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Study of E-Waste- Hazards & Recycling Techniques- A Review

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Abstract: The fastest growing waste streams at current scenario in the world is considered to be Waste from Electrical and Electronic Equipments (WEEEs) raises from 3% up to 5% per year. The recycling of Electrical or electronic waste (E-waste) products could allow the reduction of the usage of fresh resources in manufacturing sector and, consequently, it could contribute in reducing the environmental pollution. The recycling of electronic waste (e-waste) in an informal method is an emerging source of environmental pollution in world. Polycyclic aromatic hydrocarbons (PAHs) are considered to be a major health concern among other toxins present in e waste for the exposed individuals. This paper deals with the study of e-waste (electronic waste) hazards and proper recycling process. Many researches have been made in order to reduce the e-waste hazards through some advanced techniques. The review of these researches has been well studied and the future scope of the techniques has been given in detail.
Key words: E-waste, Recycling, RRS, Hazards.

I. Introduction

Huge amount of wastes has been dispatched from electric and electronic equipments due to the development of electronic industry and information technology. It has been estimated that around 20e50 million tons of e waste per year generated continuously worldwide. E waste consists of toxic components such as lead, chromium, cadmium, etc. which in turn produces adverse effects to human beings and environment.

First of all, WEEEs represent the widest source of wastes with the highest growth rate per year. Disposal of WEEE globally is estimated to be around 30–50 million tons each year, with an estimated annual growth rate of 3–5% [1]. Within these wastes there are different substances (critical, valuable and hazardous ones) requiring a dedicated recycling process to avoid, from one hand, environmental and health problems and, from the other hand, problems associated with the extraction and refining of primary new materials through environment. It is re-known by the experts that these activities could offer the chance to reduce Green- house gas emissions [2]. Furthermore, the recycling market can be considered as one of the key industries able to close the materials loop. However, there is a large proportion of precious and special metals present in WEEEs that is still lost in there cycling process [3]. The production of modern Electric and Electronic Equipments

(EEE) requires the use of scarce and expensive resources and so the recovery of these materials represents a significant economic opportunity [4].

Manufacturing has traditionally been understood as the process by which raw materials are transformed linearly into value-added products for consumers. The future of the manufacturing industry however, looks very different; it will require manufacturing firms to be highly agile enterprises, capable of- exploiting rapid market changes by increasing flexibility in their physical infrastructures and production processes.

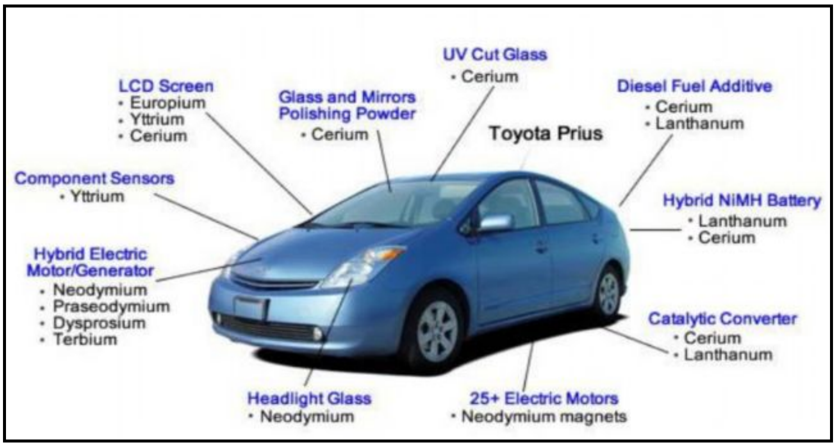

Fig. 1 Increase in design and material complexity of certain modern vehicles

A number of challenges driving these future changes within the manufacturing industry include:

- Increase in the demand for product variability [5-6].
- Increase in complexity of the material mix within products e.g. increased use of rare earth elements (REE) [7-8].
- Increase in complexity in the design and construction of products (Fig. 1) [9-10].

These challenges are already driving an increase in manufacturing responsiveness which has led to a shift away from traditional, high-volume, dedicated, in flexible production lines which are unable to respond quickly to product or material requirements, towards manufacturing systems that have flexibility and adaptability built-in from the outset [11]. These systems enable manufacturers to capitalize on the opportunities within dynamic markets where product variance and volume are rapidly changing. This shift away from dedicated lines has not been echoed by the recycling industry, especially within the recycling and material recovery systems that deal with end-of-life (EoL) of electrical and electronic products; this has created a substantial gap between the volume of products that are manufactured globally and the volume of high-quality material recovered from e-waste recycling. The introduction of flexible and adaptable systems into the recycling industry could potentially enhance material recovery from EoL products enabling the material to be used again in high-quality, high-value applications, promoting a circular use of resources without a need to down-cycle.

The largest dumping ground for e waste has been identified as China, the world's leading manufacturing country. The collection of the processes by most of the legal and publically accepted business sectors has produced much e waste recycling in China. These can generate harmful consequences to both the environment and human health. Application of crude methods such as strong acid leaching and the open burning of dismantled components in order to extract precious metals or to separate substances or material of interest from the electrical/electronic equipment have led to the release of large quantities of toxic metals and organic pollutants into the surrounding environment.

The major source of toxic heavy metals has been considered as informal e-waste recycling in China. Heavy metals such as lead and cadmium in circuit boards, cadmium in computer batteries, and copper in electrical wiring are widely used in the manufacturing of a variety of electronic products. These heavy metals persist in the environment and lead to poisoning at low concentrations through bioaccumulation in plants and animals or bio concentration in the food chain. Absorption of the heavy metals can take place through uptake from the soil by plants and through food, water, air, soil/dust ingestion and skin contact and by animals and humans. Human exposure to lead interferes with behavior and learning abilities; copper results in liver damage; and chronic exposure to cadmium increases the risk of lung cancer and kidney damage.

The international scientific community agrees that an optimized management of wastes can allow achieving economic, environmental and social benefits [12]. The European Union (EU), since the last two decades, tried to put the bases for the development of a circular economy, where wastes should be considered as resources and, so, used in an efficient and sustainable way [13]. To approach the target, renewable energy utilization in a sustainable way has already been developed and performed in various areas [14–21].To this aim; different directives were activated during the years. The WEEE Directive (Directive2012/19/EU) on the End of Life (EoL) management of wastes from electric and electronic equipments and the RoHS Directive (Directive2011/65/EU) on the restriction of the use of certain hazardous substance sin electrical and electronic equipments are the most relevant examples. Among all the different waste streams the attention of the European Commission was specially focused on the treatment of WEEEs because of a series of explicit warnings.

The hazards and the impact of e-wastes on the environment and human health has mentioned earlier will be described in detail with the advancements in the recycling process of e-waste in the next sections. A systematic study has been done on the previous researches and the present scenario with a future scope in this review.

I. Literature Review

The recycling of Electrical or electronic waste (E-waste) products could allow the reduction of the usage of fresh resources in manufacturing sector and, consequently, it could contribute in reducing the environmental pollution. Development of a circular economy based on the misuse of resources recovered by wastes has been tried by EU, for the last two decades. Federica Cucchiella [22] have done a comprehensive framework supporting the decision- making process of multi-WEEE recycling centres. An economic assessment have also been done which define the potential revenues coming from the recovery of 14e-products (e.g. LCD note books, LED notebooks, CRT TVs, LCD TVs, LED TVs, CRT monitors, LCD monitors, LED monitors, cell phones, smart phones, PV panels. Qingbin Song [23] has made a review on body burdens and human health effects of heavy metals from the major e-waste recycling sites in China and also recorded possible outcomes associated with exposure to e-waste (to heavy metals). Barwood. M [24] examined the adoption of key features in reconfigurable systems to increase flexibility and automation in recycling activities. Torsten Feldt [25] has observed significantly that the higher urinary polycyclic aromatic hydrocarbons (PAH) metabolite concentrations in the exposed individuals to e-waste recycling was high when compared to people who were not exposed to e-waste recycling activities. This comparison has been done by using a multivariate linear regression analysis including sex, cotinine and tobacco smoking as variables. It was shown that exposure to e-waste recycling activities was the most important factor for PAH exposure.

II. Review of Study

A. Materials & methods

Photovoltaic (PV) panels represent the most significant waste stream. PV panels (especially the silicon-based ones. Representing almost the 90% of the market) are not interesting from a recycler's point of view and, usually, end into landfills. Only the remaining 10% of PV panels is really recycled (because of the, even limited, content in key metals like cadmium, tellurium, indium or gallium), but their recycling cost usually goes over the recoverable value coming from the selling of materials.

Liquid Crystal Displays (LCDs) gradually substituted Cathode Ray Tubes (CRTs) displays and monitors in many application fields. The most important material that can be extracted (even if in limited amounts) by LCD screens is, without doubts, indium. However, many studies show that also in Printed Circuit Boards (PCBs) coming from LCD monitors and displays there are interesting contents in other valuable materials (e.g. copper, gold and silver). In addition, the great content of high-tech plastics used for their production (and, nowadays, almost without value) could play a relevant role in recycling, if specific recovery processes and alternative application fields will be developed. Light Emitting Diode (LED) screens are the natural evolution of LCD screens and it is expected by the experts a similar trend in their adoption like what previously described for CRTs and LCDs. These new types of screens add to materials embedded into LCDs also gallium, germanium and other rare materials, present in high concentrations into small LED components

Notebooks and tablets, together with desktops and servers, are the most valuable WEEE category, given their extremely high content of key metals in some of their main sub-systems

In general terms, PCBs constitute from 3% to 6% of the WEEE mass. Different types of metals such as gold, silver, and platinum (precious); copper, aluminium and steel (base); and antimony, arsenic, mercury and lead (toxic); ceramic compounds and plastics are present in a a typical PCB.

The economic convenience coming from the reuse of materials embedded into wastes, with the aim to make new products with secondary raw materials, represents nowadays one of the most important sustainability challenges. The recycling process of a product can be generally divided into three main steps, each of which requires an appropriate management method with the aim to optimise the economic result

- Collection of e wastes;
- Pre-treatment of the collected e wastes;
- Recovery of valuable materials and disposal of non-recyclable materials from the pre treated wastes.
- To this aim, the methodological structure is the following
- Product's selection based on a previous literature analysis
- Material's characterization for each of the selected products
- Generated WEEE volume's quantification, both in the ASIS and TO BE scenarios for each of the selected products
- Recovery economic potential evaluation for each of the selected products
- Overall recovery economic potential evaluation for expected WEEE volumes to be generated
- Results consolidation, obtained through a sensitivity analysis conducted on critical variables

B. Recycling

The fastest growing manufacturing sector in today’s world is the electrical and electronic equipment (EEE) industry. Due to the growing demand for technological innovation and shortened technology lifecycles, increasing amounts of waste from electrical and electronic equipment (WEEE) has become one of the fastest growing waste streams. It is estimated that up to 50 million tons of EEE is reaching EoL worldwide every year and needs to be recycled.

E-Waste Collected at different areas is sent to pretreatment plant, for disassembly and Segregation process. In this process, Plastics, Cables, Wires & Glass will be removed. After removing the cables and capacitors from the PCBs, they are sent to the Heavy Duty Shredder for shredding. The Shredded PCBs are sent to the Ball Mill to reduce the size of the PCB and they are fed to the Magnetic Separator to separate the Ferrous and Non-Ferrous Metals. Non Ferrous metals are fed to the Eddy current Separator to separate Aluminum. After the removal of Aluminum, the remaining Non-Ferrous Metals are fed to the Electrostatic Separator to separate the conductors (copper), semiconductors (extrinsic silicon), and nonconductors (woven glass reinforced resin). Crushed E-Waste material are fed to the Leaching tank to extract the noble metals such as copper, Silver and gold. Complete recovery of Noble metals is achieved by means of Electro Deposition and Electro generative process.

C. Reconfigurable Recycling Systems

RRS are defined as systems with the built-in ability to rearrange or modify their recycling processes to adapt to the specific characteristics of a waste stream. Fig. 2 represents the Reconfigurable Recycling System.

RRS has the following capabilities when compared to conventional recycling system of e-waste

- Ability to recycle high value of e-waste streams containing precious metal
- Allows for the transformation of its configuration on different levels to meet changing requirements after its original setup and installation
- Designed to consist of a number of autonomous units that are linked together to form a processing line in order to reduce unnecessary processing and could increase the quality of the recovered materials

Check the quality of the recovered materials in the processing line, adjust system parameters and hence provide consistent quality materials from waste streams.

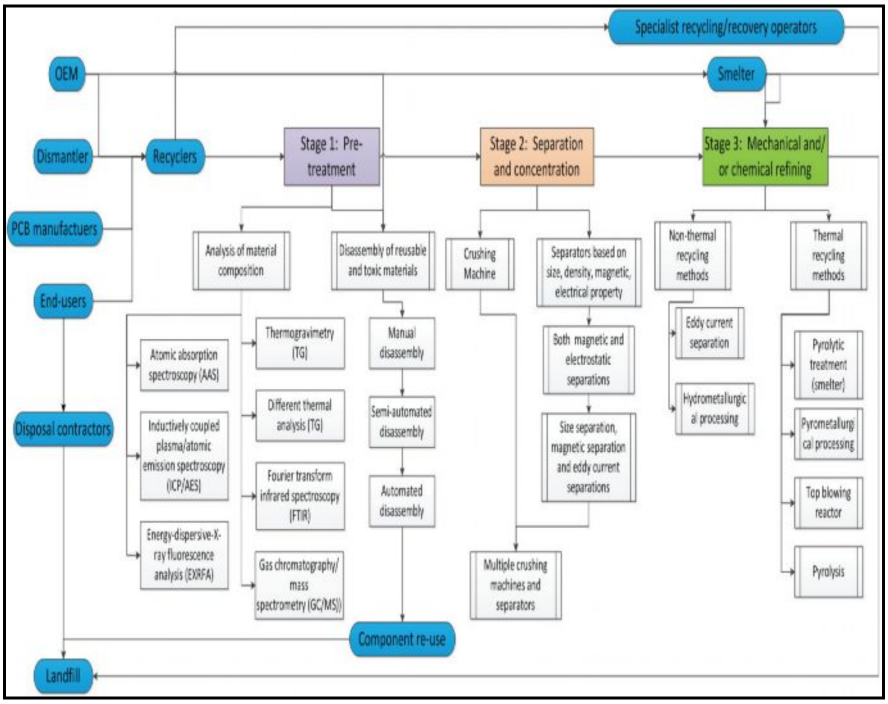

Fig. 2 Reconfigurable Recycling System

D. **A robotic disassembly cell as a reconfigurable recycling system for material recovery**

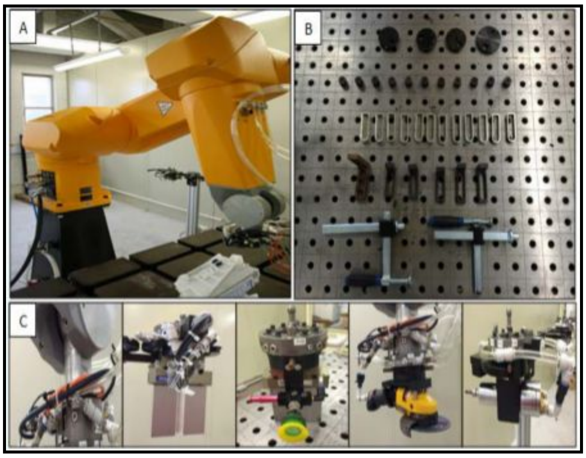

Fig. 3 Staübli RX160 robot disassembly cell with accessories

Disassembly systems designed at present have to be flexible to increasing number and variety of products designs and changing demand volume for recycling. In general, manual disassembly often takes a long time which is associated with a high labour cost. In order to investigate the challenges involved in recycling of EVs, an automated robotic disassembly cell has been adopted for semi-destructive disassembly [21] of EV components i.e. electronic control units (ECUs) and separation and concentration of high value parts/sub-assemblies i.e. PCBs.

A standard six-axis Staübli RX160 robotic arm with a specially designed set of tools for drilling/milling, cutting, and gripping and fixturing platform shown in Fig. 3, has been setup at a lab scale levelAdditionally the robotic setup has the ability to diagnose error statuses of the system and respond by suspending the operation, alerting the operator and waiting for further instruction or error resolution.

E. Occupational Safety & Health

A large amount of e waste has been continually generated worldwide with the development of the electronic industry and information technology. They have become the major pollutant of environment and human health. E waste consists of toxic components such as lead, chromium, cadmium, etc. which in turn produces adverse effects to human beings and environment.

E1. Exposure sources

The exposure to the e-waste can occur though the following:

- Inhalation from air,
- Dietary intake,
- Soil/Dust ingestion and
- Skin contact.

Surrounding soil, dust, air, and water, and food sources can become a major contact sources to make the people come in contact with e-waste materials, and associated pollutants. The exposure sources and average daily dose of heavy metals from e-waste are essential to investigate in order to know the influence of heavy metal transferred into the human body.

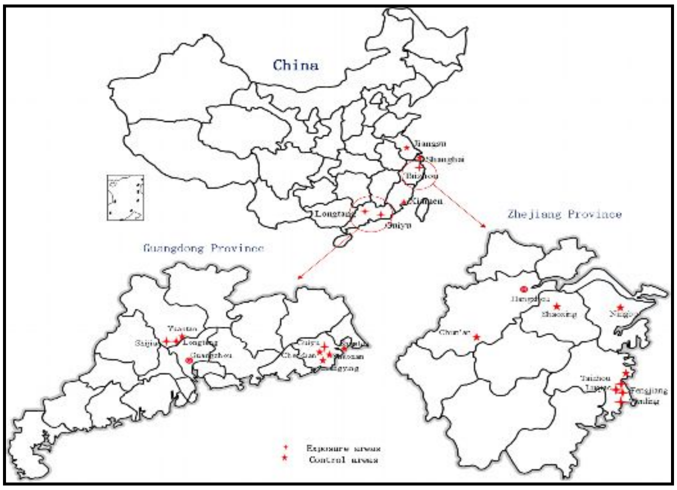

Fig. 4 E-waste exposure lands

Fu et al., 2008 evaluated the exposure sources of people in china to heavy metals from e-waste and shown that the main source of heavy metals for Taizhou residents' is from rice. He has compared the daily intakes of heavy metals at tolerable limit with the mean estimated daily intakes given by World Health Organization, the comparative results has been shown in the following table 1.

Table1. Comparative results of heavy metals exposure from rice

Heavy metals from rice	Daily intake mg/ (day.kg bw)	Estimated intake mg/ (day.kg bw)
Lead (Pb)	3.7	3.6
Cadmium (Cd)	0.7	1

The ingestion of heavy metals to the residents of Longtang town by consuming vegetables has been calculated by Luo et al., 2011, It has been observed that level of Cadmium (Cd) exceeded 2% of normal level. Zheng et al., 2013 compared the above results and investigated more sources such as food (vegetables, rice, pork, chicken and fish), house dust, and groundwater, to estimate the daily intakes of heavy metals. The result shows that the daily intake of heavy metals to children is high.

The workers in e-waste recycling workshops were faced with more serious potential health risks when compared with the residents in the e-waste recycling areas. Humans will be suffering from serious body burden when the heavy metals entered the human body through inhalation from air, dietary intake, soil/dust ingestion and skin contact. Due to those exposure of heavy metals, they will be accumulated in the 5 human tissues such as placenta, umbilical cord blood, blood and serum, hair, and urine.

Finally, the human body burden of heavy metals leads to all kinds of diseases on human health. For example: cancers, mental health and neurodevelopment disorders, thyroid dysfunction, and general physical health deterioration.

III. Conclusion

The study of e-waste recycling made in this paper reveals the details about the hazards and as well as the beneficial derivatives obtained from the recycling of e wastes. The case study on robotic cell setup for the reconfigurable recycling system insists its establishment on a large scale at the areas of e-waste recycling. The recycling methods of e waste can be automated in order to extract the valuable metals from the electronic equipments on a large scale.

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