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# Recovery and treatment of hazardous waste. Modern management of hazardous waste in Poland

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**Abstract.** The organization of comprehensive hazardous waste management makes the number of facilities at which the hazardous waste is treated decrease. The desired result of such measure is the limitation of number of potential sources of environmental contamination and greater economic effects (than in case of individual enterprises). One cannot also omit the fact that the comprehensive hazardous waste management has a positive impact on the choice of optimal technology of disposal of hazardous waste and this in turn is related with enabling the introduction of modern technologies, full application of technological operations, increase in work efficiency, obtaining lower operating costs and ensuring the environment protection at a proper level. In case of waste disposal, residues coming from that process can be utilized economically. Economic and ecological considerations require minimizing the consumption of primary raw materials from nature and use of any waste arising at different stages of cargo turnover and material trading to the border of economic profitability.

In the article legal acts regulating the management of hazardous waste have been analyzed. Methods of recovery and treatment of hazardous waste applied in the Malopolska province have been discussed. Economic and technological criteria for the selection of technology of hazardous waste disposal have been analyzed.

## 1. Introduction

Problems of protection of the environment and raw materials are becoming a challenge all over the world. The rational waste management allows for improvement of the environmental condition as well as increase in resources of raw materials. The depletion of materials and strict requirements of the environment protection must be taken into consideration as decisive factors for decisions taken by manufacturers and consumers of goods. It refers first of all to the management of both industrial and hazardous waste. The least favorable form of waste disposal is the landfilling. It is connected with the necessity of study on the secondary emission of heavy metals present in the waste [1]. Those contaminants are mostly emitted to the atmosphere and pollute water and lands.

The selection of technology of hazardous waste treatment should take place according to the principle of sustainable development. It means that the rational waste management, taking into account both ecological and economic factors, enforces the demand for maximizing the utilization of waste in all possible applications while limiting its negative impact on the environment at the same time [2-4]. While selecting the technology of hazardous waste disposal the major factor cannot be only the economic efficiency, but first of all reducing the pressure on the environment through the use of low- and non-waste technologies, recycling and effective waste treatment [5, 6]. This is why one should be guided by many criteria when choosing the proper technology of hazardous waste treatment. The knowledge of the following is necessary [7,8]:



- sources, conditions and amount of waste generation,
- physical, chemical and biological properties of waste,
- posed eco-toxicological threat and emission of pollutants,
- possibility of transforming waste into a less burdening form,
- environmental and technical conditions of waste landfilling.

## 2. Hazardous waste – Legislation

The primary legal act relating to the waste is the Act on waste (Journal of Laws 2013, item 21) of the 14<sup>th</sup> of December 2012 [9]. It determines principles of proceeding with the waste, in particular rules for preventing waste generation, preparation for its re-use, recycling, as well as recovery and disposal of waste. The amendment of the act was a necessity arising from the adjustment of Polish law to the European Parliament and Council Directive 2008/98/WE [10]. It introduces new definitions and ways of waste classification and solutions facilitating its utilization. In the article 3.1.34.4 the newest definition of hazardous waste has been presented. According to the definition *hazardous waste is the waste which demonstrates at least one of hazardous properties. The properties regulating the waste as hazardous are defined in the appendix 3 of the Act.*

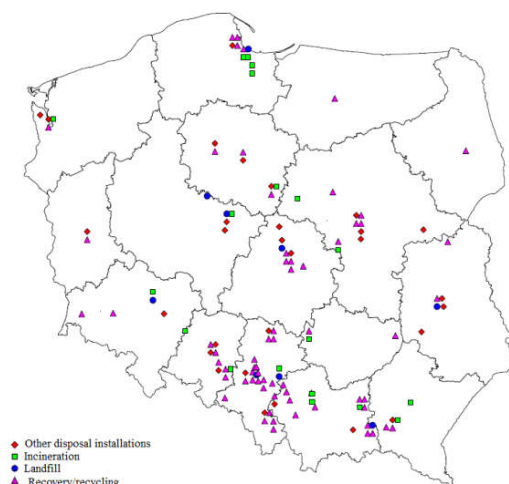
Therefore the basis for classification is the characteristics of waste which cause a hazard to the life, health and environment defined in the appendix 3 with symbols of H1-H15. In the appendix 4 waste components (1 to 50), in case of which exceeding the limits of concentration of hazardous substances may cause that the waste is classified as hazardous, have been described. The classification of waste was listed in the regulation by the Minister of Environment (Journal of Laws 2014, item 1923) [11].

Implementing acts of the law on waste [9] which concern the management of hazardous waste are:

- Regulation of the Minister for the Environment as of the 30<sup>th</sup> of April 2013 (Journal of Laws 2013, item 523) on waste landfills [12].
- Regulation of the Minister of Economic Development of the 21<sup>st</sup> of January 2016 (Journal of Laws 2016, item 108) on requirements concerning the conduct of process of thermal transformation of waste and ways of proceeding with waste resulting from that process [13].
- Regulation of the Minister for the Environment as of the 23<sup>rd</sup> of September 2016 (Journal of Laws 2016, item 1601) on details of conditions for recognizing hazardous waste as the waste other than hazardous [14].
- Regulation of the Minister for the Environment as of the 7<sup>th</sup> of October 2016 (Journal of Laws 2016, item 1742) concerning details of requirements for the transportation of waste [15].

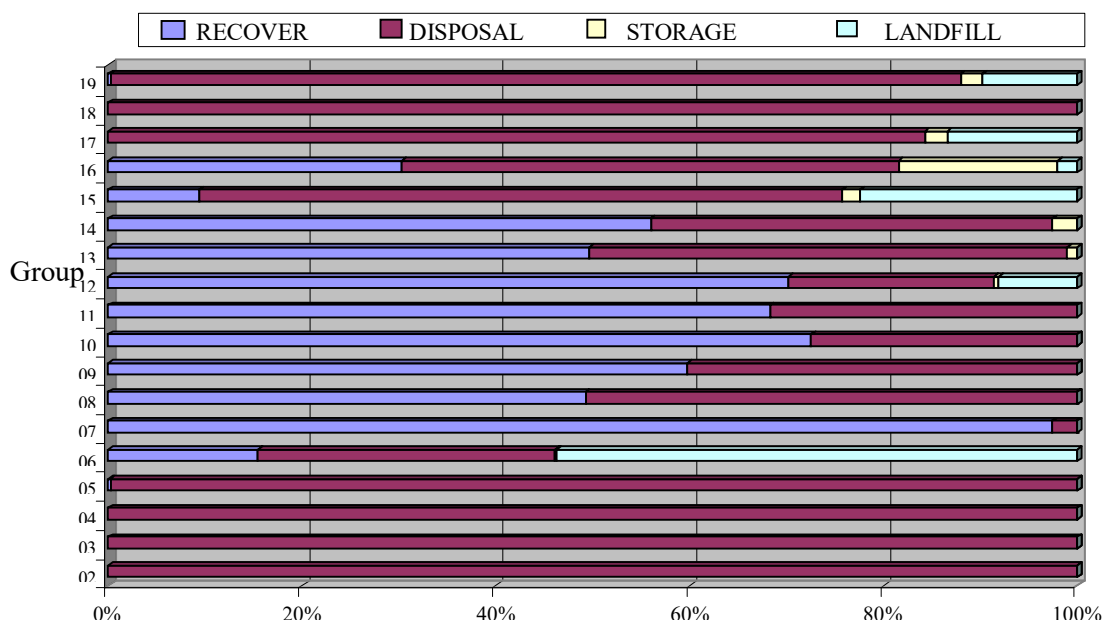
## 3. Structure of generation and management hazardous waste in Poland

Changes in quantity and quality of produced hazardous waste depend on the development of particular industry branches. The vast majority of hazardous waste generated as a result of conducting economic activity in Poland was concentrated in several sectors of the economy: in chemical, fuel and energy, mineral, metallurgic and electromechanical industry. 1 876 577 Mg of hazardous waste was generated in Poland in 2014 [16]. In comparison with the year 2012 it was a decrease of 3.45%. In figure 1 existing installations for the recovery and disposal of hazardous waste in Poland are presented. The largest number of installations is located in south Poland (voivodeships: silesian (24), malopolska (17) and opolskie (8)). In central Poland most of facilities are located in masovian (9), lodzkie (9) and kujawsko-pomorskie (7) voivodeships. And in the north of Poland in the pomorskie voivodeship the number is 11. It is connected with the location of industrial plants producing hazardous waste in those voivodeships.



**Figure 1.** Location of installations of hazardous waste recovery and disposal in Poland [17].

In figure 2 the division of methods of management with particular groups of hazardous waste produced in Poland in 2014 is listed and it takes into account numbering of groups of waste according to the catalogue of waste [11] (Journal of Laws 2014, item 1923). Waste from groups 02, 03, 04, 05 and 18 virtually all undergoes processes of disposal (D10), while waste from the group 07 almost all is subject to processes of recovery (R1 and R11).

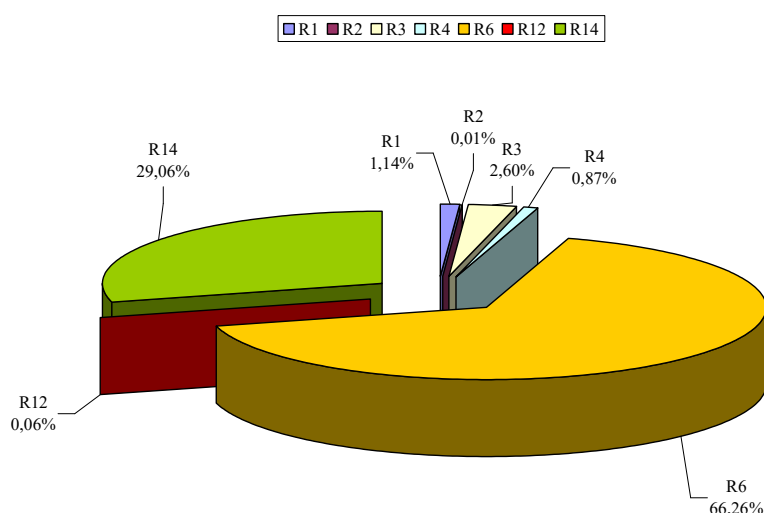


**Figure 2.** Percent share of techniques of management hazardous waste generated in Poland in 2014 in particular waste groups. Source: Own research based on [18].

On the basis of performed calculations and inventory checks of data obtained from the Marshal Office in Cracow [19] it appears that the biggest amount of hazardous waste generated in Malopolska in 2012 underwent the R6 process – reclamation of acids and alkalis – which comprised 66.26% of total recovery processes (figure 3). Another process, in which the waste was utilized, was R14 – other

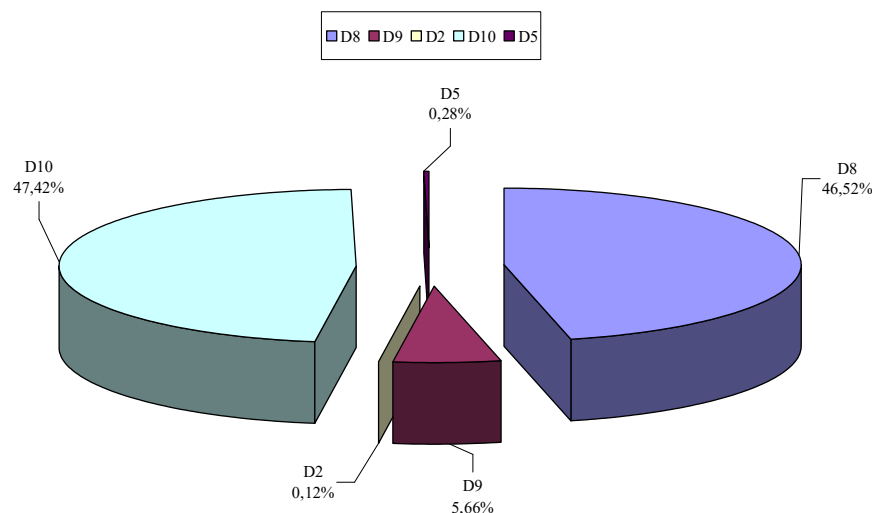
operations consisting in the total or partial use of waste (number of process compliant with the appendix 5 of the Act on waste (Journal of Laws 2001 no 62, item 628 with further amendments) [20] effective from the 14<sup>th</sup> of January 2013. 29.06 percent of hazardous waste recovered or utilized in the Malopolskie voivodeship was subject to the process. Other processes, in terms of quantities of recovered or utilized waste, were:

- R3 – recycling and reclamation of organic substances which are not used as solvents – 2.6%,
- R1 – used as a fuel or another resource of energy generation – 1.14%,
- R4 – recycling and reclamation of metals and metals compounds – 0.87%,
- R12 – exchange of waste for the purpose of treatment with any of activities mentioned in points R1 to R11 – 0.06%,
- and R2 – reclamation and recovery of solvents – 0.01%.



**Figure 3.** Quantity (in percent) of hazardous waste subject to processes of recovery in 2012 in Malopolska. Source: own research on the basis of data obtained from the Marshal Office in Cracow [19].

From the data placed in figure 4 it appears that the largest amount of hazardous waste generated in 2012 in the area of malopolskie voivodeship underwent the disposal in the process D10 (thermal transformation of waste in installations and equipment located on land) – 47.42% of all treated hazardous waste. The other process in respect of the quantity of disposed hazardous waste was the process D8 (biological treatment) in our case biological wastewater treatment plants. Up to 46.52 percent of hazardous waste is treated with the aid of this method. Only 5.66% of hazardous waste underwent the physic-chemical treatment (D9) even though processing capacities of installations existing in the area of Malopolska are much higher. There is an alarming fact that 0.28 percent of produced hazardous waste got to landfills – process D5. The most rarely applied process of hazardous waste disposal is D2 (treatment in soil and on land). Only 0.12 percent of hazardous waste was treated with that method.

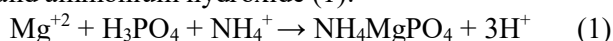


**Figure 4.** Amount (in percent) of hazardous waste treated in Malopolska in 2012. Source: own research on the basis of data obtained from the Marshal Office in Cracow [19].

Currently it has become common to utilize the waste coming from different economic sectors as materials for processes of producing useful products. It depends not only on economic considerations, but also on environmental protection grounds. Due to the significant growth of price for mineral resources in the world markets, it is necessary to treat the waste as cheap, available and useful materials.

An interesting example of managing the waste going to piles and dumping grounds is the attempt to develop waste solutions from the process of removal of magnesium from the zinc blende generated in the Trzebionka S.A. (in Malopolska). Authors of the paper [21] conducted research the aim of which was indicating the possibility of recovery and then use of magnesium compounds obtained from the waste solution. After the removal of heavy metals (Pb, Fe, Zn, Cd) contained in it, the following substances were added to the solution in order to obtain the magnesium in a form of phosphates:

— phosphoric acid and ammonium hydroxide (1):



The output of the reaction was the ammonium-magnesium phosphate hexahydrate technically pure ( $\text{NH}_4\text{MgPO}_4 \cdot 6\text{H}_2\text{O}$ ) which can be utilized as a mineral fertilizer.

— phosphoric acid (2):



The product of the reaction is the magnesium phosphate tri-hydrate which can be used as an addition to the feed and as a mineral fertilizer.

#### 4. Hazardous waste management in Poland

The primary objective of all plans related with the hazardous waste disposal is ensuring secure and economically justified processes of transportation, treatment and storage. The plan should also include the waste which will be generated in the future.

In order to draft plans regarding the disposal of hazardous goods it is necessary to take a look at the following issues [8, 22-25]:

- characteristics of waste: type of waste, chemical and physical stability, chemical properties of waste, manner of storage (selective or not) – the identification of those features allows to choose the technology for disposal properly,
- quantity of generated waste and forecast for production,
- way of ‘transporting’ chemical components from waste to the environment,

- influence on the natural environment (air, water, earth, fauna and flora),
- assessment of the influence of a given technology on the ecosystem and human,
- characteristics of location of potential hazardous waste disposal facilities in geographical, topographical and hydrological terms,
- criteria of the selection of a given technology taking into consideration the Best Available Technique (BAT),
- drafting procedures for handling in potential events of breakdown,
- drafting programs of long-term oversight and control after closing a given hazardous waste disposal facility.

#### 4.1. *Economic criteria*

In the economic balance both direct economic and ecological effects of an undertaking should be taken into consideration. Because of difficulties in determining the value of obtained ecological effect, ecological issues are often entered into the economic efficiency balance through the estimation of ecological losses, that is economic consequences of the environment degradation, excluding values of obtained ecological advantages.

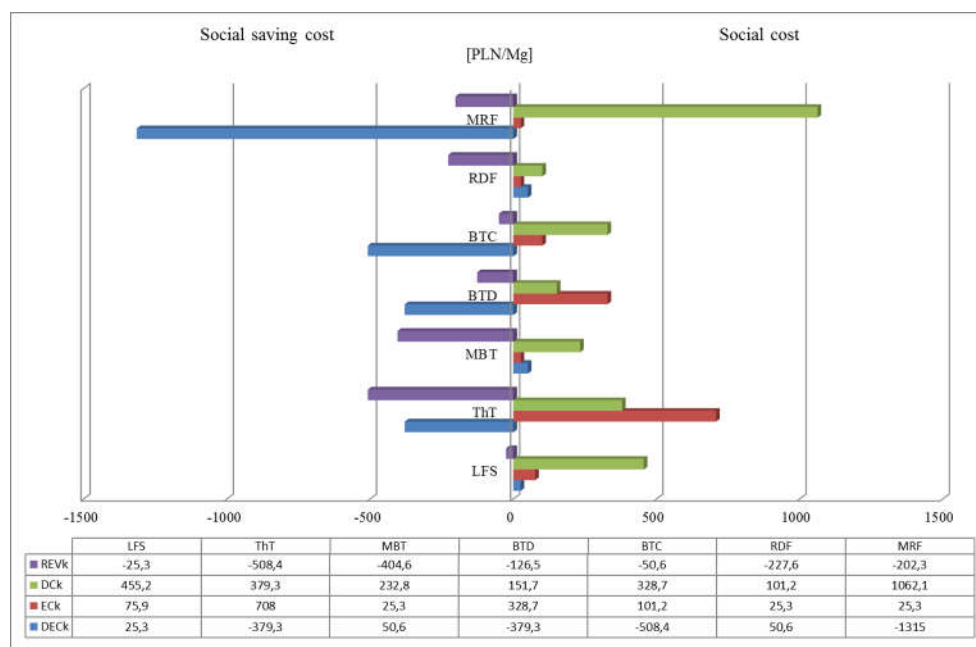
In the literature [26-30] ecological losses are defined as negative effects and phenomena caused by the environment pollution which lower the level of satisfying social needs and quality of life. The losses are of economic (measured with the aid of money) and social nature (immeasurable or difficult to measure and connected mainly with work and leisure conditions) [27]. Determining real values of economic and ecological losses is extremely problematic due to existing methodical difficulties. The difficulties arise from the complexity of determining losses in particular components of the natural environment, especially their productivity in natural units and transition from the physical recognition of losses to their real meaning (money) [28]. An additional complication in this area is the fact that total interaction of greater number of various pollutants causes significant growth of threat to human health and the environment in comparison with influence of only one type of harmful substance (synergy effect) [29]. One should also pay attention to the fact that some social and economic losses show only after a long time or in a different category and that half of losses is immeasurable, e.g. social and health losses and other losses difficult to estimate due to the lack of sufficient knowledge on the influence of harmful factor on the environment [8, 31, 32]. The valuation and estimation of economic losses caused by degradation of the environment is a very difficult task.

System of economic instruments should especially reward the prevention of waste generation at the source, raw material recovery, re-use of waste – including the energy contained in it, final disposal of unused waste in an environmentally safe way, decrease in energy and material consumption in production (application of cleaner technologies), use of alternative renewable energy sources, practical application of results of the analysis of full ‘lifecycle’ of product, production, transport, packaging, use, probable re-use and disposal [25, 33]. Yet, one should note that so far no methodology of how to estimate the balances was developed. Moreover, external costs related with hazardous waste management were not assessed. The linking of economic and ecological efficiency and calculation of economic and ecological effectiveness enables conducting a sozo-economical assessment [32]. As the outcome of execution of such balance it is possible to assess ecological losses caused by a particular economic activity taking into consideration immeasurable losses understood in a wider sense and to estimate social and economic benefits gained as a result of economic activity continuation [8, 22, 27, 29]. In other words it is a balance of ecological losses and social and economic advantages caused by a particular economic activity.

In figure 5 costs related with processing of waste on particular installations are presented, in division by social costs as well as recovered social costs.

Processes of waste processing generate social costs. Within those costs there are expenses of waste management (labour costs, incurred operational and maintenance costs of a given facility) as well as environmental expenses (e.g. direct expenses and costs incurred by the environment as a result of

elimination of a given factor) and social cost saving (related with energy and matter recycling) which one should treat as the income.



where:

MRF – “clean” Mechanical Recycling Facility, RDF – “dirty” Mechanical Recycling Facility, BTC – Aerobic Biological Treatment, BTD – Anaerobic Biological Treatment; MBT – Mechanical-Biological Treatment, ThT – Thermal Treatment, LFS – Landfill Site;

DCK – Disposal Costs, ECK – Environmental Costs, DECK – Displaced Environmental Costs, REVk – Social saving Costs

The given values have been calculated from the original data (stated in Euro for the year 2005) with the use of GDP Deflator (annual percent) 1991-2016 (The United Nations Industrial Commodity Statistics Database). The year 2016 has been adopted as the reference year.

The value has been calculated from the original data in Euro with the NBP (National Bank of Poland) average exchange rate (year 2016) at 4.355 PLN/EUR

**Figure 5.** Costs(PLN/Mg) incurred as result of waste treatment with use of various methods of recovery and disposal Source: own research on the basis of [10].

According to the data presented in the figure 5 we can state that the application of technology of ‘clean’ mechanical recycling (MRF) brings the biggest social benefits – amounting to 429.9 PLN/Mg. Other technologies the use of which brings measurable social advantages are as follows:

- aerobic-biological methods (BTC) – advantage of 129.1 PLN/Mg,
- mechanical-biological methods (MBT) – benefit of 95.9 PLN/Mg,
- so-called ‘dirty’ mechanical recycling (RDF) – advantage of 50.5 PLN/Mg,
- anaerobic-biological methods (BTD) – benefit of 25.4 PLN/Mg.

Methods the application of which brings more social costs than benefits are: thermal methods (ThT) – social cost equal to 199.6 PLN/Mg and storage (LFS) –531.1 PLN/Mg.

Methods of valuation of assets and resources of the environment allow to enrich the economic balance and create conditions for taking rational decisions not only of economic, but also of ecological nature. The valuation of losses caused by the environment degradation and the valuation of advantages from human health in the aftermath of environment condition improvement should always be taken into account while making decisions connected with hazardous waste issues [3, 5, 8, 32].



#### 4.2. Technological criteria

Recovery of raw materials from waste, waste treatment and disposal require expensive installations, equipment and proper technologies. It involves costs related with waste transportation and reloading as well as investment and operating costs for facilities[35]. One should not also forget about burden to the environment through by-products such as sewage, waste gases and others [1, 25, 33]. Nevertheless, building of new facilities for waste management enables the introduction of modern technologies and ensures the environment protection at a proper level. This is why it is so important to familiarize oneself with the structure of hazardous waste generation in a given area and application of optimal organizational and technological solutions codified in a form of BAT – Best Available Techniques.

Another criterion which should be taken into consideration are changes in the process of waste generation alone. For the purpose of better protection of the environment against the waste and increase in the efficiency of technological process in an enterprise (through reduction of costs related with transportation, disposal and storage of waste), the minimization of waste production ‘at source’ is essential. Undertakings aiming at decreasing the amount of hazardous waste generated and collected in the environment should encompass [8, 33, 35-39]:

- recycling of waste in place of generation,
- recycling of waste out of place of generation,
- modification of equipment and technologies,
- introduction of low- and non-waste technologies, that is clean,
- substitution of raw materials used traditionally.

In the work [8] a concept of avoidance and maximum utilization of hazardous waste was listed. The concept consists of three possibilities (table 1).

**Table 1.** Concept of avoidance and maximum utilization of hazardous waste [8,40]

Change of technology to low-waste one – optimization of processes	As result of implementation of the method avoiding the waste is strictly connected with given installation (given production process). Such technologies include all phases – from production flow optimization to total change of whole process. Small quantities of residues result from economic application of materials.
Organization of in-plant/intra-plant circulation	The method consists in utilization of produced waste in-plant in separate installations without changes to production. The method makes sense when waste is generated on regular basis and if it can be transformed in harmless way. Through utilization of residues as substitute raw materials one gains source of inexpensive materials and simultaneously saves on costs related with disposal.
Organization of external/out-of-plant circulation	Transformation of waste outside of plant is applicable when structure and quantity of generated waste causes that in-plant disposal is not justified economically. Another case of justified disposal outside of plant is when waste is produced in large amounts and even after processing cannot be sensibly utilized in-plant.

#### 4.3. Versatility of technology

One of criteria of the selection of technology of hazardous waste disposal, apart from evident ones such as the influence on the natural environment and technical and economic conditions, is also the choice of technology which is guided by its universality. It does not mean yet that technological equipment is available, by means of which the disposal of all waste would be possible – regardless of chemical composition and physical properties, and its use would be justified economically. Unfortunately, there is not one technology or even one method of hazardous waste treatment. The notion of versatility can be related to methods which show some elasticity in the field of hazardous

waste disposal. Table 2 illustrates the division of used and proven technologies of hazardous waste disposal.

**Table 2.** Division of methods of disposal of hazardous waste taking account groups of disposed waste.

Method	Group of waste	Application
Thermal	02, 03, 04, 05, 07, 08, 10, 12, 13, 14, 16, 18, 20	In general thermal methods are applied where there is a possibility of mineralization of hazardous organic substances included in waste. Thermal decomposition can take place in classic chamber furnaces (containing special barriers causing turbulences), rotary kilns, fluid chambers and plasma furnaces[35]. Many methods of thermal utilization of hazardous waste consists in its total incineration together with other fuels and use of energy in processes of production, for example cement. In order for a given installation to be suitable for hazardous waste disposal, it must meet specific technical conditions determined in relevant regulations. The regulations define limit values for the temperature, oxygen content, time for maintaining exhaust gases in the incineration chamber [13].
Biological	02, 05, 06, 07, 08, 11, 12, 13, 16, 17, 18, 19	Biological methods are generally used for cleaning of plant protection products, heavy metals and oil derivative waste in the soil. They consist in selective actions by relevant bacterial strains decomposing toxic substances[41].
Chemical, physical, physico-chemical	06, 07, 09, 10, 11, 12, 13, 16, 17, 19, 20	The most commonly applied chemical methods consist in the neutralization of acids and alkalis. It is the precipitation of sparingly soluble chemical compounds of heavy metals included in waste in order to lower its solubility in water and processes of immobilization (sealing in concrete mass, vitrification). Another method is de-halogenation of chloro-organic compounds from used transformer oils, solvents and plant protection products. Other methods are also: distillation, gas stripping, extraction, adsorption as well as other physical processes [35].
Landfilling	10, 17, 19	Exceptional way of hazardous waste disposal is landfilling [42].

## 5. Summary

Organizing comprehensive hazardous waste management causes a decrease in number of facilities in which such waste is disposed. The desired result of such measure is the limitation of quantity of potential sources of environment contamination and bigger economic effects (than in case of individual enterprises). One cannot also omit the fact that the comprehensive hazardous waste management has a positive impact on the choice of optimal technology of disposal of hazardous waste and this in turn is related with enabling the introduction of modern technologies, full application of technological operations, increase in work efficiency, obtaining lower operating costs and ensuring the environment protection at a proper level [43]. In case of waste treatment, residues coming from that process can be utilized economically. Economic and ecological considerations require minimizing the consumption of primary raw materials from nature and use of any waste arising at different stages of cargo turnover and material trading to the border of economic profitability.

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## References

- [1] Baran A, Antonkiewicz J 2017 *Environment Protection Engineering* **43** (2) 143–155
- [2] Kikuchi R, Gerardo R 2009 *Journal of Hazardous Materials* **172** 1681–1685
- [3] Mmerek D, Li B, Meng L 2014 *Waste Management & Research* **32** 1158–1168
- [4] ZhuaD, Yang S, Sihui Z, Yu H, Yang Y, Li Y 2014 *Environmental Nanotechnology, Monitoring & Management* **1–2** 50–56
- [5] Lei L, Wang S, Lin Y, Liu W, Chi T 2015 *Ecological Indicators* **51**, 237–243
- [6] Koolivand A, Mazandaranizadeh H, Binavapoor M, Mohammadtaheri A, Saeedi R 2017 *Environmental Nanotechnology, Monitoring & Management* **7** 9–14
- [7] Pyssa J 2008 *Gospodarka Surowcami Mineralnymi/Mineral Resources Management* **24**, 1/1 113–125
- [8] Pyssa J 2010 *Przemysł chemiczny* **89/7** 927–934
- [9] Act on waste (Journal of Laws 2013, item 21) of the 14<sup>th</sup> of December 2012 (uniform text Journal of Laws 2016, item 1987, 1954)
- [10] Council Directive 2008/98/WE of the 19<sup>th</sup> of November 2008 on the waste
- [11] Regulation of the Minister for the Environment as of the 9<sup>th</sup> of December 2014 concerning the catalogue of waste (Journal of Laws 2014, item 1923)
- [12] Regulation of the Minister for the Environment as of the 30<sup>th</sup> of April 2013 (Journal of Laws 2013, item 523) on waste landfills
- [13] Regulation of the Minister of Economic Development of the 21<sup>st</sup> of January 2016 (Journal of Laws 2016, item 108) on requirements concerning the conduct of process of thermal transformation of waste and ways of proceeding with waste resulting from that process
- [14] Regulation of the Minister for the Environment as of the 23<sup>rd</sup> of September 2016 (Journal of Laws 2016, item 1601) on details of conditions for recognizing hazardous waste as the waste other than hazardous
- [15] Regulation of the Minister for the Environment as of the 7<sup>th</sup> of October 2016 (Journal of Laws 2016, item 1742) concerning details of requirements for the transportation of waste
- [16] Eurostat (2017) <http://ec.europa.eu/eurostat/web/environment/waste/database>
- [17] [http://www.access.zgwrp.org.pl/materialy/dokumenty/PlanyGospodarkiOdpadami/1/kpgo/Rozdzial\\_3.3.pdf](http://www.access.zgwrp.org.pl/materialy/dokumenty/PlanyGospodarkiOdpadami/1/kpgo/Rozdzial_3.3.pdf)
- [18] [http://swaid.stat.gov.pl/StanOchronaSrodowiska\\_dashboards/Raporty\\_predefiniowane/RAP\\_DBD\\_SROD\\_6.aspx](http://swaid.stat.gov.pl/StanOchronaSrodowiska_dashboards/Raporty_predefiniowane/RAP_DBD_SROD_6.aspx)
- [19] Marshal Office in Cracow, Cracow 2014
- [20] Act on waste (Journal of Laws 2001 no 62, item 628) (uniform text Journal of Laws 2012, item 951 and 1513) – in force from 2013.01.14
- [21] Żelazny S, Jarosiński A 2007 *Problemy ekologii* **11**(4) 191–193
- [22] Vogtlander JG, Bijma A, Brezet HC 2002 *Journal of Cleaner Production* **10/1** 57–67
- [23] Misra V, Padey SD 2005 *Environment International* **31** 417–431
- [24] Zhao J, Huang L, Lee DH, Peng Q 2016 *Transp. Res. Part E* **88** 52–75.
- [25] Pyssa J 2017 *E3S Web of Conferences* **19**, 02021
- [26] Bernaciak A, Gaczek W M 2001 *Economic aspects of environmental protection* (Poznań: Publisher of University of Economics in Poznan), p 35
- [27] Hołuj A. 2006 *Folia Oeconomica Bocheniensia* **4** 29–45
- [28] Filipiak B, Cieciora M, Czaja-Cieszyńska H, Niewęglowski A, Szczypa P 2010 *Cost account in the environmental protection* (CeDeWu Publishing House)
- [29] Augustiewicz A, Breńko T, Kozłowska A, Miłoszewski R, Karolinczak B, Werner –Juszczuk A and Winiarek P 2012 *Civil and Environmental Engineering/Budownictwo i inżynieria środowiska* **3** 17-23
- [30] Becia A, Czaja S, Zielińska A 2012 *Cost and Benefit Analysis in valuation of the natural environment* (Warsaw: Difin Publisher (in Polish))
- [31] Kikuchi R, Gerardo R 2009 *Journal of Hazardous Materials* **172** 1681–1685

- [32] Court ChD 2012 *Ecological Economics* **83** 79–89
- [33] Wu J, Guo Y, Li Ch, Qi H 2017 *Journal of Cleaner Production* **149** 49–59
- [34] Oropeza E M 2006 SUWAMAS, A Decision Support Model For Sustainable Waste Management System, Dortmund (doctoral thesis) <https://eldorado.tu-dortmund.de/handle/2003/22997>
- [35] Rao MN, Sultana R, Kota SH 2017 *Solid and Hazardous Waste Management. Science and Technology*(Butterworth-Heinemann) p.159 – 207
- [36] Blackman Jr. W C 2001 *Basic Hazardous Waste Management* Third Edition (Lewis Publishers. Boca Raton, London, New York, Washington, D.C. Library of Congress Cataloging–in–Publication Data)
- [37] Bendkowski J, Wengierek M 2002 *Logistics of Waste – Logistic Processes in Waste Management* (Gliwice: Publisher Politechnika Śląska (in Polish)
- [38] Bilitewski B, Härdtle G, Marek K, 2006 *Manual for Waste Management. Theory and practice* (Warszawa: Publisher Seidel - Przywecki. Spółka z o. o. (in Polish)
- [39] Rosik-Dulewska Cz 2015 *Fundamentals of Waste Management* (Warsaw: Polish Scientific Publishers PWN (in Polish)
- [40] Curran T, Williams ID 2012 *Journal of Hazardous Materials* **207–208** 3–7
- [41] Zhang TC, Surampalli RY, Tyagi RD, Benerji SK 2017 *Current Developments in Biotechnology and Bioengineering. Solid Waste Management* (Elsevier B.V.) p. 311–340
- [42] Pecorini I, Baldi F, Bacchi D, Carnevale EA, Corti A 2017 *Waste Management* **63** 96–106
- [43] Bendkowski J, Wengierek M, 2004 *Logistics of Waste – Facilities for Waste Management*(Gliwice: Publisher Politechnika Śląska(in Polish)