Ecodesign of electronic devices

UNIT 7: Recycling of electronic devices

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Chapter summary:

- Importance of electronic device recycling
- Collection of electronic devices
- Electronic device recycling processes

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7.1. Recycling of electronic devices

Waste electrical and electronic equipment (WEEE) has grown significantly on the global level in the last 40 years, but especially in the last decade, WEEE has the highest increase compared to other types of waste. Due to this, sustainable business practices and efficient recycling of electronic waste is crucial. Recycling presents a great challenge for today's society. Contrary to established recycling processes for metal waste recycling of electronic devices at the end of their lifetime is much more complex. Electronic devices contain many sorts of materials which are interconnected and difficult to separate. Efficient WEEE does not only depend on the recycling industry which often experiences doubts on the suitability of recycling environments and devices. For efficient WEEE it is also important that the user and device dealers who are often poorly informed on recycling, environment protection, use of energy and materials.

In the last two decades, the volume of consumer and business electronic equipment has drastically increased. At the same time, the fast changes in information and communication technologies, the concurrently increased versatility of electronic devices and low prices drastically lower device's lifetime and long-term usefulness. Nevertheless, the devices, such as mobile phones can have multiple owners in their lifetime before being disposed. In 2008 the number of personal computers had exceeded one billion, wherein most of them already reached the end of lifetime. Consequently, this leads to an enormous increase of electronic devices that are or will be discarded. Such quantities of waste are often transported to landfills in the third world. Uncontrolled disposal presents a great danger to the environment and health of the wider population. Currently, the term e-waste and when a product becomes waste are not clearly defined. EU directive defines e-waste as outdated equipment that needs electric current or magnetic field for operating. E-waste are also measuring instruments for measuring electrical units. Experts have, therefore, proposed that e-waste was characterized as outdated product and owner's decision to discard the device. The electronic product becomes waste when its structure and condition cannot provide the predefined purpose. Reasons, why an electronic product is no longer useful, can be several. Most often the electronic device is not functional due to damage. It is also possible that the used technology is outdated or the design is no longer in trend. Luckily, the recycling industry sees consumer's discarded waste as profitable as the recycled materials can be sold for reuse. The amount of e-waste, created by USA and EU, as well as by the developing countries, has considerably increased in the last ten years. Depending on the data by the American agency for environment protection on average each household in the USA uses 34 electronic or electrical devices. This equals to more than 5×10^6 tons of e-waste per years. For EU it has been evaluated that each citizen on average creates 15 kg of e-waste, which equals to 7×10^6 tons of waste per year.

Within the WEEE research, some components in electronic devices contain dangerous substances such as mercury and cadmium. Both substances are dangerous for the environment, if not handled and removed correctly. Some products contain valuable materials that can be returned to the production cycle to be processed again. Control over large and even growing quantities of e-waste, recycling and processing of

materials for reuse are the key questions from the ecological, as well as the economic perspective. Nevertheless, today even in industrialized countries only a small percentage of e-waste is recycled depending on the product category. Most of the discarded devices end in a landfill or are burned. Precise statistical data is rare, therefore we have presented some evaluated data in table 1.

Type of WEEE	Arising	Collected	% Recycled
Televison set	8000	4000	50
Video/sound	72000	3200	4
Copmuters/IT	357000	94600	26
Household appliances	392000	345300	88

TABLE 1: RECYCLING RATES

In the table, we can see, that the quota for collecting of household appliances and televisions is quite high, while the quota for recycling of small electronic devices is extremely low, only 4%. In accordance to the same report, in 1998 the low rate of collecting and recycling has caused great loss of metals and other materials, for example, 2.4 x 10^6 tone of metals, 0.625 x 10^6 ton of copper, 0.33x 10^6 tons of aluminium, 0.23 x 10^6 tons of glass, 0.23 x 10^6 tons of plastic. In this evaluation are not included metals from rare earths.

The composition of e-waste variates by product type and the same applies to the composition of materials. This is related to ambiguities about recycling of mobile phones which have enormously expanded until now. A mobile phone can have plastic or metal covering parts. Interior parts that are needed for main functionalities can also be similar; these are display, printed circuits, and battery. One example of materials in a mobile phone is presented in image 1. If we consider the whole WEEE group, the composition of a mobile phone is more complex compared to other devices, meaning it deviates from the average. Together the metals (iron and steel) present approximately half of the materials. The next extensive groups are plastic (21%) and colored metals (13%). We have to note that these values can differ significantly depending on the product model. As a general trend, the content of ferrous metals always had the largest share of e-waste, while the content of copper, precious metals, and other contaminants have decreased.

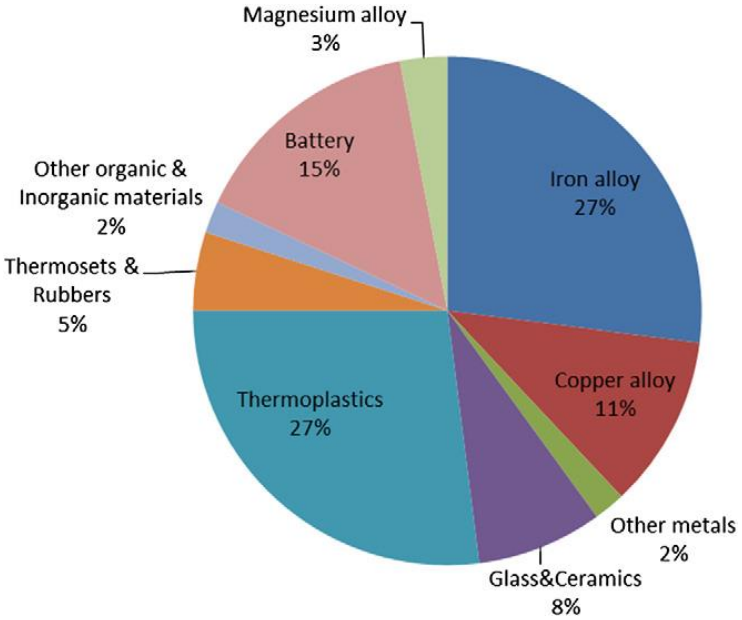

IMAGE 1: MOBILE PHONE COMPOSITION

Recycling of WEEE can be profitable if the materials in the devices can be recovered during this process. Nevertheless, there are still great differences between products, and the economic value of waste is heavily dependent on the sort of waste that needs to be recycled. Due to this, recycling of mobile phones can be much more profitable than recycling a hairdryer that contains less precious materials that can be recycled. As already mentioned, e-waste contains relatively large quantities of precious materials, such as iron, aluminum, and copper. These materials can be recycled and reused in new products. E-waste contains precious metals that have a number of uses in electronic devices as contacts. They also contain special materials, such as indium, gallium and rare earths. Often these materials are only present in very small quantities. For example, in a mobile phone, the total amount of these materials is approximately 0,15% of the total mass. A small percentage of content makes the recycling and reuse difficult. The recycling processes need to be economically sustainable, meaning that the separation and processing of different materials are only done if the materials can be profitably sold as secondary materials for reuse in new products. The driving force for processing of secondary metals and development of new recycling technologies are the increasing prices and limited availability of materials, for example, rare earths.

Some components of electronic devices contain hazardous substances that can be harmful to the environment if processed and disposed inadequately. The studies show that most mercury and cadmium in the landfills in the USA and EU come from e-waste. Although these substances are not used in most modern electronic products, the outdated products can still pollute the environment after their lifetime if disposed at inadequate landfills. Uncontrolled processing of e-waste, such as incineration outside can also cause negative effects to the environment and people who are directly or indirectly in contact with the incinerator.

All electronic and electrical equipment that is on the market will be over time outdated and will need to be recycled. With this, we can save unused resources and use materials that were already in use. The recycling process can also save energy. To slow down the increase of e-waste, the main principles in e-waste management are:

- **Reduce the number of devices:** Fewer products on the market and the current ones need to be maintained.
- **Device reuse:** By donating or selling we can give the device for reuse.
- **Recycling:** Products that are not functioning or useful.

Image 2 presents different possibilities for a typical electronic device when it has reached the end of the lifecycle. In each of the options are also possible bad practices that are related to the following facts. For example, recycling at the end of lifetime can be executed in a correct or incorrect manner. During product's lifetime, several users can use the product that could go through a phase of upgrade or repair. The product can be sold directly from the user to the user or through different mediums. But many discarded electronic devices, especially small sized ones, for example, mobile phones, laptops and consumer electronics stay at home as spare devices in case of breakdown, for memories or as the consumer overestimate the real value of the products and do not recycle it. With today's growing technology, the electronic products are quickly losing their value.

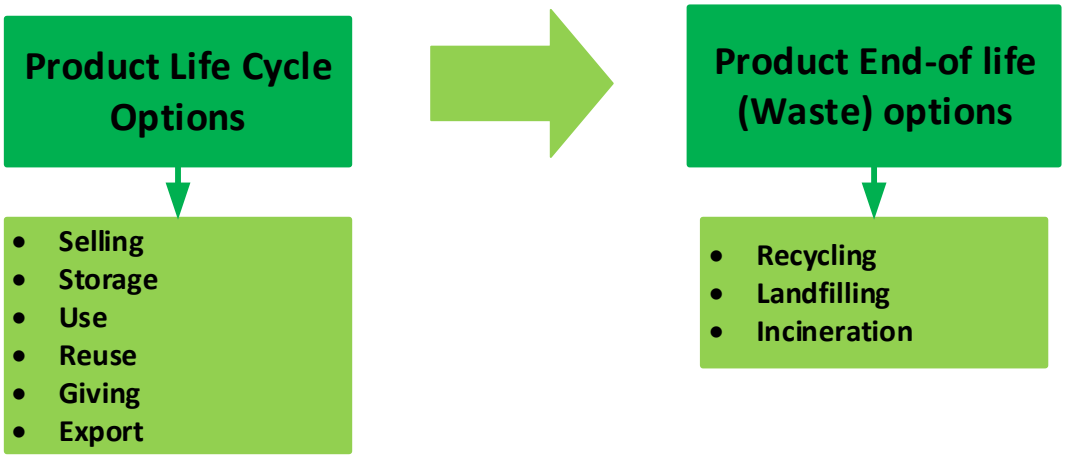

IMAGE 2: POSSIBLE LIFECYCLES OF ELECTRONIC DEVICES

In image 3, we can see results of the last study on discarded electronic devices. The study included a limited number of electronic devices, such as phones, tablets, music players, etc. In the developed countries, almost 40% of discarded devices stay at home, and only 12% are given to the recycling process. The ratio between recycled and preserved devices at home is an indicator of general awareness of consumer on recycling and its importance.

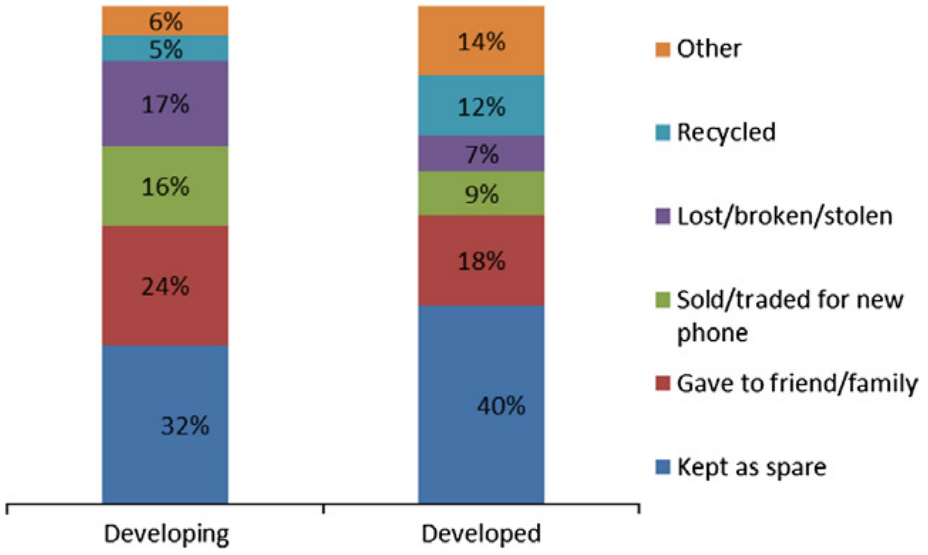

IMAGE 3: RESULTS OF THE STUDY ON THE USE OF ELECTRONIC DEVICES, WHICH WE DO NOT NEED

Uncontrolled and often illegal export of used devices to the developing countries presents great risk and concern. Developing countries often do not have regulated acts, directives, and laws that would revise the recycling of electronic devices. With the rise of electronic waste in the developed world, this fear is only increasing as at the same time the export to these countries is also increasing. Due to this, it is important that also in the developed world as well as in the developing countries we have established infrastructure for recycling of electronic waste. When the product finally becomes waste and cannot be used for its primary purpose, there are two options on what to do with the device. The preferred option is recycling and processing of contained precious materials. The second option is less wanted, and it is disposal or incineration. The second option can be in the majority avoided as it has negative effects on the environment and the society.

According to the definition processing of waste into material lowers the environmental contamination. Essentially, the appropriate recycling processes enable processing of precious materials as a secondary source of materials and the possibility for reuse in the new products. This leads to lowered use of primary resources. It also affects energy saving and helps lower air pollution, greenhouse gas emissions (from incineration) and water pollution (from disposal). Efficient collecting and recycling of products from only one material, such as newspapers, glass bottles, plastic bottles, metal tools, are in many countries an already established practice. A similar system needs to be established in collecting of electronic waste as well.

7.2. Electronic waste management policy

The amounts of e-waste are increasing on the global level, which creates a need for national, as well as international waste management models. Different interest groups around the world, including international organizations, governments, academics, industry and nongovernmental organizations deviate on suitable e-waste management. The main reason for concern is that e-waste cause health and environmental problems in the developing countries. The waste is especially hazardous to the environment due to risky processes and bad practices that are used by the non-formal sector when searching for precious metals and different used products.

The general goal in planning the national policy for e-waste management is creating a sustainable society for recycling. This includes the establishment of reliable models and infrastructure for collecting and recycling, but also efforts for increasing awareness and changing consumer behavior. All the new practices will need time to develop. The solutions will become efficient and pervasive because recycling will become everyday practice.

Important steps towards sustainable development and responsibility for the environment and public health have been made with the restrictions on the use of hazardous substances in electronic devices. The restriction of hazardous substances is defined in Directive 2002/95/EC and RoHS. Other directives have also been adopted that have involved the recycling processes, for example, Directive 2002/96/EC. There have been attempts to establish similar directives outside the European Union. The scheme of e-waste collection was first established in Europe. It is based on the principle that the users can hand over the device to the recycling process anytime without any additional payments. The goal of this scheme is increasing awareness amongst users and promoting the increase of recycling capacities. Directive RoHS demands that all heavy metals in electronic devices, such as lead, mercury, cadmium, hexavalent chromium and flame retardants, such as polybrominated biphenyls or polybrominated diphenyl ether should be substituted by less hazardous materials.

Despite these regulations on collecting and recycling, only one-third of electrical and electronic waste in EU is collected, separated and appropriately processed. The other two-thirds are likely to still be in landfills and unauthorized areas in EU or are illegally transported to the developing countries. In European countries, electronic waste is regulated by the legislature that defines manufacturer's responsibility for the products after the end of lifecycle and that he leads incentive for recycling and disposal. To achieve higher efficiency and related savings at costs were established organizations PROs (Producer responsibility organization) which are managed separately to respect the given responsibilities regarding management of discarded devices in the name of the larger electronic equipment manufacturers.

For an efficient solution of e-waste management problem, the countries have in the last decade accepted regulation on the extended producer responsibility EPR.

EPR requires that manufacturers of electrical and electronic equipment take back the user's equipment and recycle their products when they reach the end of the lifecycle. EPR is based on the assumption that the manufacturer's responsibility to recycling own products will force and encourage them to design new devices to have lower recycling and disposal costs. An important aspect of EPR is that the rate of returned resources would be higher which would decrease environmental effects and lower the production of electronic devices. In practice, we know individual EPR where the manufacturers pay for removal and recycling of their products and collective EPR where all manufacturers in quotas pay for removal of all electronic products. The quotas are estimated according to the market share and number of produced devices.

Currently are in the European Union in use different models for estimating quotas for financing certain costs in the recycling chain. Quota models are differentiated by what will be financed and how to estimate the costs for different product categories and their collection. Costs of product category evaluation and collection are based on the manufacturers who are in the same scheme and produce different electronic devices. Usually, the establishment of e-waste collection systems is the most efficient if it is organized in a collective way, meaning several manufacturers share the same collection system and the costs. In Europe, this has been achieved with the establishment of PROs.

In e-waste management are included different interest groups that have assigned roles in the whole recycling process. This means from the collection of outdated products to the final removal of components that cannot be recycled at landfills. It needs to be provided that all interest groups participate in the e-waste management system. Only this way it is possible to follow the strategy that optimizes the collection efficiency with the highest capacities of precious materials and reduced the amount of materials that need to be removed. At this state, it is not enough that the responsibility is limited only to the manufacturer but also on the traders, governments, local authorities, end users, and the recycling industry. All mentioned have an important role and effect on the recycling efficiency. To develop efficient and sustainable solutions, all involved have to agree on financing and cost sharing. All stakeholders, national or regional governments, consumers, non-governmental organizations have an important role in providing that recycling of WEEE is done in a sustainable, cost-efficient, accessible and fair way for everyone involved.

7.3. Recycling of electronic components

The end of product's lifecycle can be divided into several subprocesses which are intended to recover the used materials and energy. Optimization of the whole recycling process chain is key for achieving efficient recycling for the environment, as well as for the economy. This means that all steps of the recycling approach need to be considered because they are interconnected and interdependent. The efficiency of e-waste recycling does not only depend on the technical capacities, but also on other factors. There are challenges related to the politics, legislation, economy, society, and culture. One of the main obstacles in recycling is still the lack of consumer awareness on

possibilities for recycling electronic waste and their positive impact on the environment and creation of a society that is focused on sustainable development. The obvious lack of awareness can be seen in the low rate of collected discarded electronic products. The last studies in Europe show that only 10% of electronic devices is returned to the recycling process.

At the end of product's lifecycle, the recycling process can be divided into three phases that need different management methods and different technical approach, as seen in image 4. The first step is collection and consolidation of waste, called »take back«. This is mainly a logistic challenge that requires a high level of awareness and consumer's readiness to return outdated electronic devices for recycling. In the second step before waste processing, the waste is taken over by specialized recycling companies. Those sort the devices according to the device type. For example, separately are sorted computer monitors, television sets, audio devices, personal computers, portable devices, such as mobile phones, laptops, and tablets, printers, household appliances, etc. The sorting is also done by the built-in materials in the device. This process of separating is done before the devices go in the recycling process. Materials that cannot be recycled are used for generating energy at incineration or are finally discarded at a landfill. Each step is a smaller side stream that cannot be further processed. Depending on the electronic device type and its composition it depends how difficult the recycling process is. Efficient achieving of the second and third recycling phase depends on the device itself. Therefore, it is important that each product or device type has a prepared recycling plan.

The second recycling phase includes manual disassembling of the device and mechanical or chemical processing. The third recycling phase presents the return of the processed materials back to the market. The first phase of waste collection is organized at a local level. An important role have local communities, local politics, and organizations for environment protection. The second phase is also done at the local or regional level, depending on the availability of recycling capacities and companies. A part of the third step usually includes special techniques that are usually organized at national or international level. One example is refining of precious metals or metals from rare Earth materials that need complex and more expensive processing for recycling. As image 4 shows, the collection, recycling and reuse of materials is connected to certain costs. These costs are in total or partly returned by sales in the third phase. From the economic perspective, incineration and disposal at landfills are null activities. The materials that are hazardous and cannot be recycled represent only a cost because management of these waste requires specialized landfills and strict supervision. With the introduction of policy »care for the device through the complete lifecycle and takeover of outdated device«, manufacturers are lead to use materials that can be recycled as much as possible.

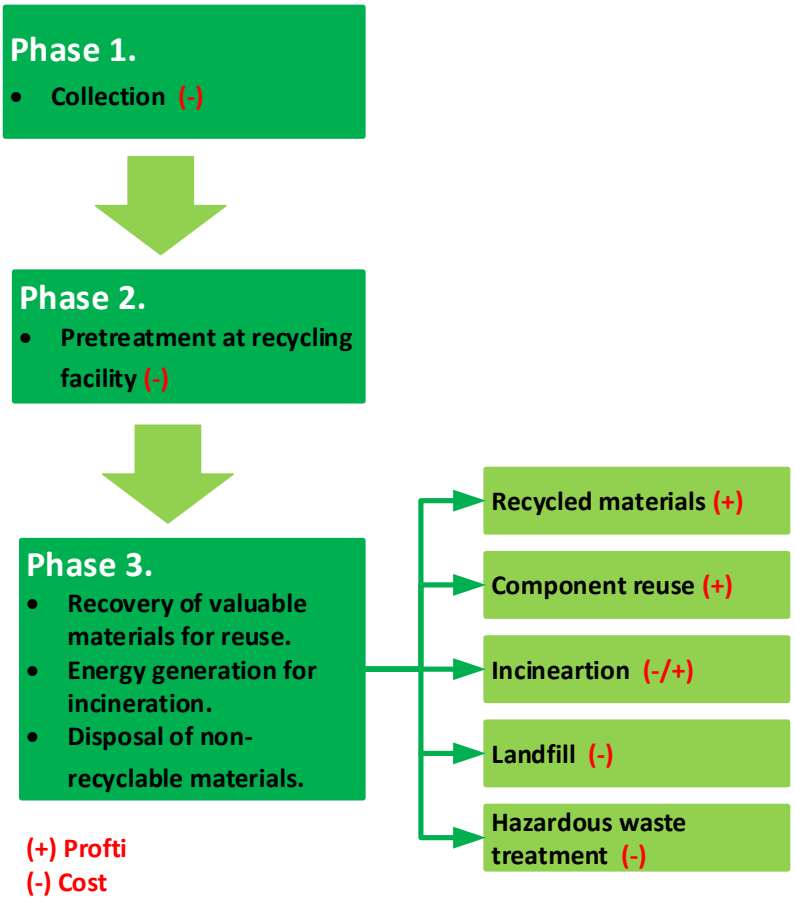

IMAGE 4: THREE PHASES OF ELECTRONIC WASTE RECYCLING

Efficient electronic waste management requires similar infrastructure than management of any »ordinary« waste. The three main bases of efficient waste management are collection infrastructure, recycling industry and supporting activities, such as awareness and reporting systems. All these bases need to be established before electronic waste recycling can be done in an efficient and sustainable way.

7.4. Collection points and infrastructure

Collection and transport of electronic waste present the main cost of the whole recycling process. Collection costs can enormously increase if the costs for increasing user awareness through different public media are added to the costs. Optimization of the collection process, together with the establishment of cost-efficient ways of communication and increasing awareness of the existing programs for recycling is crucial for efficient WEEE recycling. For example, collection of packages in roadside mailboxes are very convenient for the consumer but present a great logistic cost for collectors of packages (the post office). Many collector schemes that enable the consumer to return outdated electronic equipment anytime cause accumulation of electronic waste which leads to lots of expensive additional sorting. Convenient

collection points are in stores with electronic equipment or in places where the massive transition of people require additional space and supervisory staff. The convenience of waste disposal and operating costs of waste collection take place at the same time. Collection points outside of settlements and high coverage of cities mean high operating costs for waste collection. Lowering of operating price means fewer collection points and an increased probability that less outdated devices will be collected. The key role here has the increased awareness and readiness of consumers to transport discarded devices to the collection points that are often not part of their daily transportation route. Collection of waste and costs are not equal for all electronic devices, for example, collection of mobile phones and refrigerators require quite a different approach.

The establishment of a cost-efficient scheme for e-waste collection that will be positively adopted by the users requires a lot of work and time. Introduction of recycling program and construction of needed infrastructure are the first steps to the establishment of collection network for e-waste. Once the program is tested and validated, it can be extended with cooperation with different partners such as retail businesses, educational institutes, non-governmental organizations and local or regional authorities. The next phase is an improvement of the collection network and further development of the program with collecting and analyzing data and a better understanding of local consumer behavior. In the Europen Union countries, the manufacturers have established PROs (Producer responsibility organizations) that establish permanent collection infrastructure for e-waste in the name of manufacturers. This way the requirements, given by the European directive WEEE, are fulfilled.

Although infrastructure for collection of small electronic devices, such as mobile phones, music player, and tablets is in many countries in use for a long time, most consumers still do not know about the possibility to recycle their outdated devices. Lots of communication with the public and easy opportunities for overtaking the waste are used as the main messages in increasing consumer awareness with the intention to significantly increase the number of disposed electronic devices. Visible collection points that very effectively present to the user the options for device recycling are located near kiosks and other collection places as seen on image 5. In this case, the collection points need to be accessible to the users and safe. Often it is difficult to evaluate when the waste bin is full and needs to be emptied. This is why it is necessary to establish a logistical solution that is economically justified. Also, people often leave other types of waste at these collection points, such as empty cans, paper cups, biological waste, especially if these collection points are in shopping centers or in coffee shops. This increases the need for additional sorting of waste.

IMAGE 5: COLLECTION POINT FOR ELECTRONIC WASTE

For the consumer, one of the easiest ways for returning small-sized electronic devices is recycling by using postal services. As seen in image 6, the consumer can use a prepaid envelope to leave the device in the nearest mailbox and send it to the appropriate recycling. The envelopes can be obtained in several ways. Prepayed packages and addresses can be downloaded and printed from the internet, while the envelopes can be sent directly to the consumers, distributed to stores or be a part of the package when buying a new product. The envelopes provide an easy process for returning but are slightly more expensive than reverse logistics.

IMAGE 6: ENVELOPE FOR RECYCLING MOBILE PHONE

7.5. The electronic waste recycling process

Recycling of a variety of different metals, such as black alloys and aluminum have a long history in the metal processing industry. The recycling technology is well developed and very efficient. The recycling technology for electronic waste and metal processing is different as it is a source of secondary resources. The processes have a short history and less established technologies. The electronic products have a complex composition and contain different materials. These materials are integrated among themselves. Usually, they are present in small quantities and are built in thin layers. Separation of materials on different groups makes the recycling process different. Also,

there is a mass of different electronic devices that have different structure and components. Due to this, the recycling processes vary between devices and can be summed up in some main steps of the electronic devices recycling process:

- Sorting by components.
- Decomposition and disassembly. Removal of hazardous elements and batteries.
- Preparation of material for further processing. Metallurgical or mechanical processes.
- Recycling. Return of materials to reuse.
- Incineration. Use of energy.
- Removal of materials that cannot be recycled.

Most recycling companies pay a lot of attention to the process before recycling. This means that e-waste are sorted on different materials that are prepared for final processing. Processed materials are returned to the market; some are incinerated, others are disposed at landfills.

Before processing, different technological processes for separation of materials are used. Different material fractions can be involved in suitable recycling processes. The separation process is shown in image 7. Disassembly of complex electronic equipment is done only if the device contains precious parts. Those usually cannot be diluted with less precious ones. Just like in separated recycling, the printed matter (PCB) which contain hazardous substances require special handling. For example, bulbs that contain mercury are mostly disassembled manually which creates bottlenecks in handling of large quantities of e-waste. In the disposal of potentially hazardous substances in production of electronic products, much has already been done. Many directives and laws have been set that restrict or prohibit the use of these substances. For example, materials, such as lead, brominated flame retardants, and polyvinyl chloride are completely removed from the production of electronic devices.

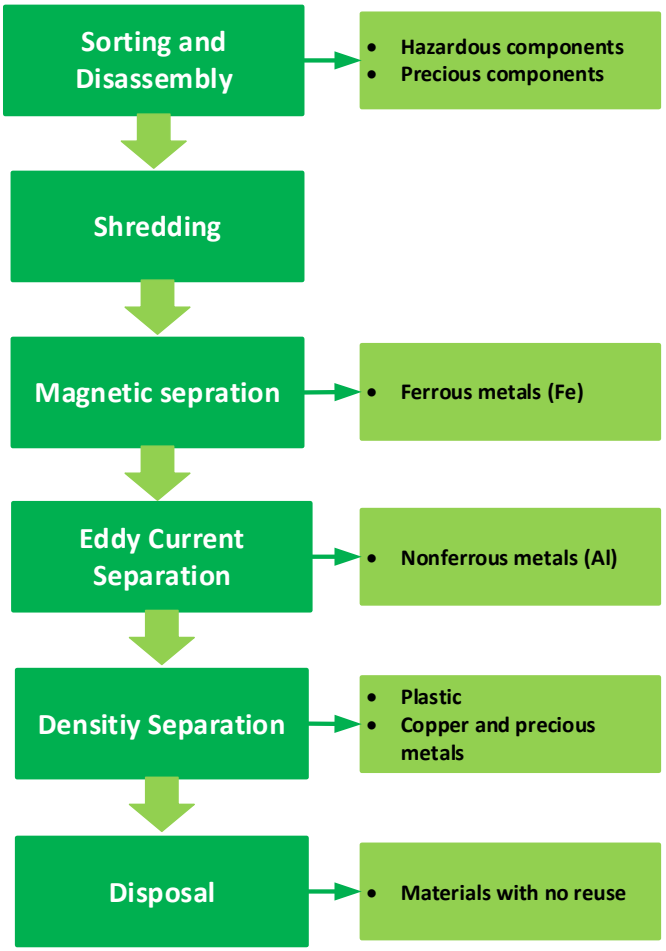

IMAGE 7: WASTE PROCESSING

The next phase of the processing is usually a reduction of the material volume with the use of shredders. The next step after shredding is separation of ferrous metals, aluminum, and plastic from ground material. We know three technological approaches that are based on the use of magnetic field for magnetic metals, vortex flows for non-magnetic metals and conductive metals and the principle of separation of density for non-metals. We need to emphasize that the processes are adjusted according to the processed mixture, and the separation is only done to the needed extent. Different material fractions acquired by separation before processing and recycling are sold to the same companies that produce materials from primary sources, as well as secondary resources acquired by the recycling processes. In recycling of the most precious materials, as well as precious metals the integrated copper smelters report on high processing rates, that reach up to 95%. Organic materials are in this process used as substitutions for coke, the reduction agent and as fuel. Iron and aluminum transform into slag in the process of integrated copper melting and are not regenerated as metals. Slag is disposed at landfills. Many electronic products contain flame retardants that can form dioxins during processing if not properly monitored and managed. In integrated copper smelteries e-waste can be processed without dioxin emissions.

Recycling of plastic is more complex than metal recycling. E-waste contains different plastics that need to be identified and separated for recycling. Plastics are often coated, colored and protected from fire. All synthetic materials are seen as impurities in recycling which makes the material less precious and less profitable. Plastic can also be used as fuel in the copper and precious metal recycling processing.

Early design phase can also contribute to the efficient recycling of electronic devices. This can significantly contribute to the efficient processing of WEEE and effect the recycling costs. Due to the different structure of electronic devices, it is difficult to develop advanced recycling technologies that are suitable for all devices. The main factor that obstructs the development of advanced recycling technologies are small quantities of collected e-waste. These facts can confirm why there are not many companies specialized in recycling certain types of e-waste. It is also the reason why the existing companies cannot accept all waste to the recycling process. Because quantities of collected e-waste are still low, the level of automatized recycling is still in more or less early stages and development phase.

Product recycling does not only differ in structure, but also in economic justification of recycling. Certain products contain relatively large quantities of precious materials and recycling of these products generates value and profit. These are usually products with precious metal that contain printed matter (PCB) or large metal pieces. Some products contain hazardous materials that need to be separated and processed in specialized objects for waste processing. These are usually refrigerants in old refrigerators or cartridges for toners. Some electronic devices are produced of materials without any selling value. In these cases, device recycling is not justified as it only presents a cost. It has been shown that in the recycling of products that contain relatively high quantities of precious metals (mobile phones, tablets, computers) the separated collection and processing including higher logistic costs will bring higher environmental and economic value.

For products that contain more than 250 ppm of gold and 150 ppm of palladium the separated collection is always more ecologically efficient than mixing of these products with others that contain smaller quantities of precious metals.

7.6. References

[1] Pia Tanskanen, Management and recycling of electronic waste, ACT Materialia,(61)2013, p.1001-1011

[2] Jirang Cui, Roven J. Waste – a handbook for management, Elsevier: Academic Press; 2011. p. 281–96.