

# Lecture 10

## Waste Electrical and Electronic Equipment (WEEE)

### 1. Introduction



- WEEE refers to waste equipment that is dependent on electric currents or electromagnetic fields to work properly and equip for the generation, transfer and measurement of such currents.
- Technological innovation and market expansion accelerate the replacement of equipment and result in a significant increase in WEEE.
- In 2005, the volume of household WEEE was estimated to be over 20 million tonnes globally.



## 1. Introduction



- Due of their hazardous material contents, WEEE may cause environmental problems if not properly managed.
- Many countries have drafted legislation to improve the reuse, recycling and other forms of recovery of WEEE so as to reduce disposal problems.
- The WEEE Directive (2002/96/EC) has been adapted by all EU member states by 2007.
- In Turkey, a similar legislation was entered into force in 22 May 2012.

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## 2. Quantities of WEEE



Methods used for estimating quantities of WEEE are:

- *Market supply method* uses past domestic sales data coupled with average life of products for a certain region
- *Consumption and use method* is based on extrapolation from the average amount of electronic equipment in a typical household
- *Saturated market method* assumes that for each new appliance bought, the old one reaches its end of life.

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## 2. Quantities of WEEE



- In EU:
  - Generation rate = 15 kg/ca.year
  - WEEE generated = 7.0 million tons (in 2005)
- In USA:
  - Generation rate = 22 kg/ca.year
  - WEEE generated = 6.6 million tons (in 2005)
- In Japan:
  - Generation rate = 24 kg/ca.year
  - WEEE generated = 3.1 million tons (in 2005)

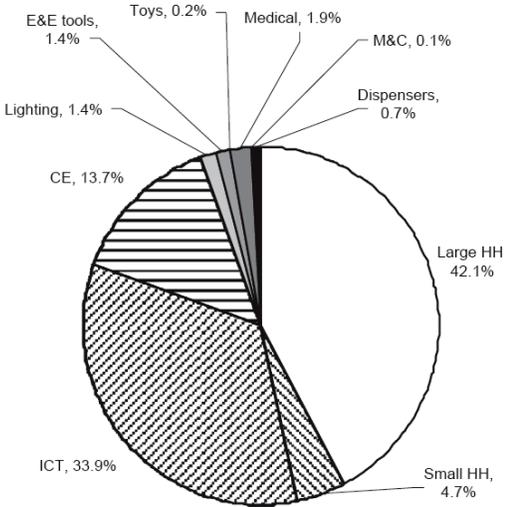
5/38 C. Bastiaan et al. Int. J. Adv. Manufacturing Technol. 47 (2010) 415-436



## Composition of WEEE



Composition of WEEE for Western Europe



Category	Percentage
Large HH	42.1%
ICT	33.9%
CE	13.7%
Small HH	4.7%
Dispensers	0.7%
Medical	1.9%
E&E tools	1.4%
Lighting	1.4%
Toys	0.2%
M&C	0.1%

6/38 R. Widmer et al. Environmental Impact Assessment Review 25 (2005) 436-458



## WEEE categories<sup>1</sup>



1. **Large household appliances:** refrigerators, washing machines, ovens, air conditioner appliances
2. **Small household appliances:** vacuum cleaners, irons, toasters, grinders, coffee machines, fryers, tooth brushing, clocks, watches, scales, etc.
3. **IT and telecommunications equipment:** personal computers, laptops, notepads, calculators, printers, copying equipment, facsimile, telephones

7/38 <sup>1</sup> 10 categories covered by WEE Directive of EU



## WEEE categories<sup>1</sup>



4. **Consumer equipment:** televisions, radio sets, video cameras and recorders, amplifiers, etc.
5. **Lighting equipment:** straight or compact fluorescent lamps, high-intensity discharge lamps, etc.
6. **Electrical and electronic tools:** drills, saws, sewing machines, tools for mowing or other gardening activities
7. **Toys, leisure and sports equipment:** electric trains, car racing sets, video games/consoles, coin slot machines

8/38 <sup>1</sup> 10 categories covered by WEE Directive of EU



## WEEE categories<sup>1</sup>



8. **Medical devices:** radiotherapy equipment, cardiology, dialysis, pulmonary ventilators
9. **Monitoring and control instruments:** smoke detectors, heating regulators, thermostats
10. **Automatic dispensers:** automatic dispensers for hot or cold drinks, solid products, money, etc.

9/38 <sup>1</sup> 10 categories covered by WEE Directive of EU



## 3. Characteristics of WEEE

### Major Hazardous Components

- **Batteries:** A large proportion of heavy metals such as lead, mercury, and cadmium is present in batteries
- **Cathode ray tubes (CRTs):** Pb in the cone glass and fluorescent coating over the inside of panel glass
- **Hg containing components:** Hg is basically used in thermostats, sensors, relays and switches (e.g. in measuring equipment and discharge lamps). Also used in medical equipment, data transmission, mobile phones

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### 3. Characteristics of WEEE

#### Major Hazardous Components

- **Asbestos wastes:** Have to be treated selectively
- **Toner cartridges, liquid & pasty, as well as colour toner:**  
May contain hazardous chemicals that are moderately toxic if acute exposure occurs
- **Printed Circuit Boards:** Pb and Cd are common in solder; Cd occurs in certain components, such as SMD chip resistors, infrared detectors and semiconductors
- **Polychlorinated biphenyl (PCB) containing capacitors:**  
Have to be removed for safe destruction

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### 3. Characteristics of WEEE

#### Major Hazardous Components

- **Liquid Crystal Displays (LCDs):** Pb and Hg occur in old designs. LCDs of a surface greater than 100 cm<sup>2</sup> have to be removed from WEEE
- **Plastics containing halogenated flame retardants:** During incineration they can produce toxic components
- **Equipment containing CFC, HCFC or HFCs:** The ODS present in the foam and the refrigerating circuit must be properly extracted and destroyed.
- **Gas discharge lamps:** Hg has to be removed

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## Material composition

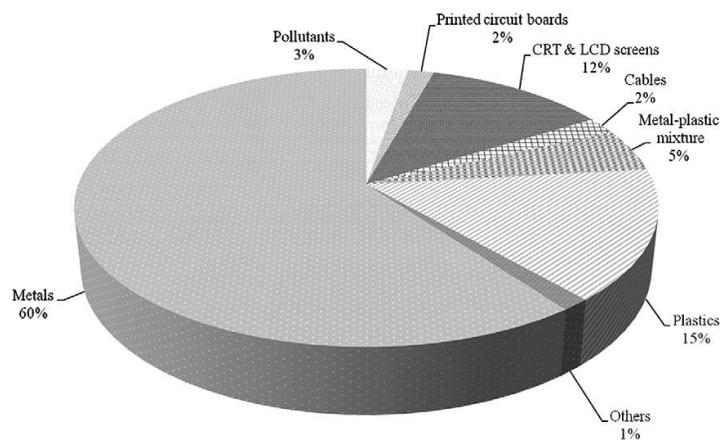


- WEEE are composed of metals, particularly Cu, Al and steel, attached to, covered with or mixed with various types of plastics and ceramics.
- Precious metals have a wide application in the manufacture of electronic appliances, serving as contact materials due to their high chemical stability and their good conducting properties.
- Pt group metals are used among other things in relays and switches or as sensors to ascertain the electrical measure and as a function of the temperature.

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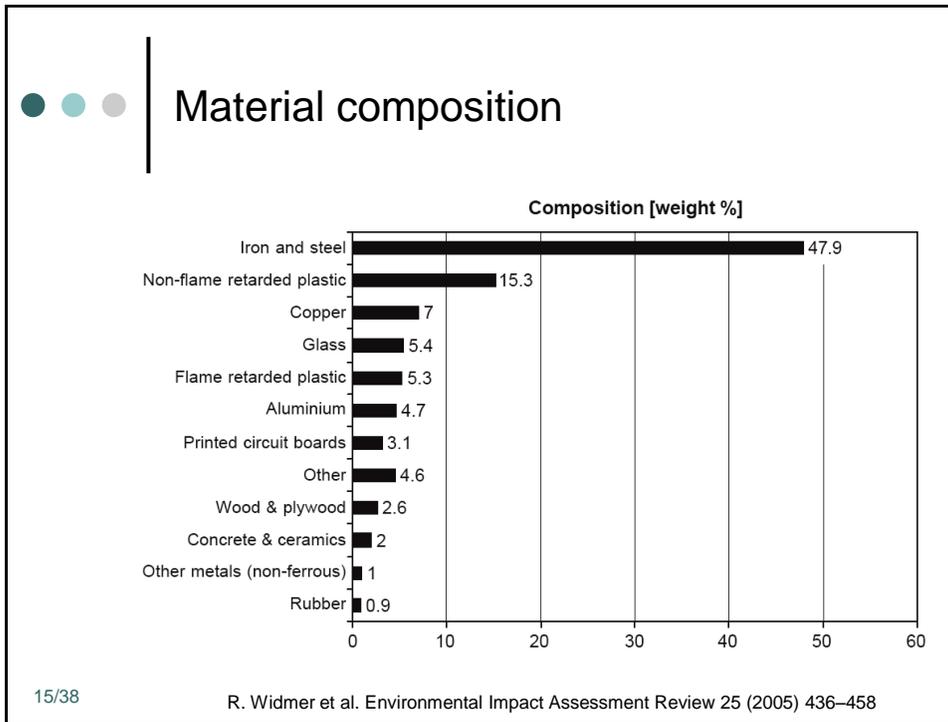


## Material composition



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F.O. Ongondo et al., Waste Management 31 (2011) 714–730



## Material composition

- Cu and precious metals make up more than 80% of the value for most of the WEEE.
- The recovery of precious metals and Cu is the major economic driver for WEEE recycling.
- However, the precious metals content have gradually decreased in concentration in scrap.
- This is due to the falling power consumption of modern switching circuits and the rising surface conduction.
- The contact layer thickness in the 1980s was 1-2.5 mm.
- Today it is between 300 and 600 nm (gold wafer).

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## 4. Environmental Concerns

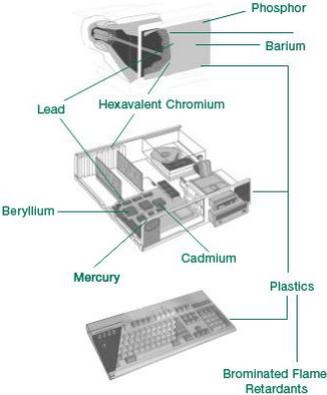


- Disposal of WEEE is of environmental concern for a number of reasons.
  - fate of dangerous materials in the waste,
  - depletion of resources and
  - impacts of waste treatment methods.

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## Dangerous materials

- WEEE contains a wide variety of dangerous materials and components including:
  - Printed circuit boards
  - Flame retarded plastics
  - Cathode ray tubes
  - Liquid crystal displays
  - Batteries
  - Mercury switches
  - Capacitors and resistors.



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## Dangerous materials

- These components contain environmentally problematic substances such as;
  - Mercury (Hg)
  - Lead (Pb)
  - Cadmium (Cd)
  - Chromium (Cr)
  - CFC's (chloro-fluorocarbons)
  - PCB's (polychlorinated biphenyls)
  - PCN's (polychlorinated naphthalenes)
  - Brominated flame retardants.
- These substances make up only a small proportion of the total weight, but their potential environmental risks are serious enough to warrant concern

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## Mercury (Hg)



- It has been estimated that 22% of the annual world consumption of Hg can be attributed to electrical and electronic equipment (ENEA, 1995).
- Many older appliances contain Hg-bearing components.
- A large use of Hg is for fluorescent tubes, where it transforms the UV-light created in the gas discharge to visible light.
- Also used in relays, tilt switches & in medical equipment.

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## Cadmium (Cd)

- Cd is used in batteries, as a pigment and stabiliser in plastics, in specialist treatment of mechanical surfaces and in speciality solders.
- It is also used as a fluorescent material in screens and was used in old cathode ray tubes (CRT's).
- Consumer electronics have been found to contribute 9% of total cadmium in MSW.
- Of this Cd, 95% is attributed to batteries and only 0.1% to CRT's.

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## Lead (Pb)

82  
Pb80  
Hg

- By far the largest source of the Pb in consumer electronics has been found to be contained in CRT's.
- CRT's are found primarily in television sets and computer monitors and can vary considerably in their composition but all contain substantial proportions of Pb. A television CRT contains 15-20% lead oxide.
- Other important Pb sources include soldering on printed circuit boards, pigments and stabilisers in plastics, and leaded glass

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## Hexavalent Chromium Cr(VI)

- Electrical and electronic equipment does not account for a significant share of chromium use and most producers no longer use it at all.
- It is used as a corrosion protector for steel plates and in printed circuit boards and plastic covers.

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## Brominated Flame Retardants (BFR's)

- It is estimated that flame retarded plastics make up around 5.5% of WEEE by weight or 25% of all plastic used in EEE.
- Of these flame retarded plastics, approximately 80% are treated with brominated flame retardants.
- BFR's are designed into electronic products as a means of ensuring flammability protection.
- They are mainly used in printed circuit boards, components (connectors), plastic covers and cables.

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## 5. Hierarchy in management of WEEE

- Options for the management of WEEE are *reuse, remanufacturing, recycling, incineration* and *landfilling*.
- **Reuse** of obsolete electronic equipment has first priority.
- By re-using the usable lifespan of the equipment is extended resulting in a reduced volume of waste stream.
- **Remanufacturing** is a production process in which used products are disassembled, cleaned, repaired or refurbished, reassembled and qualified for new or like-new equipments.

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## 5. Hierarchy in management of WEEE

- Recycling means, reprocessing of the waste materials for the original purposed products or for other purposes.
- **Recycling** of WEEE involves disassembly and/or destruction of end-of-life equipment to recover materials.
- **Incineration** of WEEE is the least favorable option.
- For example, Cu acts as a catalyst in dioxin formation when flame-retardants are incinerated.
- This is of particular concern for the incineration of brominated flame retardants at low temperature.

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## 5. Hierarchy in management of WEEE

3 major steps of WEEE recycling:

- **Disassembly**: separating hazardous and/or valuable components for treatment
- **Upgrading**: using mechanical and/or metallurgical processing to up-grade desirable materials content, that is preparing materials for refining processes
- **Refining**: recovered materials are retreated or purified by using chemical (metallurgical) processing so as to be acceptable for their original use

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## 6. Disassembly of WEEE



- It is a systematic approach that allows removal of a component/part from a product or separating a product into its parts for a given purpose.
- Phases for developing a disassembly process plan:
  - Input and output product analysis
  - Assembly analysis
  - Uncertainty issues analysis
  - Determination of dismantling strategy

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## 6. Disassembly of WEEE

- In the first phase, reusable, valuable and hazardous components and materials are defined. After preliminary cost analysis, optimal disassembly is identified.
- In the second phase, joining elements, component hierarchy and former assembly sequences are analyzed
- Uncertainty of disassembly comes from defective parts or joints in the incoming product, upgrading of the product during consumer use and disassembly damage.
- In the final phase, it is decided whether to use nondestructive or destructive disassembly.

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## 6. Disassembly of WEEE

- Full- or semi-automated disassembly processes have serious limitations.
- Obstacles preventing automated disassembly are:
  - too many different types of products
  - the amount of products of the same type is too small
  - general disassembly unfriendly product design
  - general problems in return logistics and
  - variations in returned amounts of products to be disassembled.

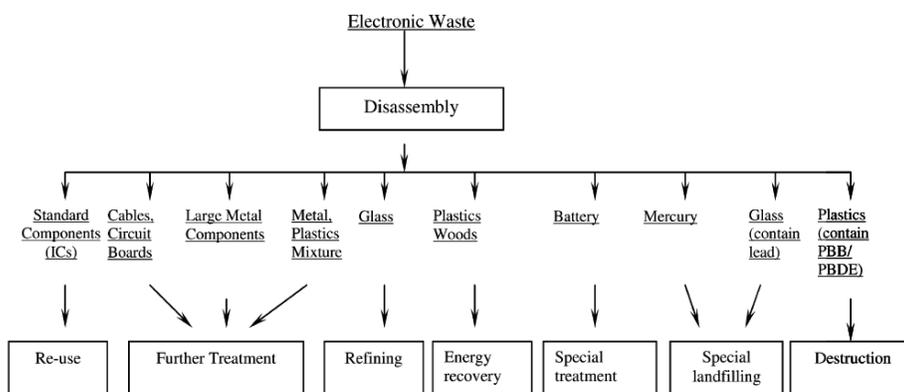
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## 6. Disassembly of WEEE

- Selective disassembly (dismantling) is an essential process because:
  - the reuse of components is the first priority
  - the dismantling of hazardous components is needed
  - it is also common to dismantle highly valuable components and high-grade materials such as printed circuit boards, cables and etc. to simplify the subsequent recovery.
- Most of the recycling plants use manual dismantling which also involves a variety of tools.

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## 6. Disassembly of WEEE



32/38 Cui J, Roven HJ, Electronic waste. In Waste: A Handbook for Management, 2011 Academic Press



## 7. Recycling processes

- **Magnetic Separation:** Widely used for the separation of ferromagnetic metals from non-ferrous metals and other nonmagnetic components.
- **Eddy Current Separation:** Eddy currents can be induced in an electrical conductive particle by a time-dependent magnetic field
- **Density-Based Separation:** Gravity concentration separates materials of different specific gravity by their relative movement in response to the force of gravity and one or more other forces.

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## 7. Recycling processes

- **Optical Sorting:** Measuring the particle properties (colour, texture, morphology, conductivity, etc.) allows high-quality sorting of mixed materials into fractions.
- **Pyrometallurgical Process:** The crushed scraps are burned in a furnace or in a molten bath to remove plastics, and the refractory oxides form a slag phase together with some metal oxides.
- It has been used for the recovery of Cu and precious metals from WEEE for years.

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## 7. Recycling processes

### *Limitations of pyrometallurgical process:*

- Integrated smelters cannot recover Al and Fe; they are transferred into the slag component. Al has undesirable influences on the slag properties.
- The presence of halogenated flame retardants in the smelter feed can lead to the formation of dioxins unless special installations and measures are present.
- Precious metals take a long time to separate and are thus only obtained at the very end of the process.

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## 7. Recycling processes

### *Limitations of pyrometallurgical process:*

- Ceramic components and glass in the WEEE increase the amount of slag from blast furnaces, which results in a loss of precious metals and base metals from scrap.
- Only partial separation of metals can be achieved, resulting in a limited upgrading of the metal value. Subsequent hydrometallurgical processes and/or electrochemical processing are therefore necessary.

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## 7. Recycling processes

- **Hydrometallurgical Process:** consists of a series of acid or caustic leaches of solid material.
- Solutions are then subjected to separation and purification procedures such as precipitation of impurities, solvent extraction, adsorption, ion-exchange to isolate, and concentrate the metals of interest.
- Consequently, the solutions are treated by electro-refining process, chemical reduction or crystallization for metal recovery.

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## Videos

- What is E-Waste and Why does it Matter?  
[http://www.youtube.com/watch?v=h\\_ZqSige34c](http://www.youtube.com/watch?v=h_ZqSige34c)
- Waste Electronics - How they are recycled:  
<http://www.youtube.com/watch?NR=1&feature=endscreen&v=RaKLgovVkJQ>
- E-Scrap Recycling (Electronic Waste):  
[http://www.youtube.com/watch?v=-i48XaeO\\_vU](http://www.youtube.com/watch?v=-i48XaeO_vU)
- WEEE Recycling Process - European division:  
[http://www.youtube.com/watch?v=w5varrki7qc&list=UUwKIFe\\_VzwHuoi6M0fbT8lQ&index=9&feature=plcp](http://www.youtube.com/watch?v=w5varrki7qc&list=UUwKIFe_VzwHuoi6M0fbT8lQ&index=9&feature=plcp)
- How Computers and Electronics Are Recycled:  
[http://www.youtube.com/watch?v=lw4g6H7alvo&list=UUwKIFe\\_VzwHuoi6M0fbT8lQ&index=3&feature=plcp](http://www.youtube.com/watch?v=lw4g6H7alvo&list=UUwKIFe_VzwHuoi6M0fbT8lQ&index=3&feature=plcp)
- CRT Recycling Process for TVs and Computer Monitors:  
[http://www.youtube.com/watch?v=wYLTiPsYuY0&list=UUwKIFe\\_VzwHuoi6M0fbT8lQ&index=11&feature=plcp](http://www.youtube.com/watch?v=wYLTiPsYuY0&list=UUwKIFe_VzwHuoi6M0fbT8lQ&index=11&feature=plcp)
- Fridge Recycling Process - UK:  
[http://www.youtube.com/watch?v=xnmQx3tyg6Q&list=UUwKIFe\\_VzwHuoi6M0fbT8lQ&index=10&feature=plcp](http://www.youtube.com/watch?v=xnmQx3tyg6Q&list=UUwKIFe_VzwHuoi6M0fbT8lQ&index=10&feature=plcp)

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