Environmental Protection Engineering in Mineral Resources Treatment in Mining, Metallurgy and Chemical Industry

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The environment as a source of mineral resources

The natural environment is the only source of all resources – materials used in the course of economic activity of human and processed in a variety of technological processes in order to obtain products with a direct consumptive and non-consumptive (e.g. investment) application. Between the individual main areas – component parts – of the natural environment occur multilateral relationships that in particularly depend on flows of streams of materials, energy and information. Figure 1 depicts a schematic layout of major components (functional and matter areas) of natural environment:

- Human – factor using an environmental resources and affecting at the same time the state of other parts of it – it is simultaneously initiating and causative element of all events and processes discussed here,
- Resources – material resources drawn from environment – the objects of all economic activities,
- Energy – derived from the environment – an essential factor enabling all economic activities, particularly involving the processing and use of natural resources,
- Environment, described here briefly – includes other components of widely understood natural environment.

In the overall context of economic activity involving the sphere of material production as a first step of e.g. acquisition and processing of resources, there are two main areas:

- Production
- Utilization, also determining the demand on individual products.

Figure 2 shows a schematic layout of both areas. From the utilization sphere there are information about demand transmitted to production sphere, causing certain decision and enforcement actions. The demand characteristic on different products (widely understood as e.g. intangible products from the field of knowledge, culture, etc.) is presented in the figure by means of horizontal stripes derived from demand sphere: the shape of their ends symbolizes the qualitative characteristic of desired product, width – the quantitative demand. Analogous stripes derived from production sphere present in the same way the real production results.

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The example in Figure 2 shows various options for qualitative and quantitative compatibility of demand and production. Streams 1 and 2 demonstrate full compatibility, others: 3 – qualitative compatibility with an excess production quantity; 4 – production shortage; 5 – full qualitative and quantitative compatibility; 6 – partial compatibility – quantitative and qualitative. Streams or their parts corresponding to each other in every way of demand and production are called balanced streams.

In the cases 3, 5 and 6, unused products are formed, which can be particularly production wastes. In the case of their direct use as raw materials for any type of production, they are secondary materials. In other cases, there is usually the potential for processing the waste into resources by means of suitable technological processes. This justifies the perception of all wastes as useful wastes (waste resources). Yet, in Poland, there is no proper name for such wastes, although the Law on Wastes from 2001 (according to Journal of Laws 2007: No. 39, item 251 and No. 88, item 587) largely contributed to its creation and segregation.

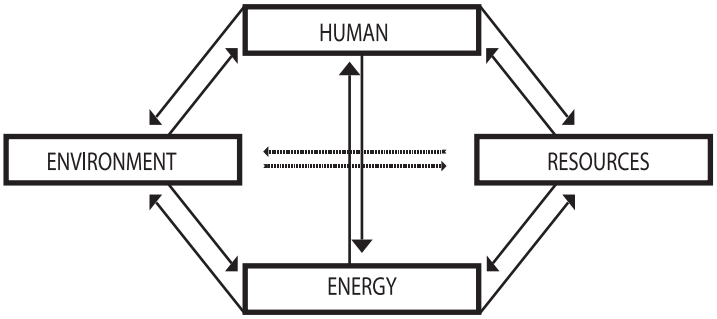


Fig.1 Schematic layout of major components of natural environment

Rys.1 Schematyczny układ głównych części składowych środowiska przyrodniczego

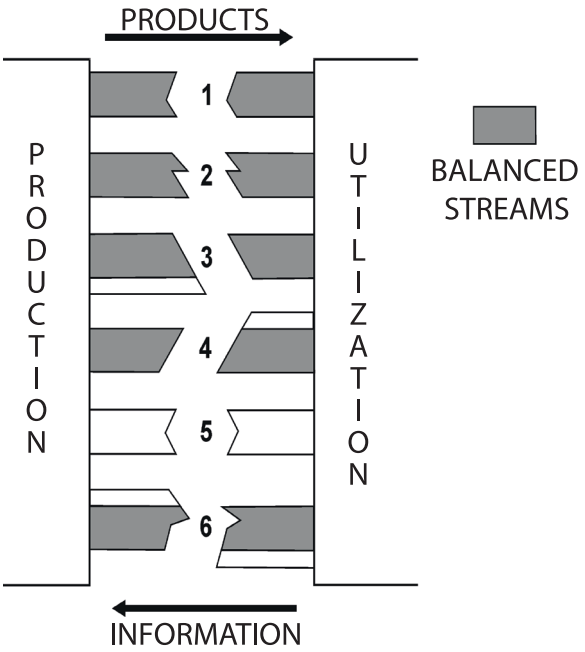
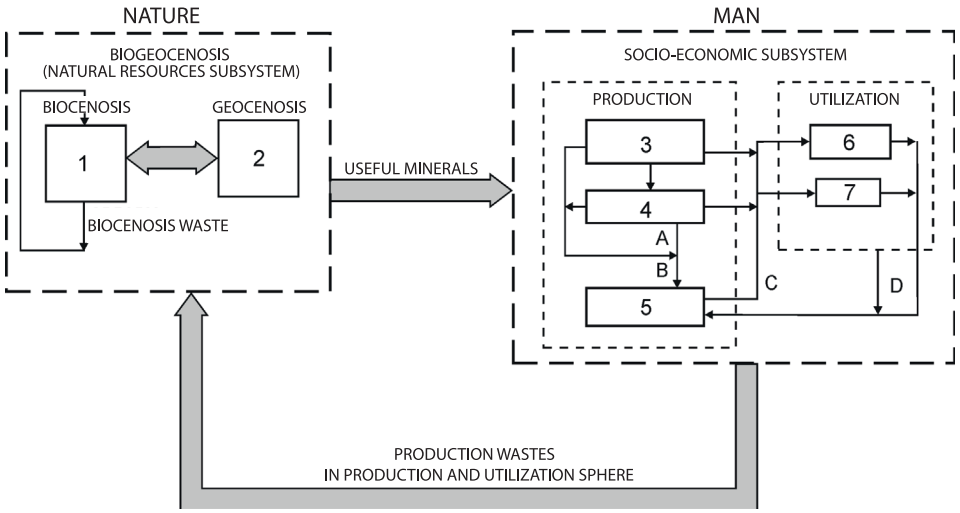


Fig. 2 Schematic layout of production and utilization areas

Rys. 2 Schematyczny układ sfer produkcji i użytkowania

Fig. 3 Relationship between the environment and the sphere of human activity

Rys. 3 Relacje zachodzące pomiędzy środowiskiem a sferą działalności ludzkiej



Due to the possibilities to access to primary resources and their recovery, they can be divided into following groups:

- Reproducible – e.g. agricultural and breeding products,
- Non-reproducible – mainly resources of mineral origin.

The subject of this lecture contents are solely the environmental effects of processing the non-reproducible resources, mainly of mineral origin (minerals and products of their treatment having characteristics desired by various clients, as well as the general effects of their further utilization for manufacturing final products).

Figure 3 depicts relationship between the environment (nature) and the sphere of human activity (man) in connection with the use of resources. From (1) biocenose and geocenose following materials are derived: reproducible and non-reproducible. According to previously accepted limit, the latter is considered here. Primary useful minerals undergo the processing in production sphere: minerals treatment (3) and secondary materials treatment (4), giving the materials that are transmitted to utilization sphere, where they are consumed (6) or used for non-consumptive purposes (7). Processing of primary resources (3 and 4) leaves production wastes (from mining and treatment – A and B), utilization results in post-consumption wastes (used items, scrap, waste, etc. – D). They can be (and should be) utilized (5), giving useful (C) products (mainly raw material), that are brought back to utilization sphere, but also final wastes which are impossible to be utilized with currently known technologies. The latter are called raw material loss. They are transported back to the nature sphere where they are generally subjected storage on piles (heaps), settlers, etc., in a certain part they are also dispersed in the environment in the uncontrolled way.

For any raw material it is not possible to fully use it without any final wastes production. The main reason is natural composition of useful minerals (as well as other useful mineral resources) created by means of metallogenic processes, which remains beyond any regulation possibilities. In any case it practically does not balance with the demands related to utilization of given mineral, which is exploited in order to obtain one or more components that only occur in certain amounts in the mass of barren components (with at most a small usability). For example, in the copper ore, this metal stands for about 1.5 – 2.5% of the total mass. The remainder is the rock material with a low utility, which must be excavated and properly processed and treated in order to acquire copper and other elements – mainly metals – that accompany copper. In the best scenario, about 90 % of the total weight of the extracted ore is posed by final wastes.

The stream of final wastes locally violates – depending on quantitative and qualitative characteristics of many other factors – the balance of the natural environment. Natural processes occurring in the environment are generally not effective enough to maintain the equilibrium disturbed by wastes inflow (they are inefficient – from the point of view of economics, they occur too slow). As a result, there is a constant change in the natural environment, which usually has to be - because of its further consequences – seen as a degradation of this environment – its raw material characteristics negatively affect the possibility of extraction of desired mineral resources. Of course, this is also related to natural parameters of the environment, which forms a complete picture of its characteristics as the environment of our lives and activities.

Final wastes carry a certain amount of valuable components (some of post-consumer wastes, like scrap, contain even a large quantities of such components). Possible full reuse of these components allows to save some part of the incremental resources and to reduce the cost of their pre-treatment. Therefore, it has a very important economic aspect, while even the mere reduction of the waste stream passed to the environment has a beneficial ecological aspect.

Maximal use of all components and performance characteristics (e.g. mechanical properties of gangue) of primary resources and formed secondary resources and wastes (due to treatment and use) is a fundamental assumption for complex utilization (management) of mineral resources. When this problem is considered from the point of view of quantity and quality of obtained waste, this principle is identical to the implementation principle of low-waste or waste-free technology. It also allows to reduce the amount of primary resources (minerals) derived from natural deposits and by reducing the disturbances level in the environment, it becomes almost essential element of sustainable development – the unquestioned priority principle in the relationship between the man and the environment, that determines the proper and stable development of human society in possibly long period of time.

The result of analysis of wastes condition (their quantity and quality), which will arise from the use of certain raw materials, becomes a basic criterion of established method of use. Figure 4 depicts a schematic developed procedure for minimization of environment effects of certain activities. After the demand analysis, which delivers data for production planning, an analysis of wastes condition (projected) is proceeded. If the result is unsatisfactory (-), the preventive activities are implemented, and then – depending on the status of each of analysis – utilizing and disposing activities are performed. In the extreme case – when the condition of wastes is still unsatisfactory – there may be a necessity of change of resource use concept. The results of the subsequent stages of the proceeding may indicate the need for adjustments in the determining the previous stages.

Environmental effects of wastes deposition

A wide variety of direct effects, which the disposal of wastes cause in the natural environment, can be structured as follows:

A) Passive impact consisting of:

A.a) occupation of space, which cannot be used for any other purpose,

A.b) devastation of the landscape, that cause, among others, aesthetic discomfort felt by residents,

B) Active impact consisting of:

B.a) terrain deformation – in the case of a weak foundation with simultaneously large masses of accumulated waste; these deformation in practice relate mainly to large accumulations (heaps) of raw material or wastes, as well as settling ponds artificial embankments (settlers) in which the waste is stored as suspension that sediments over time, but also retains semi-solid or liquefying (thixotropic) properties; deformations of these embankments (or any other infringement and faulty service delivery!) lead in extreme cases to their break, which could have a very serious multilateral as well as tragic consequences,

B.b) pollution of the environment caused by fine-grained wastes fractions, blown by winds or washed away by rain water; this material changes soil structure, and particularly may bring in to it – depending on the chemical composition – compounds that are harmful for the environment (toxic, caustic, etc.), and also can cause – after penetration into human body (particularly to the lungs) – occupational diseases (e.g. pneumoconiosis) including allergic type, sometimes with severe course and serious prognosis,

B.c) pollution of landfill environment: soil, water and atmosphere by chemically active products obtained through spontaneous conversion of substances contained in wastes, especially atmospheric oxidation products – particularly in the presence of water (including oxygen dissolved in water) – such as heavy metals sulfides (e.g. in the case of hard coal wastes it is mostly pyrite – FeS_2) and others, easily oxidizable – or amenable to other chemical reactions – substances, including organic; soluble in water and volatile products of these processes (SO_2, NO_x, CO, polycyclic compounds etc.), can migrate in the environment in a manner impossible to predict and control, over long distances, and strongly exothermic course of some of reactions (particularly oxidation of pyrite contained in the coal waste) can additionally cause ignition of coal residues in wastes, resulting in not only endemic fire of such accumulations of wastes (dumps "burning up"), but also fire of heaps unenriched with coal – especially fine coal (fines) – that are stored temporarily before dispatch to customers.

The range and scale of these impacts depend on the characteristics of accumulated waste and landfills, including:

- type of waste (including the form in which they appear),
- chemical composition of the waste,
- amount of waste on the landfill,
- degree of fineness of stored waste material, which is decisive in case of the total size of the outer surface of particles of stored material, which are a foundation for previously mentioned reactions,
- characteristics of the bedrock under landfill (physical properties: mechanical strength, permeability to water etc.),
- spatial configuration of the landfill (including the form and manner of embankment settlers),
- intensity of rainfall in the area of the landfill,
- wind accessibility and its characteristics (dominating directions, intensity) in the area of the landfill.

These factors, and others less important, impact on the environment in complex systems dependent on local con-

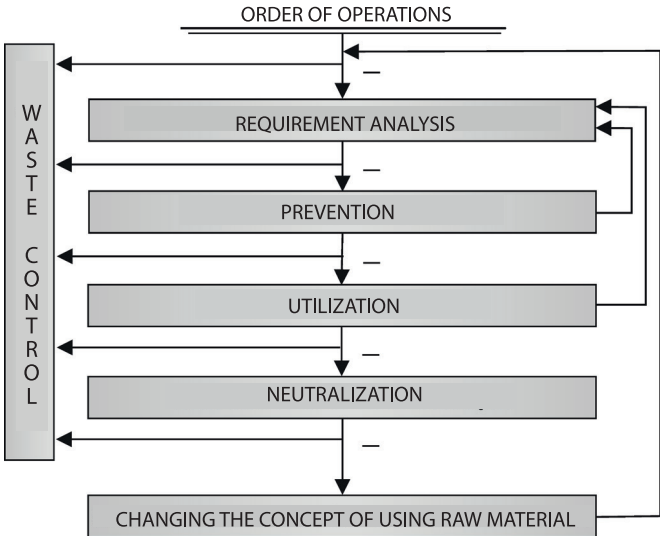


Fig. 4 Denotations and points of control and measurement

Rys. 4 Oznaczenia i punkty kontrolno-pomiarowe

USE PHASE (and its localization)		PRODUCTS	SOURCE OF THE ENVIRONMENTAL EFFECTS
EXPLOITATION (mine)		**raw coal**, mine water, mining solid waste	**pyrite,** ash salts (mailny Cl^{-1}), suspension, area occupation, pyrite *
ENRICHMENT (coal treatment plant)		**coal concentrate**, solid wastes, washings	-- **pyrite**, area occupation, **suspension**, reagents **
ENERGY PRODUCTION	POWER PLANT (CHP Plant)	**electric energy (thermal energy)**, power plant's waste ***	– waste heat **** (look ***)
	DISPERSED CONSUMERS *****	**thermal energy**, ash and slag, exhaust gases	-- environment contamination **CO_2, CO, SO_2, NO_x, polycylic compounds (e.g. dioxins)**, aerosols

* mining wastes do not contain significant concentrations of pyrite,
** residual concentrations of flotation reagents (after processing of coking coal) and flocculants,
*** the main types of power plant wastes and effects of their storage for the environment:
- slag: occupation of the area and its contamination, possible harmful compounds content that origin from incomplete combustion of combustible materials,
- fly ash: occupation of the area and contamination,
- exhaust gases: CO2, CO, SO2, NOx, aerosols, polycyclic compounds (especially dioxins), most of the power plant's solid wastes is suitable for various forms of disposal, mostly for production of a wide range of construction materials,

**** waste heat is a specific kind of "wastes", which may influence the local climate condition, and above all the temperature, and therefore the saturation of surface waters with oxygen, having an effect on the living conditions of all organisms,
***** households, factories (usually small) and workshops, block district boiler rooms burning coal for heating purposes, and others.

ditions, causing the effects of details that are not always possible to accurately predict.

Environmental effects of using solid fossil fuels

In the individual phases of solid fossil fuels use – hard coal and lignite – there is a variety of products (main and by-products) and diversified effects on the environment (risks: main and side effects). For example, in the case of hard coal (table on the top).

In the case of lignite exploited with strip mining, additional quantitatively significant material having mine wastes character is overburden (formally it is not treated as a waste, but it does not change its actual role in the environment), in which one may distinguish a top layer of soil, that is usually removed selectively and for the recultivation and agro-horticultural purposes, and a whole set of remaining overburden materials. These materials deposited during exploitation of the bed on the landfills (initially on external and then on internal parts of already exploited strip mine) may contain sandy and silty formations suitable for the processing into materials for construction industry or for moulding. In general, the basic mass of overburden is intended for subsequent recultivation works. Lignite does not contain significant amounts of pyrite especially in the form of larger particles, sulfur occurs in the form of sulfates and organic compounds. This precludes – unlike in the case of hard coals – initial removal of the primary parts of sulfur by means of treatment methods.

Reduction of the environmental risks associated with using a solid fossil fuels depends on employing technological and technical measures in subsequent phases of using of such coal, which contributes to reduction of the anticipated amount of wastes according to the scheme described in chapter 1 (Figure 4) already in the phase of preparation of such raw material.

Environmental effects of using metaliferous raw materials

Side effects (economical and environmental) of using metals – starting from ores exploitation phase – are schematically presented in the Table. An arrangement of types of products and economical and environmental effects is shown similarly to the previous table related to energetic coal.

The sequence and characteristics of preventive (when there is no negative effect on the environment) and reproducing activities (when there is already negative effect) do not differ from those reported previously. Applied technological and technical solutions depend on the specific stages, types and closer characteristics of processed materials (e.g. steel and iron metallurgy, non-ferrous metals metallurgy) and predicted or already occurring environmental effects. In Polish conditions, there are no effects associated with the exploitation phase in the case of iron and steel metallurgy (due to import of these materials), but full range of environmental effects is observed in the case of non-ferrous metals industry, that processes sulfide concentrates of these metals obtained from domestic ores (n.b. some of the steel plants produced or produce – mostly because of

the environmental issues – by-products, sulfuric acid from SO2 contained in exhaust gases – possibilities and ways of management of this acid are due to its large quantity and low quality – contamination – quite limited and, for example, in copper industry this acid is partially neutralized by means of basic carbonate tailings and stored together in the bounded form – with a predominance of sulfates – in a sedimentary pond.

The characteristics of advanced stages of treatment and using of metalliferous materials are analogous to the conditions occurring in metal industry – machine-building industry.

The environmental effects of use of raw rock and mineral chemical materials.

Rock materials generally do not exhibit aggressive ("active") activity in relation to the environment. During their exploitation and use there occur a significant terrain distortions (mainly strip mine), and in the most cases, large quantities of wastes requiring disposal. The finest fractions can be spread by water and wind, contaminating the environment with the effects described in chapter 2.

In the chemical industry which uses materials of mineral origin (chemical – inorganic, including: hydrochloric, sulfuric, sodium and others) there are environmental hazards depending on the characteristics of the material being processed, applied technology and their implementation and organization. General rules of preventive and recultivation activity stays the same, as previously discussed.

Mineral wastes and sustainable development

The whole of discussions on conditions of sustainable development in terms of use of natural resources constituting a component of the natural environment leads to the conclusion, that the essence of rational activity is interference minimization into the environment, particularly reduction of its exhaustion grade, reduction of waste quantity that arise due to use of environmental resources, especially minerals and minimization of their potential risk to the environment.

Brief characteristic of mineral waste as a factors of sustainable development:

- With respect to use of natural mineral resources, usually with properties that prevent their direct application for specific economical purposes, there must occur wastes, which contain components of the input material – minerals – that do not possess characteristics allowing for their current use, as well as part of the components actually useful, which leaked into wastes due to imperfection of technological processes; wastes also arise when part of the products obtained in the course of utilization procedures have a qualitative attributes allowing for their use, but their quantity – resulting from natural composition of primary raw material – is not balanced by current needs (also including trading and stocking),
- Wastes arising in the course of managing raw materials are burden for natural environment, they impede achieving its condition violated by the exploitation of minerals to the acceptable condition and they require action – listed starting from the most desirable – for:
  - reduction of the amount of wastes, in particular through implementation of the principle of complex use of primary resources, including technological and organizational activities,
  - use of wastes – possibly after suitable technological treatment – as a recycle materials for purposes other than originally intended for mineral's components; if such utilization is potentially possible, but at the moment of wastes production is unfeasible for various reasons, these wastes should be stored on temporarily landfills with specific de-

Tab.1 Side effects of metal using

Tab. 1 Skutki uboczne użytkowania metali

USE PHASE	PRODUCTS	SIDE EFFECTS	
		ECONOMICAL	ENVIRONMENTAL
ORE EXPLOITATION	Raw ore, mining wastes	Deposit exploitation losses	Terrain deformation water regime disturbance, area occupation
ORE TREATMENT	Metals concentrates Treatment wastes	Metals losses in wastes	Wasters storage(area occupation), water and atmosphere contamination
METALLURGY	Metals and steel products, metallurgical scraps (usually fully used in situ), gases, dusts, liquid wastes other metallurgical wastes and treatment wastes	Metals losses in wastes	Wastes storage, contamination of water, soil and atmosphere
WARE USE	scrap (classical recycle waste!), useless wastes (mostly non-metalic)	Non-returnable use of metals	Useless wastes storage non-returnable products

termination of method and expected time of their elimination; the same applies to products with specific utility properties, but produced in excess,

- safe and inoffensive for the environment – in particular in relation to living organisms, but also to inanimate objects, such as landscape – deposit of solid wastes on landfills, taking into account possibility of using them for architecture creation purpose related to return to acceptable environment conditions (creating a permanent landfills in the form of large engineering constructions with the participation of waste – especially mass waste – should be regarded as the use of waste); in particular it relates to use for such purpose an underground post-exploitation caverns with the constraint resulting from geological and mining conditions of such workings and properties of the wastes,
- disposal or treatment of hazardous wastes, which are their special category, characterized by separate legislation.

Selected problems of municipal waste management

Problems of municipal waste management are included in specialist lecture in the Postgraduate Studies, so here is presented only an outline of the organizational elements of managing these wastes treated incidentally – as a complement to the preceding considerations – due to their specificity: a very large diversity, distributed origin sources of varied, but most commonly with limited unit capacity (households, small manufacturing facilities, including crafts, units of municipal services: residential area maintenance, green areas and waste removing services, etc.), which gives the possibility of completing the necessary unit actions profile, from which in conditions more uniform and concentrated production activity characterizing most of previously described problems related to treatment and use processes of fundamental mineral resources, the series of activities – such as waste collection or their pre-sorting – may not occur.

Municipal wastes are inevitable side effect of the whole of human activity , including all life processes. They are a very important element of shaping the environmental conditions (as well as an important economic factor), heavily undergoing organizational and ordinal treatments due to the dependence of the results of such treatments on practically each individual citizen. Physically, they are a set of very different quality groups of materials. One of the variants of the simplified scheme of municipal waste management is presented in the table below. Particular attention should be aimed into hazardous wastes, to which apply different regulations on collection and disposal.

Elements of properly maintained and developed municipal waste management system includes following main stages and steps:

Tab. 2 The simplified scheme of municipal waste management

Tab. 2 Uproszczona systematyka odpadów komunalnych

SOLID MUNICIPAL WASTES	
METALS	**- steel wastes** **- aluminium wastes** **- remaining metals**
GLASS	**- colorless** **- orange** **- green**
PAPER	**- direct use wastes** **- waste paper**
TEXTILES	**- direct use wastes** **- rags**
WOOD	
SYNTHETIC MATERIALS	**- (*forms*)**
MINERAL WASTES	
ORGANIC WASTES	**- animal origin (bones, skin, etc,)** **- vegetable origin (bakery, vegetables, leaves, grass, etc.)**
LIQUID MUNICIPAL WASTES	
STREET AND STORM SEWAGE	
FECAL MATTER	
DOMESTIC SEWAGE	
GASEOUS MUNICIPAL WASTES	
CO_2, CO, SO_2, H_2S, HNO_2, NO_x, CH_4, freons, other substances contained in gaseous phase (including dioxins)	
HAZARDOUS WASTES	

COLLECTING:
COLLECTION AND ACCUMULATION: selective,
SEGREGATION: manual and mechanical,

MANAGEMENT
TREATMENT (recycle materials):
– metals,
– glass,
– waste paper,
– rags,
PROCESSING:
– composting of organic waste,
– [burning: elmination of combustible waste (e.g. wood), burnout of mineral wastes and others],

DISPOSAL (NEUTRALIZATION):
BURNING: – including hazardous parts,
– remaining wastes,
CHEMICAL AND BIOLOGICAL DEGRADATION:
– wastes and hazardous wastes,

DEPOSITION (INCLUDING LANDFILLS MAINTENANCE)
USE (SALE)

of recycle materials recovered during segregation and treatment: compost, burnt materials, etc.

World experience has a developed system of studies already tested in many countries that allow for safe management of municipal wastes. This applies both to organizational systems and processing technologies, which are derived from existing mineral engineering technologies – minerals treatment, inorganic chemistry, biotechnology and others – carried out with good results for many years now – wide-ranging studies for ecological education of the society. In the advanced phase of studies are – also on the basis of polish technical and research achievements – necessary preparations in Poland. The greatest difficulties can be cause by unsatisfactorily – so far – preparation of the society to co-realization of this complex task. This implementation is not, however, an alternative providing the appropriate environment in all population centers, especially in industrialized cities, in which the burden of municipal waste is overlapped by previously described and adverse industry activities on the environment.