± | 2 540 |
| CFC-113 | 6 030 | ± | 2 110 |
| CFC-11 | 6 800 | ± | 1 640 |
| HCFC-142b | 2 270 | ± | 800 |
| HCFC-22 | 1 780 | ± | 620 |
| HCFC-141b | 713 | ± | 250 |
| Halon-1301 | 7 030 | ± | 2 460 |
| Halon-1211 | 1 860 | ± | 650 |
| Halon-2402 | 1 620 | ± | 570 |

**Table 2: Global Warming Potential of refrigerants**[4]

**On a more local level, uncontrolled discarding or inappropriate waste management/recycling generates significant hazardous emissions, with severe impacts on health and environment. In this context, three levels of toxic emissions have to be distinguished:**

- ✓ **Primary emissions: Hazardous substances that are contained in e-waste (e.g. lead5, mercury, arsenic, polychlorinated biphenyls (PCBs), fluorinated cooling fluids etc.),**
- ✓ **Secondary emissions: Hazardous reaction products of e-waste substances as a result of improper treatment (e.g. dioxins or furans formed by incineration/inappropriate smelting of plastics with halogenated flame retardants),**
- ✓ **Tertiary emissions: Hazardous substances or reagents that are used during recycling (e.g. cyanide or other leaching agents, mercury for gold amalgamation) and that are released because of inappropriate handling and treatment.**

**It needs to be understood that legislative approaches to restrict the use of hazardous substances (e.g. European Union's Directive 2002/95/EC on the restriction of the use of certain hazardous substances in electrical and electronic equipment RoHS) can address only primary emissions and partly secondary emissions. However, even the "cleanest/greenest" products cannot prevent tertiary emissions if inappropriate recycling technologies are used. The latter is the biggest challenge in particular in developing and transition countries, where "backyard recycling" with open sky incineration, cyanide leaching, "cooking" of circuit boards etc. lead to dramatic effects on health and environment.**