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ELECTRICAL AND ELECTRONIC EQUIPMENT RECOVERY AND RECYCLING IN TURKEY

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ABSTRACT

Discarded electrical and electronic equipment contains valuable materials, low value parts, and hazardous substances. There is a growing concern regarding the management of end-of-use equipment owing to the environmental concerns associated with discarding used devices. Electronic waste or scrap consumes valuable landfill space and may ultimately contaminate groundwater sources. In addition, replacing discarded components with new components typically consumes valuable virgin material resources. With the advent of the WEEE (Waste Electrical and Electronic Equipment) Directive, used electrical and electronic products are now being recovered in Turkey as a European Union (EU) candidate country, and several companies in Turkey have begun to recover latent value through disassembly and reuse/recycling of materials and components. To remain competitive, these companies must implement economical and environmentally responsible recovery processes. There are a number of research challenges associated with product recovery. This paper describes the current product recovery infrastructure in Turkey, and discusses future trends and drivers for successful product take-back.

Keywords: End-of-life, WEEE Recovery, Recycling, Infrastructure, E-scrap

INTRODUCTION

There is growing concern regarding the management of end-of-life electrical and electronic products/equipment. These concerns have arisen from the fact that not only do these discarded products/equipment contain many different kinds of valuable materials (e.g., components containing Ag, Al, Au, and Cu), and low value parts (e.g., plastic and glass parts), but also hazardous substances (e.g., batteries, parts with Pb and Hg content, liquid crystal displays, and brominated flame-retardant plastics). These hazardous substances when landfilled may contaminate ground and surface water. These concerns have motivated the establishment of the WEEE Directive in the EU, which mandates that manufacturers take back their products from the end-user. With the passage of the WEEE Directive, manufacturers become responsible for economically recovering used equipment for the purpose of material recycling and component reuse. With this new responsibility, manufacturers have assumed the daunting challenge – the design, planning, and establishment of an effective used product recovery infrastructure. For an effective infrastructure, i.e., one which economically collects, classifies, and disassembles the product, the knowledge of the recovery rate and quality of the retired products is essential to make effective decisions related to disassembly and recovery facility planning. There is also a need for an information system which keeps track of the recovery rates of the retired products as mandated by the Directive. Unfortunately, given the nascency of the recovery/recycling effort in Turkey, there is neither any official statistical data nor research about current electrical and electronic equipment being used and discarded in Turkey.

Recycling of electronic equipment is on the rise in Turkey, fueled by international regulatory developments. Heightened interest in managing both the asset value and waste stream created by the growing use of electronic equipment is another motivation for the recovery of the retired products. Electronic products have a fairly predictable life expectancy, but anecdotal evidence indicates that these products are most often outdated long before they reach their failure point. Traditionally, as new technology was introduced into new products, old models of the product would become obsolete and almost always discarded by the consumer. Under the WEEE Directive, which calls for the recovery and recycling of end-of-use products,

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upgrading retired products represents one promising and under-explored alternative; at present, however, upgrading is very seldom done due to the technical difficulties and negative consumer perception associated with the purchase of "used goods".

As noted previously, many electronic goods contain hazardous materials which can have potentially harmful effects. Connections on printed circuit boards (PCB) have historically been made using Pb-Sn solder, and Lead is a hazardous material of concern. Circuit boards are becoming ever more densely crowded with components, to give them as many functions as possible and to make them smaller and less expensive. This makes it increasingly difficult to disassemble and reuse them. Although the disposal of lead and other hazardous substances into landfills may result in groundwater contamination, most PCBs are simply crushed and buried without any reuse or recycling effort. Today, after removal of a small number of components for reuse or recycling, most of the WEEE is land-filled or incinerated in Turkey.

Development of environmental regulations and standards is a topic of great interest in both the electronics manufacturing and recycling industries in Turkey. The focus is largely driven by the European Union's WEEE [1] and RoHS [2] Directives. The Directives are aimed at reducing the waste from electrical and electronic equipment, improving the environmental performance of all aspects of the life cycle of electrical and electronic products, and protecting human health and the environment by restricting the use of certain hazardous substances in new products/equipment.

The main objective of the WEEE Directive is to minimize waste by maximizing the recycling of electrical and electronic products. It is predominately concerned with the mitigation of the e-waste (electric and electronic equipment which has reached the end of its useful life) problem by mandating take-back of obsolete (end-of-life) products to meet fixed recycling quotas. Collection targets and goals for recovery (recycling and re-use) are defined based on the product family, with recovery rates typically in the range of 60 to 80%. The RoHS directive, on the other hand, restricts the use of certain hazardous substances in new equipment.

Recovery is simply another stage in a product's life cycle and its challenges must be addressed in the same way as those of others stages (e.g., manufacturing and use). However, there is still no single or mandated strategy for the management of retired products in Turkey. At the end of life (EOL) of a product, some collectors choose to bury EOL products as a special waste, but most of the society supports a more environmentally conscious approach, where recovered EOL products are reused in another form or product. According to the current draft of the WEEE Directive, the manufacturers will be responsible for the collection, disassembly, further treatment, material recycling, and elimination of the waste. The financing of these operations will be supported by the manufacturers, for new as well as for old products, i.e., products which were sold before the introduction of the Directive. It is to be expected that ultimately the cost for complying with the Directive will be internalized within the company, and eventually passed along to consumers. Multiple recovery options will be set up, in order to allow the consumers to dispose of their products easily and "free of charge". To insure the efficiency of the system collection targets and recycling quotas will be applied. Thus, the directives are intended to influence product design; the manufacturers will change the product design, which will enhance the use of recyclable materials, collection and recovery options, and disassembly for part and material reuse.

A number of researchers have studied the collection of EOL products and reverse supply chain. Pochampally and Gupta [3] have addressed some of the crucial issues of the reverse supply chain. Spengler et al. [4] have stated that cost effective management of material flows between suppliers, producers, customers, and recycling companies requires an integrated information management system as well as advanced planning systems. They also state that integration of the recycling companies into the supply chain of the original equipment manufacturers (OEMs) as "spares" suppliers or secondary materials suppliers is important for a closed-loop supply chain. Teunter and Inderfurth [5] have given a list of problems associated with the planning and control of a supply chain for a remanufacturing facility.

Sutherland et al. [6] presented a model for a demanufacturing facility that describes the disassembly process activities, the accumulation of component inventories, component sale based on market price behavior, and inventory management costs. Wentland et al. [7] quantified the role of physical part shape in possible post-use options. Metrics were established to relate the geometric attributes of the parts to the environment. They proposed a Reprocessability Index (RPI) to compare the reprocessability of various parts at the end of product use. Tumkor et al. [8] looked at selective disassembly to extract the maximum value out of a product before it is recycled. The focus was on optimizing the conflicting objectives of minimizing environmental impact and maximizing profit. Several end of life options like reuse, remanufacturing, primary recycling, secondary recycling, disposal, and special handling were considered to develop an optimization model. This model was used to find the best alternative for different scenarios of minimizing environmental impact or the disassembly time, and maximizing the rate of return. In another study, Fidan et al. [9] developed a simulation environment for an electronics remanufacturing system. Automated disassembly processes and tools were developed to enable the handling of multiple product variants. These developments are currently being implemented in several prototype hybrid disassembly systems for large- and small-size electrical and electronic consumer goods such as washing machines [10] and cell phones [11].

This paper focuses on recovery and recycling in response to the WEEE Directive in Turkey. It describes the results of an initial study to characterize the current product recovery infrastructure in Turkey. In this paper WEEE-driven demanufacturing and final disposition of collected e-wastes are also described to provide a better understanding of the current electronic recycling technologies. This description will provide a comprehensive view of the technologies available for the recycling of e-waste.

QUANTITY AND TYPES OF E-WASTE IN TURKEY

E-Waste may be differentiated by its origin – used household appliances or defective/returned appliances from industry, distributors, and retailers. Table 1 shows the distribution of e-waste from defective/returned appliances from industry, distributors, and retailers into different product categories such as white goods, brown goods, and consumer equipment. This information was collected by surveying separate collection centers in Turkey. As is evident from the table, nearly half (by weight) of all the non-consumer related e-waste is associated with large household appliances. This may be expected due to the size of the items themselves as compared with the other types of e-waste; however, it may also be providing information on the consumer assistance for the white goods.

Table 1. Amount of defective/returned electrical and electronic equipment from industry, distributors, and retailers

Product Category	Examples	Weight
Large Household Appliances, White goods	Washing Machine, Dishwasher, Boiler	40%
Large Household Appliances, Brown goods	TV Set, Screen	15%
Small Household Appliances, Video and Audio Equipment	Camcorder, Radio, Amplifier, CD-Player, VCR, Vacuum	9%
Other Appliances, small	Vacuum Cleaner, Coffee Machine,	9%
Consumer Equipment	Consumer Battery, Accumulator, Fluorescent tube	6%
Inf. & Comm. Tech. (ICT) Equipment	Personal Computer, Photocopier, Fax Machine	19%
Other Appliances	Cooling Appliance, Cameras	2%

While Table 1 provides information on the e-waste attributable to returns/defectives from commercial businesses, it should be noted that there are no specific records for the e-waste collected from used household appliances at this time, due to lack of a special collection network for this stream of e-waste. They are collected as part of the municipal waste stream. However, end of life household appliances from end users are assumed to follow a similar distribution, if they were to be collected separately.

Once an electrical/electronic product reaches the end of its useful life, it is critical that the product be handled in an environmentally responsible manner because such products often contain significant amounts of hazardous materials such as mercury, lead, cadmium, and polychlorinated biphenyls. Table 2 provides a list of pollutants in e-waste and the source of these pollutants. The table suggests that the sources of pollutants are not centralized in the equipment. They are spread throughout the product in components like screens, batteries, transformers, and switches. Thus, it is important to improve the design of all the components of the equipment in order to reduce the impact of the hazardous substances.

Table 2. Pollutants in electrical and electronic equipment

Pollutant	Source
Antimony trioxide	Flame retardant (FR) in plastics
Asbestos	Isolation and flame retardant, e.g., in night-storage heaters
Barium	Screens (face plate)
Lead	Screens (funnel), solder material
Bromine	Bearing chemicals flame retardant
Cadmium	Batteries, pigment and stabilizer in plastics
Chlorine	Flame retardant
Polychlorinated Biphenyls	Dielectric liquid in capacitors, transformers
Mercury	Tilt switches, relays, fluorescent tubes

In addition to the hazardous substances, electronic products also contain high value materials such as steel, gold, and copper (Figure 1). As can be seen from the figure steel and plastics represent the majority of the material (i.e., 88 %) found in e-waste. The recycling and separation technology for steel as well as plastics is well developed. This separation technology will be discussed later in the paper.

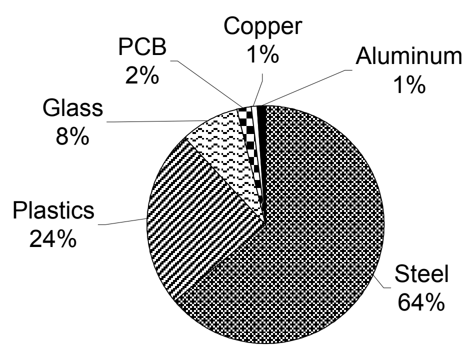

Figure 1. Quantity of Recycling Material in e-waste

Figure 1 indicates that plastics account for approximately 24 percent (by weight) of all the electrical and electronic equipment. This large percentage suggests that it may be useful to identify the specific products that serve as the source of plastic content within the e-waste stream. Figure 2 provides a Pareto chart for the average plastic content associated with various electrical and electronic devices [12]. From this chart, it is evident that plastic content represents an extremely large portion (by weight) of telecommunication devices (58%) and small appliances (35%). This implies that if it is desired to recover plastic content from e-waste, it may be advisable to focus on these product categories first.

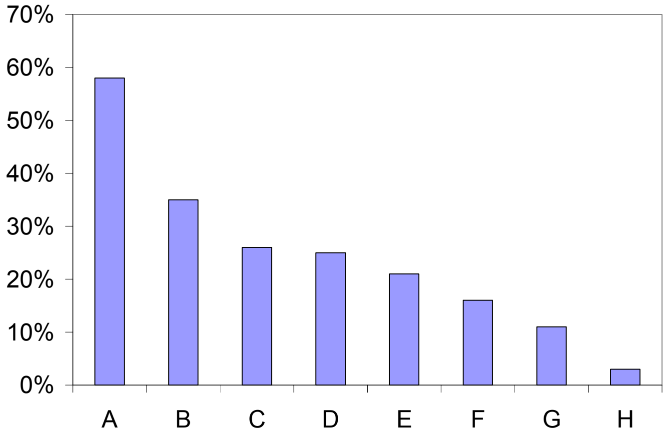

Figure 2. Percentage of Plastic content in Various Types of Equipment

In Turkey, WEEE plastics contain an average of 75% flame retardant (FR) plastic types. The major groups of flame retardant plastics contain either brominated or phosphated flame retardants. There are also contaminants in WEEE plastics like wood, pallet debris, screws, brass inserts, circuit boards, wires, labels, glues, rubber, ceramics, coils, glass, paints, and magnets. Furthermore, several obsolete electronic devices or parts can be reused if identified and sorted out by experts.

E-WASTE COLLECTION & SEPARATION IN TURKEY

Several studies have been conducted in Europe and in the U.S. [13-15] to determine the necessary collection and take-back scenarios for used products in those regions. On the other hand, to a large extent, the disposal routes for e-waste in Turkey are virtually unknown and have received little study. It is expected that in response to the WEEE legislation, recycling rates are going to be higher and that mandatory take-back will drive manufacturers to establish new logistic systems which include demanufacturing operations. They may even want to have their own collection, separation, and recycling facilities.

The collection market in Turkey is currently composed of three actors or entities: metal scrap dealers, local municipalities, and private recycling companies. A take-back obligation would create new needs for these entities and an improved collection system would be the first mandatory step in recycling of the discarded appliances. Presently, collection and transport costs for the used products, which are larger than the profit from recovery, are paid by the municipalities with the taxes paid by the citizens. After the implementation of the EU-Directive, financial contributions will also come from the manufacturers. There are three ways to collect the e-waste; home collection for household appliances; enterprise collection, and collection points by distributors and retailers. That means a new market would also be opened for transporters.

Today end-of-life equipment is mostly regarded as scrap and treated in a destructive way – in other words, only material is extracted from the products/equipment. To increase the economic and environmental benefit, it would be desirable to recover working components from the equipment for subsequent reuse. With this in mind, damage of reusable equipment must be minimized by careful handling, transportation, and storage. In fact, the separation of the reusable parts must be done as early as possible, even at the collection point if possible [16].

Especially for electrical and electronic equipment, there are several EOL options (see Fig. 3). Priorities for the processing of these products, from an environmental and economic perspective, are listed below in decreasing order of desirability:

1. Reuse the product as a whole. When one consumer discards a product, it will only become waste if other consumers are unwilling to use the product because it offers poor functionality. In addition, even poorly functioning products can be given another life if they can be repaired. There are mainly two categories of products which are economically viable from a reuse perspective: computers and white goods. However, in a use and throwaway society, product reuse is not always considered acceptable or desirable. The reconditioning of computers requires qualified manpower, but rapid technical evolution (product obsoletion) limits the possibilities of such an activity. If a product is in good working condition, it may be refurbished and resold or donated to an organization, such as a school or charitable group. The take-back obligation would create more potential products for these groups to collect and repair. There is some concern by OEMs that the reconditioning business will have a negative effect on their own business and the perception of their product. When repaired products are re-sold on the market, most likely under their original label, the performance of the reconditioned product will be linked to the OEM brand-name. There is a whole range of warranty, liability, and brand-image issues related to the re-sale of reworked products.
2. Reuse of subassemblies and components. Disassembly for part reuse is a very attractive recovery option. If it does not make economic sense to refurbish a piece of equipment, then it may be disassembled into its components. After disassembly, if there are any working parts that have value, they are sold on the second-hand market. For brown and white goods, this activity is done to recondition the complete product. The PC market is more specific and the possible value of printed circuit boards (PCBs) is attractive. Classical PCBs, such as mother-boards or video cards, could be sold on the second-hand market to support the reconditioning of complete PCs. Processors could be reused in other products, such as toys or electronic appliances.
3. Material recovery. If, at any stage, during one of the two options above, the economics associated with recovery/reuse are not favorable, then a third option is pursued. The third option is material recovery. Any remaining parts and materials produced by disassembly operations are separated and go through further processing for material recycling. The goal is to separate the discarded products into several fractions which will be combined with

virgin materials to form the raw material stream for production. In the short term, this is probably the most efficient way to achieve current recycling quotas.

4. Incineration and disposal: The remaining streams are "used" in an incineration facility or disposed in a landfill. Although incineration and landfill are the worst EOL options for the environment, most of the e-waste follows this path.

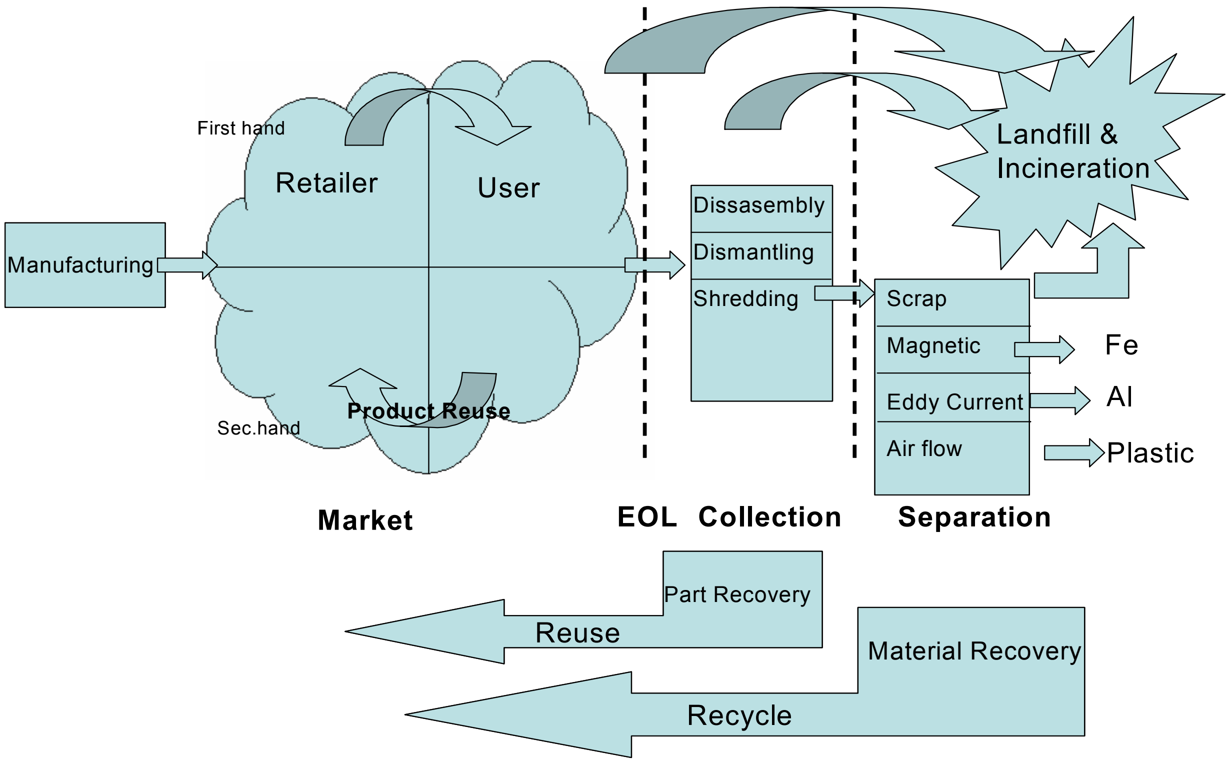

Figure 3 EOL Options for the WEEE

REUSE AND RECYCLING TECHNOLOGIES FOR SCRAP MATERIAL

Material recovery technologies for e-wastes are described in this section to provide a better understanding of the processes involved. Today most recovered materials from the WEEE are steel and plastic. These materials are first separated from the other scrap. Once e-waste is shredded, the pieces end up on a conveyer belt passing through an electromagnetic system that pulls out the steel. After this magnetic separation, an eddy current is used to separate the aluminum from non metallic pieces. After the separation, metal pieces are sent to refineries for smelting.

For the plastic separation, different methods are being developed using an electrostatic separation principle [17]. Today, recycling equipment is commercially available that accurately detects more than 20 kinds of plastics found in durable goods, identifies various additives that may be present, and separates end-of-life electronic plastics into single "pure" streams [18]. Furthermore, technology is in use that enables plastics recyclers to separate plastics with FRs from other types of plastics. The recovery options for plastics are listed below.

- Mechanical Recycling: Reprocessing scrap plastics by mechanical means into plastic recyclates.
- Chemical Recycling: For chemical recycling of plastics several processes have been developed. Depolymerization and conversion process [19], coke oven process [20], reducing agent for Fe_2O_3 in blast furnaces [21].
- Thermal Recovery: Incineration for energy recovery, plastic materials can be incinerated and produce energy in the form of heat. Plastics have a high heat value and serve as a valuable fuel supplement as a feedstock. [22].

An important element of WEEE is cathode-ray tubes (CRTs). CRTs consist of two major parts. One is the set of glass components (funnel glass, panel glass, solder glass, and neck) and the other is the non-glass components (plastics, steel, copper, electron gun, and phosphor coating). CRT glass consists of SiO_2, Na_2O, CaO, other components for coloring, oxidizing, and protection from X-rays (K_2O, MgO, ZnO, BaO, PbO). Because CRTs contain lead, proper handling is essential to avoid contamination of air, soil, and groundwater. There are technologies currently available for CRT recycling, like Glass to Glass and Glass to Lead recycling.

Another important part of the shredded e-waste is PCB scrap. Coating materials on boards may include gold, silver, tin, nickel, etc. These materials are eventually removed through a sequential separation process designed to separate each individual metal component. The toxic sludge must be further separated to remove liquid from nontoxic solids. Obviously, much chemical processing must take place that is relatively costly. PCB designers can minimize or eliminate these expensive end-of-life costs through proper selection of materials, processes, and components. There is no refinery to recycle the boards in Turkey. Some people are trying to recover gold from PCB wastes via *ad hoc* “backyard” businesses, but such a practice is unhealthy and very dangerous. Most of the shredded PCBs are sent to refineries in other EU countries. Currently, the PCB waste that is being recycled is the portion that has an inherent value because of its precious metal content. Of course, this somewhat narrow view limits recovery to only metal content via smelting. With growing pressure to recycle more end-of-life circuit boards, there is a clear need to develop and implement recycling methodologies that enable more of the materials to be recovered.

CONCLUSION

Electronic waste recycling in Turkey has a relatively short history, so that there is not yet a broad and well-established infrastructure in place to accomplish product recovery and processing. Factors that affect the recycling infrastructure are the amount and composition of the waste stream, the recycling technologies available, government regulations, and the economics of end-of-life products. Among those factors, recycling technologies appear to be the most critical factor. Electronic products are an integration of numerous modern technologies and are composed of many different materials and components. This means that to recycle WEEE effectively, many technologies should be involved. Like any other growing industry, it will take time to put the entire WEEE recovery and recycling infrastructure in place.

If Turkish government synchronizes their regulations with the EU directives, manufacturers will be fully responsible for the recovery and recycling of the WEEE. This will provide the stimulation to drive them to organize for most efficient EOL product treatment. This will also lead them to better design electrical and electronic equipment for easy recovery, remanufacturing, and reuse of the products and their components. These design improvements will improve recycling and reuse rates dramatically.

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