Critical, Strategic and Deficit Raw Materials in the Waste of Electrical and Electronic Equipment and in Batteries and Accumulators

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Abstract

This article presents the waste electrical and electronic equipment and batteries and accumulators as a potential source of critical, strategic and deficit raw materials.

The dominant types of waste obtained after the disassembly of used electrical and electronic equipment are plastics: polypropylene (PP), acrylonitrile-butadiene-styrene (ABS), polystyrene (PS) and teflon and metals. These metals include: magnesium, cobalt, antimony and tantalum (critical raw materials), aluminum, nickel, iron and zinc (strategic raw materials) as well as copper and silver (deficit resources), as well as lead, tin, gold and cadmium. Batteries and accumulators are a source, among others metals such as: nickel and zinc (strategic raw materials), manganese and lithium (deficit resources), aluminum (strategic raw material), and cadmium, lead.

The article presents the results of analysis of the material composition of the waste electrical and electronic equipment conducted at the Institute of Mechanised Construction and Rock Mining. It also presents the level of imports and exports of waste and scrap-metal that are the subject of this article. In addition, the article presents a source of information about waste and recycled materials.

Keywords: waste electrical and electronic equipment, batteries and accumulators, recyclable materials, critical raw materials, strategic raw materials, deficit raw materials

Introduction

The concept of "critical raw materials" was created in the document entitled: „Critical raw materials for the EU – Report of the Ad-hoc Working Group on defining critical raw materials. EU Commission Enterprise and Industry", published in 2010. On 26 May 2014, a Communication from the European Commission to the European Parliament on the review of the list of critical raw materials for the EU was published. The Communication includes an updated list of critical raw materials for the European Union. A total of 54 raw materials were analysed. The following raw materials were listed as critical: beryllium, cobalt, tungsten, magnesium, antimony, germanium, gal, indium, niobium, chromium, metallic silicon, platinum, rare earth elements as well as fluorite, graphite, magnesite, borates, phosphate rock and coking coal. On the other hand, the following raw materials were listed as strategic: rhenium, tellurium, iron, aluminium, molybdenum, manganese, vanadium, zinc, nickel and bauxite, while the composition of the group of scarce raw materials has not changed and includes: barite, diatomite, perlite, talc, silver, copper, quartz sands, lithium, titanium and limestones. The following raw materials were listed as scarce: barite, diatomite, perlite, talc, ceramic clays (including kaolin), feldspar raw materials, boron raw materials, bentonite, silver, copper, quartz sands, lithium, titanium and limestones.

The list of raw materials critical for the EU is regularly updated at least every three years to take into account changes in production, market development and technology. On 13 September 2017, another Communication on the list of raw materials critical for the EU was published based on the previously conducted criticality assessment for 78 raw materials. This communication presents an updated list of 27 critical raw materials. Compared to the 2014 rating, the extended scope includes nine new raw materials: barite, bismuth, hafnium, helium, natural rubber, phosphorus, scandium, tantalum and vanadium. Two raw materials (chromium and magnesite) were not considered critical on the basis of the 2017 assessment.

The Branch Office of the Institute of Mechanized Construction and Rock Mining in Katowice conducted analyses regarding the problems of critical, strategic and scarce mineral resources, as shown in: (Baic et al., 2016; Biel et al., 2013, 2014a, 2014b, 2015; Blaschke et al., 2015a, 2015b, 2015c, 2016; Witkowska-Kita et al., 2016, 2014, 2015a, 2015b, 2016). Such studies were also carried out at the PAS Institute for Mineral Resources and Energy, which was presented, among others, in: (Blaschke, Ozga-Blaschke 2015, 2016; Galos 2011a, 2011b) and at the National Geological Institute, which was presented, among others in: (Radwanek-Bąk 2011; Smakowski 2011).

The subject of this article will be waste electrical and electronic equipment as a potential source of critical, strategic and scarce raw materials, i.e.: magnesium, cobalt and antimony (critical raw materials), aluminium, nickel, iron and zinc (strategic raw materials) as well as copper and silver (scarce raw materials), as well as lead, tin, gold, cadmium and tantalum. Batteries and accumulators are a source, among others, of metals such as: nickel, zinc and aluminium (strategic raw materials), manganese and lithium (scarce raw materials) and cadmium, lead, mercury.

The natural consequence of the constantly advancing technological development in the field of electrical and electronic equipment and the desire to have the new generation equipment is the increase in the amount of waste electrical and electronic equipment. An important element of waste prevention in the case of waste electrical and electronic equipment is extended producer responsibility for the electrical and electronic equipment placed on the market, because the entrepreneur is required to obtain an appropriate level of separate collection of waste electrical and electronic equipment from households with respect to the weight of the introduced equipment and levels of recovery and recycling for individual groups of electrical and electronic equipment. In accordance with the provisions of the Act of 11 September 2015 on waste electrical and electronic equipment, the management system of waste electrical and electronic equipment should ultimately include all users of this type of products, i.e. those introducing the equipment (i.e. producers and importers), as well as those collecting it, operators of processing plants, operators of installations for recycling and non-recycling recovery processes and finally end users. Waste electrical and electronic equipment from households should be collected by trade units on an exchange basis when the new equipment is bought (including wholesale and retailers), while municipalities should indicate places where residents can transfer this type of waste. In Poland there is a system of selective collection of waste electrical and electronic equipment based on a point located in each municipality. Unfortunately, not all such waste goes to these points - some of them are sent to scrap yards or to a stream of mixed municipal waste. In the case of used equipment from other sources than households, the equipment is picked up by specialized companies with appropriate permits, as shown in: (2016 Plan).

The amount of used electrical and electronic equipment put on the market was over 500,000. Mg/year. Whereas the mass of collected equipment amounted to over 170,000. Mg/year, of which almost 90% is equipment from households. The mass of selectively collected used equipment is gradually increasing and amounts to approx. 4 kg/inhabitant/year, as described in: (Krajowy 2014).

Batteries and accumulators, which supply small electrical and electronic equipment, should also be mentioned here (Krajowy 2014). Batteries and accumulators are also covered by the separate collection system. They come from both the municipal and the economic sector. Batteries and accumulators are a source, among others, of metals such as cadmium, lead, mercury, nickel, zinc, manganese and lithium. Aluminium can be recovered from used batteries and accumulators used to supply computers and mobile phones. The market for the production of lithium and lithium-ion batteries and accumulators (increases by 12–15%/year). In Poland, only approx. 4,000 Mg/year of used portable batteries and accumulators is collected. The level of collection of these wastes is systematically growing and reaches the level of approx. 40%. Every year, approx. 500 million pieces of batteries and accumulators are supplied to the market.

Metallic mineral raw materials are also necessary for the functioning and development of, among others automotive industry, metallurgy, as well as the computer industry, mobile telephony, electronics and electrical engineering, as well as the armaments industry or medical diagnostics.

Therefore, it is extremely important to ensure the security of raw materials supply and their effective management, which should lead to the creation of the "circular economy" system. This is particularly important if the country has limited own resources. Currently, in the European Union countries, including Poland, there are problems with ensuring a sufficient raw material base, mainly concerning metallic raw materials.

The possibilities of obtaining mineral resources in Poland are small, among others due to: lack of economic resources (e.g.: beryllium, magnesium, niobium, cobalt and antimony, tungsten and bauxite), lack of prospects for the discovery of new deposits, e.g. niobium ore, tellurium and fluorite, co-existence of raw materials with other metals (e.g. gallium, indium, germanium, manganese, molybdenum and nickel), depletion of mineral deposits or their low availability, and the mineralogical meaning of some deposits (e.g. rare earth elements).

In the last period of time, the importance of raw materials obtained from secondary and waste sources has increased. This is due to environmental, economic and technological reasons. Raw materials from these sources should be characterized by parameters similar to raw materials obtained from primary sources, being their full substitutes. Potential sources of obtaining raw materials are: mineral waste substances produced in industry, mineral secondary raw materials classified as waste, anthropogenic deposits, as discussed in: (Ney 2009).

Mineral secondary raw materials classified as waste are raw materials that can be used economically due to technological and economic reasons. Thus, despite their classification as waste, it should be treated as mineral waste raw materials, meaning mineral raw materials obtained from waste, i.e.: metal packaging, glass packaging, waste of electrical and electronic equipment, batteries and accumulators, spent catalysts, lining and refractory materials, waste of building materials, waste and scrap metal, as discussed in: (Ney 2009).

Strategic, critical and deficient raw materials in waste electrical and electronic equipment as well as in waste batteries and accumulators

The electrical and electronic equipment is mainly made of plastics (often with the content of flame retardants) and metals, and in a smaller amount of glass and paper. The percentage shares of particular types of materials obtained as a result of disassembly of waste electrical and electronic equipment are as follows:

- in the group of small household appliances, the basic material group consists of: metals (53.4%), plastics (24.7%) and combined materials (plastic + metal - 11.6%),
- in the group of electronic equipment, the prevailing types of materials are: metals (38.1%), plastics (29.5%), glass (12.4%), electronic components (12.5%) and combined materials, i.e. plastics + metals (6.9%).
- in the group of radio and TV equipment, the basic groups of materials are: glass (26.3%), metals (22.5%), plastics (20.2%), wood (11.8%), electronic components (7.6%), plastics + metals (6.6%) and other materials (5.1%),

Tab. 1. The turnover of waste and scrap-metals that can be recycled in the industry in 2010–2014 (wg: Bilans 2013, Bilans 2014, Bilans 2011, Rocznik 2014, Rocznik 2015)

Characteristic	Waste management and metal scrap in Poland in 2010-2014 [tys. Mg]									
	2010*	2011*	2012*	2013*	2014**	201 0*	2011*	2012*	2013*	2014**
	import					export				
Magnesium waste and srap	0	0	0	0	no data available	0.88 9	0.961	1.044	0.98	no data available
Cobalt waste and srap	-	-	-	0	no data available	0,00 1	-	0	0.008	no data available
Aluminium waste and srap	84.9	106.4	111.8	176.5	130.2	124	150.6	156.1	154.8	8.4
Nickel waste and scrap and its alloys	0.9	0.6	0.3	0.4	no data available	1.2	0.7	0.7	0.3	no data available
Steel and iron scrap	382.3	408.8	383.4	509.4	0.8	139 6.6	1889. 3	1989.2	1972.4	92.6
Iron-bearing wastes	1.7	26.7	20.4	15.5	no data available	29.9	20.7	2.6	0.2	no data available
Copper waste and scrap	24.1	26.9	53.6	49.7	4.3	71.2	59.5	49.2	58.9	2.3

*wg Bilans gospodarki surowcami mineralnymi Polski i Swiata 2013, IGSMiE PAN, PIG PIB, Kraków-Warszawa 2015
** wg Rocznik Statystyczny Przemysłu, GUS Warszawa, 2015
Explanations:
– the phenomenon does not occur
0 – value less than 0.5 in the unit of measurement used

- in the group of power tools, the prevailing materials are: metals (73%), plastics (18.8%), plastics + metals (7.8%), and the remaining materials constitute 0.4%, according to: (Projekt 2013).

The dominant types of waste, according to (Projekt 2013, Witkowska-Kita et al. 2014, Witkowska-Kita 2015), obtained after the process of dismantling used electrical and electronic equipment are therefore plastics: polypropylene (PP), acrylonitrile-butadiene-styrene (ABS), polystyrene (PS) and teflon, as well as metals (mainly aluminium, copper, iron, cadmium and metal alloys, e.g. brass).

In (Projekt 2013, Stankiewicz et al. 2010), it was stated, among others, that:

- we can recover from a used computer set (computer + monitor) weighing 27 kg: 6.8 kg of glass, 6.2 kg of plastic, 5.6 kg of steel and metals in quantities: 3.8 kg of aluminium, 1.9 kg of copper and 1.7 kg of lead,
- we can recover from a used fridge weighing 51.3 kg, the following raw materials: iron scrap (23.7 kg), aluminium (approx.1 kg), copper (0.2 kg), glass (1 kg), polystyrene (26.8 kg), PUR foam (3.5 kg) and an aggregate weighing 0.9 kg, the rest being: pipes, gas and cotton wool,
- we can recover from the used kitchen stove primarily iron scrap, which accounts for as much as 92.2% of the stove's weigh. Other metals and alloys that can be recovered are: aluminium (1.7%), copper (0.1%) and brass (approx. 0.9%),
- a used washing machine may be the source of: 52.3% of ferrous scrap, 0.8% of aluminium, 0.1% of printed circuit boards. Other raw materials and elements are: concrete (27%), glass (1.1%), polystyrene (1.1%) and capacitors, motors, pumps, wires and rubber,
- the following waste materials can be recovered from a television set: printed circuit boards (8%), ferrous scrap (95%), aluminium (0.4%), kinescopes (35.1%), sodium and lead glass (in total: 28.5%), polystyrene (14.4%) of the device weight. Other raw materials and components are: coils, transformers and wires,
- from one million pieces of mobile phones you can recover the following amounts of metals: 34 kg of gold, 350 kg of silver, 15 kg of platinum and 18.85 Mg of copper,

and in: (Projekt 2013, Stankiewicz et al. 2010), it was found that: the share of gold-plated and silver-plated elements (based on copper alloys) in the TV set is around 0.8%, and gold and silver – 3.44 and 0.02 g respectively. Noble metals from electronic systems can be recovered in almost 100%. Printed boards account for almost 9% of the weight of such a set. Iron scrap is up to 32.5% of the used printer's weight, while printed circuit boards are 5.2%, plastics (as ABS) – 45.4%, and the remaining elements are: engine, power supplies and wires.

Whereas in: (Ney 2009) it was stated that the fans are constructed of plastic or aluminium. Silver was used for the production of various types of plugs. Silver has also been used as a component of solder. Some types of typewriters have a metal casing or a metal coating made of nickel, nickel-chromium or copper-nickel-chromium. On the other hand, among the materials used for the construction of computer speakers, the most common is copper in the form of a coil.

In: (Projekt 2013) it was found that printed circuit boards account for approx. 3% of the total mass of generated electronic scrap. Recycling of printed circuit boards involves the removal of metal (mainly copper and gold) and ceramic elements, as well as the separation of parts intended for re-use and toxic materials that need special treatment to reduce the harmful effects on the environment. For example, in the material composition of printed circuit boards (computers, mobile phones, TV sets and RTV equipment) the following metals can be distinguished: copper, iron, aluminium and beryllium, chrome, tin, zinc, gal, cadmium, nickel, lead, palladium, rhodium, mercury, tantalum, silver and gold. Copper is one of the basic materials included in printed circuit boards. From one ton of printed circuit boards we can recover up to 200 kg of copper. The standard computer set includes approx. 2 kg of this metal. The electronic sub-assemblies, coils and transformers of TV sets include approx. 400 g of copper (in total). Copper is also the basic material of power cords, plugs (cabling) and batteries. 1 Mg of printed circuit boards can also be source of 0.5–3 kg of silver.

In: (Projekt 2013) it was also found that the difficulty in determining the exact material structure of printed circuit boards is related to their complex construction and diversified material composition (metals, polymers, paper). Currently, there are two technologies for recycling printed circuit boards - thermal and non-thermal. The thermal technology includes pyrolysis, hydrometallurgy and metallurgy. The non-thermal technologies involve disassembly (manual or automatic), grinding, separation and chemical treatment. All elements recovered as a result of non-thermal methods require further transformation.

Available sources of information on the production and use of mineral waste materials

Referring to the fact that the importance of raw materials obtained from secondary and waste sources has recently increased, the available sources of information on the production and use of mineral waste materials can be found below. This knowledge is very dispersed.

Available sources of information include:

- „Bilans gospodarki surowcami mineralnymi Polski i świata” (IGSMiE, PAN, Kraków) (Bilans 2011),
- „Bilans zasobów złóż kopalin w Polsce” (PIG, Warszawa) (Bilans 2013, Bilans 2014),
- „Krajowy program zapobiegania powstawaniu odpadów” (National waste prevention program) (Krajowy 2014),
- Central Waste System maintained by the Ministry of the Environment, merging 16 Provincial Waste Systems,
- "Statistical Yearbook of Industry", publication by the Central Statistical Office (year 2014, year 2015).

In Poland, both imports and exports of waste and scrap of some of the discussed metals are carried out. On the basis of available sources, table 1 gives data on the trading of waste and scrap of some of the discussed metals and recyclable in industry in the sample years 2010–2014.

The export of metal waste and scrap in the sample years 2010–2013 remained at a similar level, while in 2014 the exports of aluminium waste and scrap, copper as well as steel and iron scrap slumped.

Data on exports concerning waste and scrap of other metals are unavailable for 2014.

Imports of magnesium and cobalt waste in the sample years 2010–2014 were not carried out.

The import of waste and scrap of aluminium, copper as well as steel and iron scrap in the analysed years increased, while the import of nickel waste and scrap as well as iron-bearing waste remains at a similar level. However, the level of imports of this waste and scrap can only slightly cover the demand for these metals, of course after the recycling operations. Nevertheless, the use of metal scrap and waste is a very important secondary source of these metals, that can have economic use.

Conclusion

1. The dominant types of waste obtained after the disassembly of used electrical and electronic equipment are plastics: polypropylene (PP), acrylonitrile-butadiene-styrene (ABS), polystyrene (PS), as well as teflon and metals. These metals include: magnesium, cobalt and antimony (critical raw materials), aluminium, nickel, iron and zinc (strategic raw materials), as well as copper, silver (scarce raw materials), lead, tin, gold, cadmium and tantalum.
2. Batteries and accumulators are a source of, among others, metals such as: nickel and zinc (strategic raw materials), manganese and lithium (deficient raw materials) aluminium (strategic raw material), cadmium, lead, mercury.
3. If the country has limited own resources of raw materials, ensuring security of raw materials supply and their effective management should lead to the creation of the "circular economy" system.
4. The export of metal waste and scrap in the sample years 2010-2013 remained at a similar level, while in 2014 the exports of aluminium waste and scrap, copper as well as steel and iron scrap slumped. Data on exports concerning waste and scrap of other metals are unavailable for 2014. Imports of magnesium and cobalt waste in the sample years 2010-2014 were not carried out.

The import of waste and scrap of aluminium, copper as well as steel and iron scrap in the analyzed years increased, while the import of nickel waste and scrap as well as iron-bearing waste remains at a similar level.

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