Selected Problems of Processing and Risks Connected with Recycling of Waste Electric and Electronic Equipment

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Abstract

In the recent years significantly increased interest in the recovery of non-ferrous metal from waste of electrical and electronic equipment (WEEE) has been observed. This waste is classified as hazardous waste because it contains both toxic metals such as lead or mercury and organic components such as polychlorinated biphenyls. For these reasons disposing of this waste is understandable. In Poland many companies have been founded that are involved in recycling of WEEE waste. Typically, companies operating in this sector are one of the Small and Medium Enterprises (SMEs). The overriding objective of the SME sector recycling is to increase the degree of exploitation of metallic waste in an economically justifiable way. This paper focuses on some of the above-mentioned issues of technological and qualitative assessment of risks associated with recycling of metal, in principle copper, from WEEE. There are several examples given of the risks faced by domestic companies in the SME recycling WEEE sector.

Keywords: processing of waste of electric and electronic equipment, risk of small and medium-sized enterprises, non-ferrous metal recycling

Introduction

In today's world economic development of many countries is determined among others by their access to raw materials, ability to obtain their new deposits or by having access to technologies of raw material recycling from wastes.

Unfortunately, the economies of EU, constantly cope with increasing deficit of raw materials, including those metallic ones, which makes it necessary to implement certain measures in order to ensure continuity of their supply. Therefore, the overarching goal of UE has been to develop a unified raw materials policy, especially in the area of non-energy minerals, which would enable it to become independent from monopolistic suppliers (like Russia or China). For those reasons, special attention has been paid to the recycling of nonferrous metals and their alloys in the EU countries, which should reduce the deficit of those non-energy minerals. Recycling can also positively affect environmental protection. For example, in order to obtain 1 Mg of copper from commonly used sulphide ores of copper, approximately 62 Mg of fine-grained, environmentally burdensome wastes are generated as well as 3 Mg of cinder and 900 kg of Sulphur dioxide (which is used for production of Sulphur acid). Unfortunately, the emission of this gas (approx. 2 kg) is inevitable.

By replacing the Sulphur ores with secondary raw materials (for example copper-bearing scrap metal) the above mentioned inconveniences are completely removed and in addition to that the energy-intensiveness of the process is reduced (from 140GJ/Mg for the Sulphur ores process, to even 5GJ/Mg for the high-test copper scrap metals (98% Cu)). Therefore 38% of copper produced in the EU comes from the secondary raw materials while in the US, at least 45–50% of copper is produced in this way [1]. Similar trends are being observed for the remaining non-ferrous metals (e.g. aluminum). Such trends especially apply to the critical raw materials that are not available in quantities that would limit the risk of continuity of their supply to the EU market. Report on critical mineral raw materials mentions 20 raw materials [2], among them platinum metals, Rare Earth metals, Chromium, Cobalt, etc.

In the recent years in Poland many companies have been founded that are involved in recycling of waste electric and electronic equipment (WEEE). Typically, companies operating in this sector are one of the Small and Medium Enterprises (SMEs). The overarching objective of the SME sector recycling is to increase the degree of exploitation of metallic waste in an economically justifiable way while maintaining the BAT (Best Available Techniques).

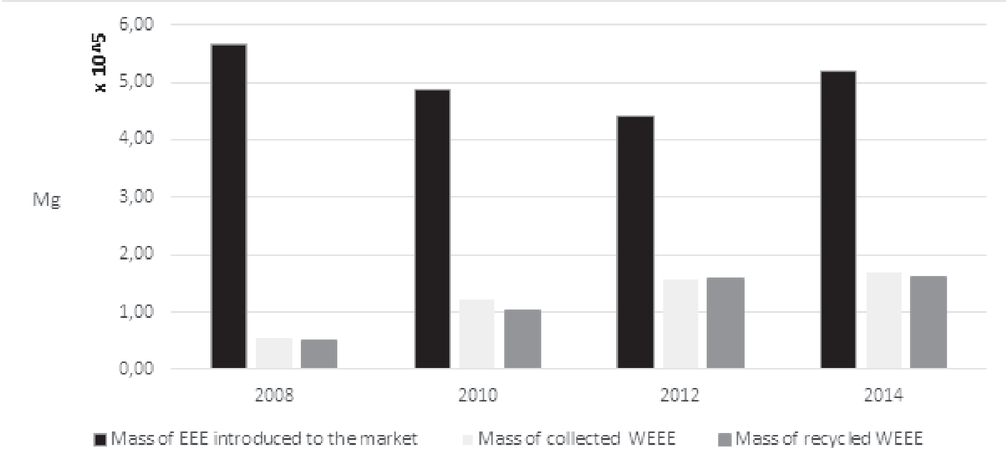

Chart 1. The mass of introduced, collected and processed electrical and electronic equipment waste in years 2008-2014 [source: own research, based on (3)]

Wykres 1. Bilans odpadów elektrycznych i elektronicznych (WEEE) dla lat 200-2014 (badania własne, w oparciu o [3]

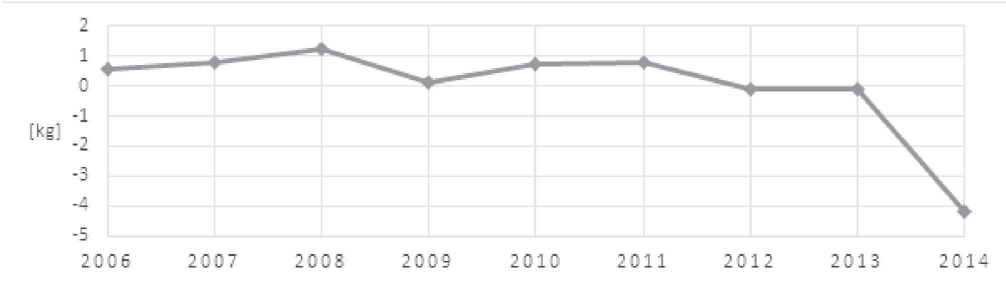

Chart 2. Increase of WEEE mass per capita in Poland since 2006 [source: own research, based on "Raport o funkcjonowaniu systemu gospodarki WEEE" by GIOŚ 2015]

Wykres 2. Wzrost ilości WEEE w przeliczeniu na mieszkańca w Polsce [źródło: badania własne, "Raport o funkcjonowaniu systemu gospodarki WEEE" GIOŚ 2015]

The following criteria influence the technological usability of wastes:

- Technological – connected with chemical and mineral composition
- Techno-economical – which comprise of the estimates of secondary raw materials resources, technical feasibility of supplies and delivery terms and technical feasibility of using those secondary materials in the recycling and processing of metals.

By looking only at the above mentioned criteria it can be stated that the SMEs operating in recycling industry are facing various operational risks: common economic risks as well as specific risks that are linked to various phases of gathering and processing of WEEE.

This paper focuses on some of the above mentioned technological aspects and on the qualitative assessment of risk associated with metal recycling and specifically – obtaining Copper from WEEE.

Selected Aspects of WEEE Processing

In the recent 20 years in the EU countries the importance of recovery of non-ferrous metal from waste of electrical and electronic equipment (WEEE) has increased significantly.

This waste is typically classified as hazardous waste because it contains in addition to nonferrous metals such as Cu,Sn, Ni, etc or precious metals (Au, Ag, Pt), toxic metals such as lead or mercury and organic components such as polybrominated biphenyls – PBB, polybrominated diphenyl ethers – PBDE or polychlorinated biphenyls – PCB.

Creation and storage of this type of waste can be avoided by increasing the degree of WEEE utilization. Chart 1 shows the mass balance of Electric and Electronic Equipment introduced onto the market, WEEE collected and recycled.

Presented data for 2008 through 2014 shows that although the mass of EEE introduced to the market has slightly decreased (most likely due to the minia-

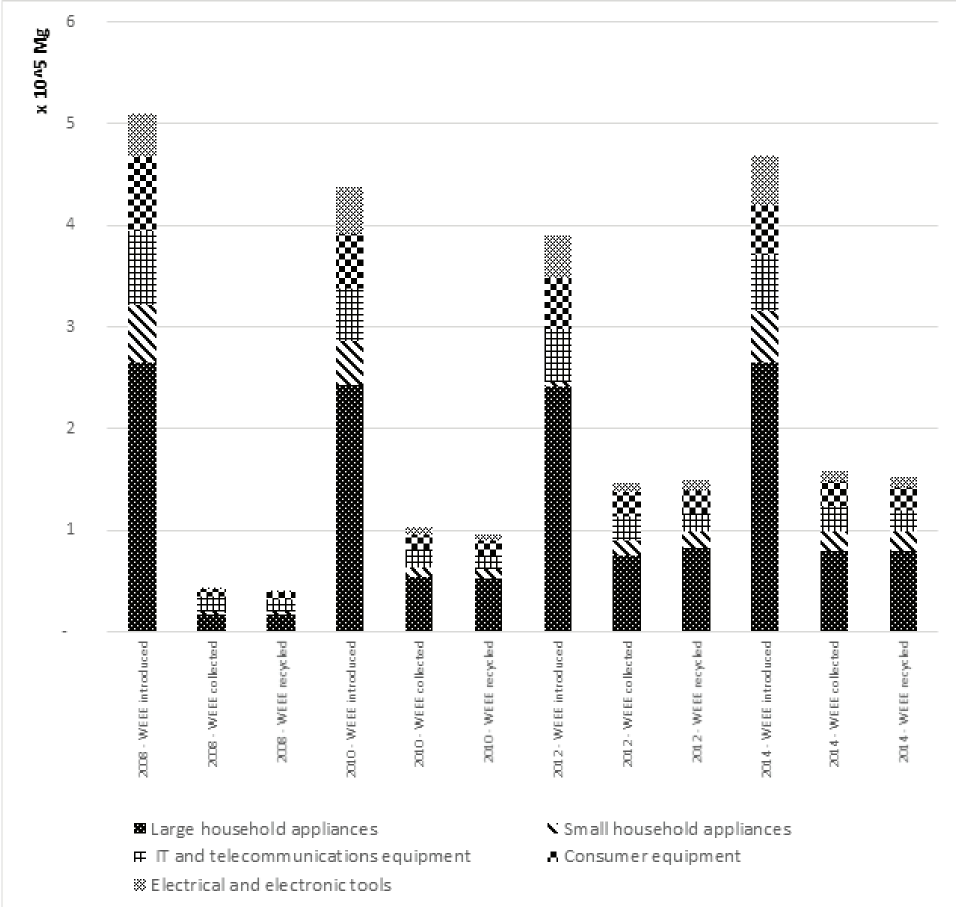

Fig. 3. The mass of WEEE recovered, recycled and reused for various waste types [source: (5)]

Rys. 3. Wielkośc odzysku, recyklingu I ponownego wykorzystania WEEE dla różnych tyów odpadów [źródło: (5)]

turization of devices, to some extent also due to the economic downturn of 2008), the mass of WEEE that has been collected and processed has increased.

Chart 2 shows the increase of mass of WEEE per capita in Poland in the years 2006–2014.

In 2006 there was only 0.13kg of WEEE per capita. The data shows an increasing trend until 2012 (4.34 kg per capita). After 2012 there has been a slightly decrease of WEEE per capita. It complies with the European Community directive 2002/96/EC of 27 January 2003 on waste electrical and electronic equipment (WEEE).

This Directive was calling for all the EU countries to reach by end of 2015 the level of 4 kg WEEE per capita. According to EU forecasts, the average index in 2020 will reach 11 kg per UE member country citizen.

Chart 3 shows data for 2008-2014 with detailed breakdown by the type of WEEE.

For example, in the period discussed, a decrease in some types of WEEE can be observed – eg. IT and telecommunications equipment as opposed to lighting equipment and electrical and electronic tools.

It is worth mentioning that in the recent years the lifecycle of EEE has shortened significantly, which may be a result of increasing customer expectations regarding better performance and lower energy consumption of modern appliances. WEEE from IT and telecommunications equipment is an important source of alloy metals as well as precious metals.

Chart 4 presents schematic diagram of WEEE processing and the lifecycle of EEE.

In each of the SMEs diverse technological lines can be found that apply different solutions, adjusted to the type of WEEE being processed. The process is aimed at maximizing the metals reclamation, while minimizing the production cost and reducing the negative environmental impact of the reclamation process (especially reclamation of copper and precious metals).

Technological recycling process consists of phases such as: disassembly, shredding and separation, reclamation of metals with pyro metallurgical and hydrometallurgical methods.

The aim of disassembly is to remove toxic elements from WEEE (e.g. mercury, cadmium, chro-

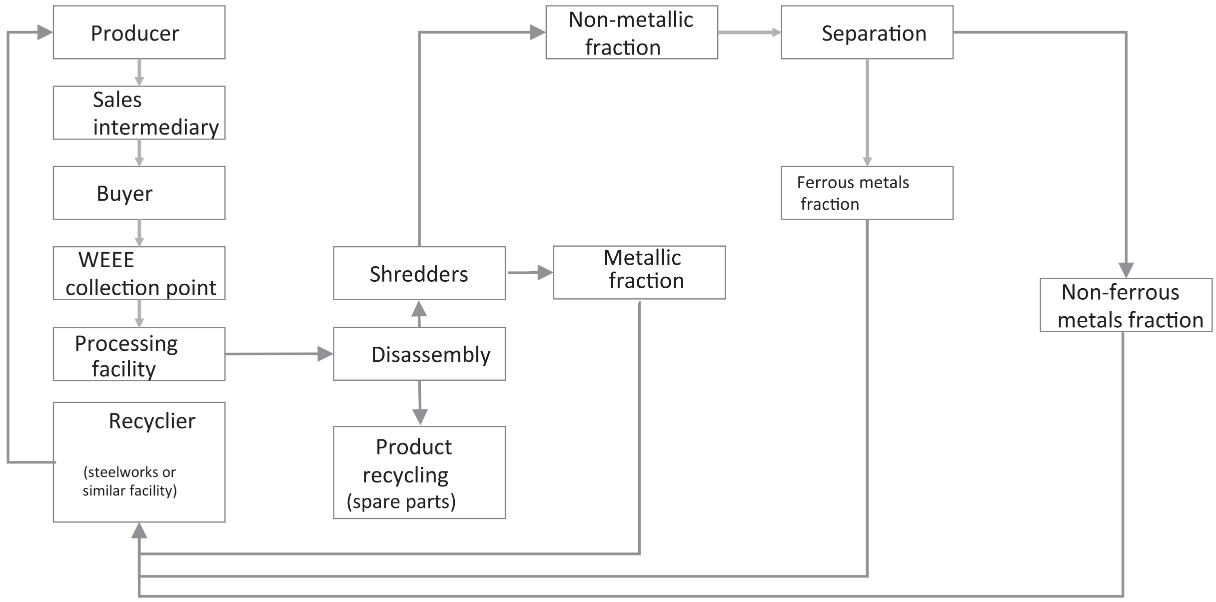

Chart 4. General block diagram of WEEE processing and cycle of life [source: own research]
Wykres 4. Schemat przeróbki WEEE I cykl życia

Tab. 1. EU regulation and Polish law in the field of WEEE [source: own research, based on (20)]
Tab. 1. Regulacje prawne w Polsce i EU w zakresie WEEE [20]

UE Legislation	Polish legislation
• Overarching legal act of UE concerning the WEEE reclamation framework - directive 2002/96/EC of the European Parliament and of the Council of 27 January 2003 on waste electrical and electronic equipment (WEEE) • Directive 2006/12/EC of the European Parliament and of the Council of 5 April 2006 on waste • Directive 2003/108/EC of the European Parliament and of the Council of 8 December 2003 amending Directive 2002/96/EC on waste electrical and electronic equipment (WEEE) • Council Directive 91/689/EEC of 12 December 1991 on hazardous waste • Directive 2002/95/EC of the European Parliament and of the Council of 27 January 2003 on the restriction of the use of certain hazardous substances in electrical and electronic equipment	• Environmental Protection Act, 27 April 2001 • Act of 27 April 2001 on Waste • Act of 11 May 2001 on Packaging and Packaging Waste • Act of 11 May 2001 on Duties of Business Operators with respect to Managing • Certain Types of Waste, Product Fee, and Deposit Fee • Act on Maintaining Cleanliness and Order in Communes of 13 September 1996 • Act on Road Transport of Hazardous Goods of 28 October 2002 • Act on Railway Transport of Hazardous Goods of 31 March 2004 • Act on International Shipments of Waste of 29 June 2007 • And additional 18 Regulations of the Minister of the Environment

mium) as well as removal of large elements (e.g. components) which could negatively affect the subsequent phases of the recycling or lower the effectiveness of the reclamation process.

Domestic SMEs in the WEEE recycling industry typically apply manual disassembly, however, in the modern installations, this phase has been automated.

The processes and individual activities in the modern installations ensure high purity of the raw materials reclaimed from WEEE while minimizing the energy expenditure and improving the impact on the personnel safety and environmental protection. For example, cables extracted at the disassembly phase are routed to installations specialized in processing this type of WEEE.

The next phase – shredding and separation – is conducted with use of shredders or hammer mills. Granulation of waste material from printed circuits that contain copper is recommended to be below 2 mm – because it translates to higher efficiency of the reclamation process.

Next phase of the reclamation process is the separation of the WEEE into the following fractions: non-metallic, containing steel and containing non-ferrous metals. In order to separate metals from non-metals air separators are used which guarantee high efficiency of the separation process. The choice of separators is strictly connected with the composition of the WEEE. In case of separating aluminum from copper, electrodynamic separators or separation with heavy liquids are the preferred methods [4]. In addition to those methods, in some countries electrostatic methods [5–7] or eddy current separators [3,8] are used.

Typically dry separators are used because they do not generate wastewater, as opposed to separators using liquids.

The fractions containing non-ferrous metals are further processed with pyro metallurgical and hydrometallurgical methods. Reclamation of copper is conducted with anode furnaces or converters. During the melting of copper the precious metals (Ag, Au, Pt, etc) transfer completely to copper, from where they can be reclaimed through electro-refining of copper as anode sludge.

Hydrometallurgical methods allow for reclamation of copper and other metals. There are many technological concepts of transferring copper to solution which can be differentiated by the type of leaching agent [9-12]. Electrolytic copper or copper powder obtained by precipitation under pressure with hydrogen are the final product of hydrometallurgical process.

Degree of reclamation of copper for both the hydrometallurgical and pyro metallurgical methods reaches even 98%. Precious metals, however, can be reclaimed only through the hydrometallurgical method.

The hydrometallurgical methods are typically preferred over pyro metallurgical ones for smaller production size. Main reasons in favor of those methods are: lower sensitivity to the variations in composition of the input, simpler separation of other metals and lower environmental impact. Sample mass balances have been presented in [13, 14].

Selected Risks Connected to Processing of WEEE

It seems that the topic of operational risks of domestic companies involved in recycling of WEEE is not fully exploited in the specialist literature. Some information on those risks can be found in paper [15] where the author has analyzed both external and internal risk factors resulting from the specific operating conditions of SMEs and has also described impact of economic and legislative changes as well as implementation of new innovative technologies.

Already at the time of setting the strategy for a company dealing with processing of WEEE it would be beneficial to decide on the types of WEEE that will be processed and the equipment that will be required. This will allow to choose the production line that will ensure high effectiveness of the recycling process, at the same time minimize the operational risk. For example, the chemical composition of the input WEEE significantly impacts the effectiveness of particular recycling processes but also the production and environmental risk.

Another type of risk that may be relevant for such companies is the risk associated with the procurement of machinery and equipment that is necessary to install certain technological lines. Companies within the SME sector typically do not have required capital at their disposal and therefore need to reach out to external financing resources like bank loans – including foreign currency loans. The fluctuations of the exchange rate can pose a significant financial risk to the SME. Whenever a modification or complete change of the production line is required, there might be certain difficulties to obtain additional loan due to the risk-diversification approach of the lender bank. SMEs can also apply for EU structural funds but the application process might be very time con-

Tab. 2. Group and examples of risks for small and medium enterprises (SMEs) connected with the recycling of WEEE [source: own research, based on [(14, 16–19)]

Tab. 2. Grupy ryzyka oraz przykłady dla MŚP w zakresie WEEE [14, 16–19]

Group of risks	Sample risks for SMEs in the WEEE processing industry
Technological	1. Chemical composition of WEEE differs significantly for the products being currently on the market. 2. Changing composition of the new generation products 3. Delays in supply and variable quality of supplied input waste (including prior disassembly of valuable parts (containing Ag, Au, etc). 4. Introduction of new, innovative technologies 5. Interruption in the supply of utilities
Economic	1. Investment required to pursue research of innovative and more effective technologies of processing WEEE. 2. Monopolistic/monopsonic behaviors of the processing plants (imposing commercial conditions due to their large processing capacities). 3. The possibility of changes in production costs 4. Risk of currency fluctuations 5. Risk of fluctuations in raw material prices 6. Increasing competition in the market of recycling of WEEE 7. Fluctuations in supply and demand and consequently in prices on domestic and international markets. 8. Dependency of the raw material prices on the international commodity and energy stock exchanges. 9. Financing costs (including loans) of activities of companies from the recycling of WEEE industry 10. Changes in the taxation of business activity 11. Fake waste commercial transactions, „grey market", inadequate transactions pricing, insufficient supervision over the non-ferrous metals market. 12. Loss of key suppliers and key customers of companies processing WEEE. 13. Organizational structure and lack or insufficient attention paid to professional risk management. 14. External sources of financing. 15. Organizational issues – lack of people and resources required to complete investment. 16. Insufficient processing capacity and dependency from other EU and non-EU countries.
Environmental	1. Risk caused by recovery and storage of hazardous materials before handing over to specialized processing 2. Higher reclamation rate with automated disassembly (lower risk of .contact with hazardous materials). 3. Risk caused by local development plan. 4. Lack of global management system which supports recycled products
Legal and political	1. Multitude of legal acts (both EU and local), interpretation issues.

suming and requires a lot of administrative work, which SMEs do not have resources for.

It needs to be pointed out that SMEs dealing with processing of WEEE do not have a complex organizational structure which results in no dedicated function (or person) taking care of risk management. Very often such a role is played by the company owner, for whom this is one of many tasks that they can't fully commit to and focus on. It is even more important as there are relatively many SMEs in this industry in Poland and instead of specializing in recycling of selected types of WEEE, the SMEs compete against each other. Furthermore, lack of cooperation between companies may result in the change of chemical composition of intermediate products which may further impact the recycling processes and the environment.

Research and development of new technologies is connected with project-type risks, for example – there are not always processing methods available and the research of new methods is associated with cost that may not always be recoverable.

One of the significant problems of the WEEE processing industry is the imperfect supervision of the regulated market of non-ferrous metals which creates opportunities for grey market to exist. Companies following strictly all the regulations may be struggling to survive as they are pushed out of the market by companies that are for example using fake trade documentation [16].

Another aspect of risk that is worth mentioning is the legal risk – due to the number of legal acts governing transportation, collection and recycling of WEEE as well as their frequent changes [17, 18]. Those legal acts can be divided into those coming from the EU and from the local legislation. Table 1 presents sample legal acts governing the WEEE processing activities that the SMEs are subject to.

The risks described above can be grouped into: resulting from the chosen recycling technology, resulting from the company's activity on the market (economic risks), generating interactions with the environment, resulting from the legislation and social risks. This risk classification along with sample risks has been presented in Table 2.

It needs to be kept in mind that these are only sample risks and in practice the SMEs might face completely different risks or current risks that were modified due to the impact of new production or processing technologies or globalization. In order to conduct appropriate risk assessment, each company needs to build its own risk matrix – by building it from the beginning or by adapting the risk matrices available in the literature [for example 16] and then assess the risks in both qualitative and quantitative aspects.

Recapitulation

Presented data shows that there are many methods and concepts of reclaiming non-ferrous metals, including copper, from WEEE. Each of them is associated with different level of risk.

The aspiration of regulators in particular the EU to create a raw material economy based on knowledge, competitiveness, innovation and that is environmentally friendly creates for companies involved in the recycling of WEEE many challenges. It is expected that they will be able to effectively model their technology processes showing high recovery of non-ferrous metals, and also will be able to properly identify and manage risks by keeping them at an acceptable level.

In this article sample risks were identified and grouped which allows for creating a basic risks matrix for an enterprise in the recycling industry. Such risk matrix enables those enterprises to effectively manage risks in a complex and competitive industry of processing raw materials, non-ferrous metals and waste, as well as to pay attention to an important aspect of protecting the environment.

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Wybrane problemy i ryzyka związane z recyklingiem odpadów elektrycznych i elektronicznych

W ostatnich latach obserwuje się znaczny wzrost zainteresowania odzyskiem metali nieżelaznych z odpadów elektrycznych i elektronicznych (WEEE). Odpady te są kwalifikowane jako odpady niebezieczne z uwagi na zawartość składników toksycznych takich jak ołów lub rtęć I składników organicznych tkich jak polichlorowane bifenyle. Z tego powodu składowanie odpadów WEEE jest niedopuszczalne. Z regóły firmy zajmujące się WEEE są fimami sektora MŚP (małe i średnie przedsiębiorstwa). Zasadą działania firm sektora MŚP jest recykling prowadzony z uzasadnionym ekonomicznie zyskiem. W artykule przedstawiono kilka aspektów technologicznych oraz ryzyka związane z odzykiem metali (głównie miedzi) z odpadów elektrycznych i elektronicznych.

Słowa kluczowe: Przetwarzanie zużytego sprzętu elektrycznego i elektronicznego, ryzyko małych i średnich przedsiębiorstw, recykling metali nieżelaznych