

Urban Mining – a New Concept

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Abstract: Population growth, increased standard of living and accelerated industrial growth have led to the increased need for all types of raw materials and energy, but have also caused increasing quantities of waste. This is why recently, in establishing new development strategies, raw material management and waste management policies have been combined at all levels. Urban mining is also a new concept for the use of mineral and other raw materials, as well as the energy potential present in waste, landfills and other anthropogenic sources. Although exploration, extraction and processing of mineral raw materials from such secondary sources are based on similar methods and procedures as in traditional exploitation from natural deposits, still adaptations, innovations and new technological solutions are needed. This paper provides a detailed review over the management of mineral raw materials and the associated waste management in both the European Union and Croatia.

Keywords: urban mining, mineral resource management, landfills, waste management

Introduction

Population growth and increasing standard of living have led to an increased demand for all types of raw materials and energy. Also, industrial growth causes more and more waste to be generated. Therefore, there is a clear need for strategic planning that will combine raw material management and waste management at all levels. In this paper a detailed review is provided over the management of mineral raw materials (mineral resources) and the associated waste management.

Generally speaking, as the need for raw materials is growing, so the efforts to recycle waste should also be increased, since estimates point to the fact that the in-

creased need for resources cannot be met exclusively from primary sources in the long run. Urban mining is a new concept that can make a significant contribution to this goal; it can be simply defined as recycling of raw materials and/or energy from secondary (anthropogenic) sources: products, buildings or waste, by which a more rational use of primary sources, i.e. natural mineral deposits (in case of mineral raw materials) is secured.

Contemporary waste management concepts are based on a hierarchy in which every form of recycling is preferred, with the aim of disposing of as little waste as possible. Increased recycling brings many benefits, such as: reducing primary raw material needs, re-using valuable materials instead of turning them into waste, reducing energy consumption and greenhouse gas emissions, as well as other negative environmental impacts.

This paper presents the main strategic guidelines within the European Union related to waste management and mineral resource management. It also gives an overview of the applicability of these strategic goals to Croatian economy, as well as the measures and activities that should be undertaken to achieve them.

Waste management

In general, it can be said that the awareness about the importance of waste and its management underwent frequent changes in the last century. From regarding waste as a civilizational problem, a new paradigm emerged in which waste is considered a resource. In this development, the most significant step towards a new model can be defined by the waste hierarchy as shown in Fig. 1. In this hierarchy prevention refers to measures that are aimed at avoiding the generation of waste or its reduction during production. The new waste management hierarchy prefers re-use and recycling, including composting and energy recovery from waste. Waste disposal is the least desirable option. Despite the fact that the general awareness of the need to change the policy of waste management is present and even officially proclaimed in national policies, there are still large differences in its application. In some EU countries, about 80% of waste is recycled, whereas in other countries large quantities of waste are still landfilled without reuse of raw materials.

EU Member States are required to implement strategic documents related to mineral raw materials and waste management, and the goals and necessary measures are described in the document entitled *“Roadmap to a Resource Efficient Europe”* (EC, 2011). This document states that during the 20th century the consumption of fossil fuels increased by 12 times, whereas the consumption of various natural re-

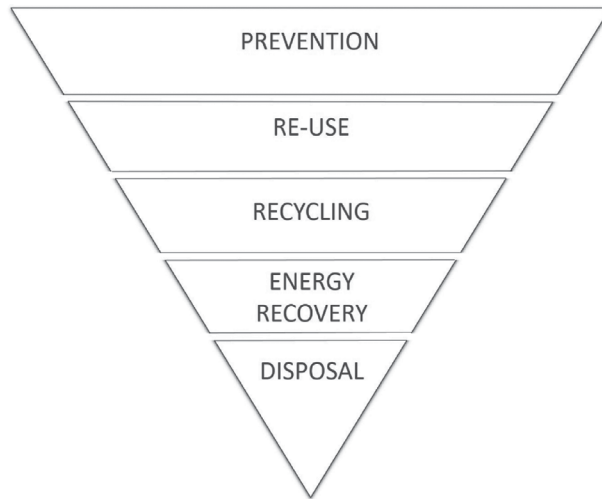


Fig. 1 – Waste hierarchy (EU Directive 2008/98/EC)

sources increased by 34 times. Annually in Europe about 16 tons of materials are spent per person, of which 6 tons are converted into waste, and 3 tons end up in landfills. If such trends persist, natural resources will soon be exhausted, according to some predictions already in the middle of the 21st century. Therefore, efficient resource use is promoted and recommendations are made on how to ensure economic development with the smallest possible use of raw materials from primary sources and least waste production. This document also defines certain goals to be achieved by 2020. Some EU countries are already quite close to achieving these goals, but there are also countries that will need to make significant efforts to reach the same goals within the prescribed deadline.

Today there is a lot of talk about “green economy” and “zero waste societies”. In an ideal situation, all metals/mineral raw materials should be recycled and the rest of the waste subjected to biodegradation processes. In this case the disposal and incineration of waste would be completely excluded (ISWA, 2011). In reality, all forms of waste management (disposal/incineration/recycling) are still present to a greater or lesser extent, as can be clearly presented in the Venn diagram (Figure 2). The least desirable option is represented by the lower left corner of the triangle, representing countries where all or almost all waste is landfilled. The most desirable option is at the top, when all waste is recycled (“zero waste society”). In most countries, there is also the third option of waste incineration, as shown at the right top. Taking into account the ratios of different waste treatments in a given country, the situation in the indicated diagram is shown by a dot within the triangle. If waste management trends are observed over a longer period of time, it is possible to spot the strategic determinants of a particular country, i.e. which course a country is taking to the ideal zero waste society. In general, the vector is usually directed from

the lower left corner to the centre of the diagram, where the current European average is also visible. More advanced countries are already close to the optimum at the top of the triangle. The least desirable option is presented in red in the diagram, representing countries where landfilling waste is still dominant. Yellow represents the so-called transitional countries, where all three waste management options (disposal/ incineration/recycling) are present. The green area is the long-term goal - with emphasis on recycling, energy recovery from waste and depositing minimum quantities of waste. The average EU status is shown by blue dots of the diagram for the period from 1994 to 2014 (Pomberger et al. 2017, Eurostat, 2017). However, some EU countries are still in the least desirable red-marked zone, and a part of them is already in the most desirable green-marked zone, while most of the countries are in the yellow-marked transitional zone. The state of waste management in Croatia is shown according to available data (Eurostat, 2017) with red symbols. It can be noted that waste disposal and recycling are quite equally represented in Croatia, while energy recovery from waste and waste incineration are minimal. The

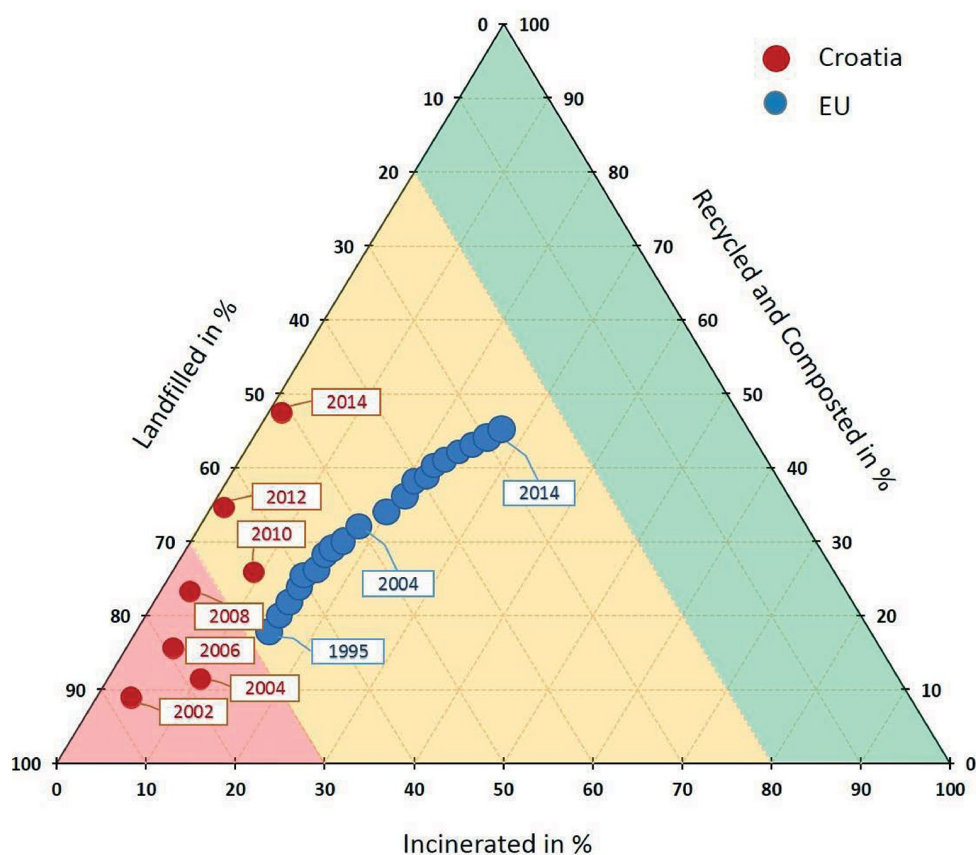


Fig. 2 – Waste management in the EU and in Croatia

mentioned diagram shows that the line of Croatia differs from the European average, since waste is mostly disposed of or recycled, and that incineration and energy recovery from waste are minimal. In the EU much larger quantities of waste are incinerated and recovered for energy. Thus, it follows that Croatia belongs to the countries that have not yet used all the options for recycling/recovery, and that in the future the waste management policy is likely to change and adapt to general trends in the European Union.

Management of mineral raw materials

According to the Mining Act of the Republic of Croatia mineral resources are “all organic and inorganic mineral raw materials found in solid, liquid or gaseous state in original deposits, alluviums, tailing dumps, melting slags, or natural solutions (Official Gazette “Narodne novine”, 2013). Mineral raw materials include: “energy mineral raw materials (hydrocarbons, fossil fuels), mineral raw materials for industrial processing, mineral raw materials for production of construction materials, dimension stone, metal ores (Official Gazette “Narodne novine”, 2013).

Mineral raw material management strategies can be based on primary sources, i.e. the mineral resources of a country, or on secondary sources obtained by recycling. Economic growth is not achievable without mineral resources, so many European countries that have a shortage of mineral resources rely on imports from the global market, in combination with implementing measures for the efficient use and recycling of mineral raw materials.

At world level, the need for mineral raw materials is drastically increasing. In addition, regional share in production is significantly altered. The global trend is that the share of production is continually increasing in Asia, and at the same time decreasing in Europe and North America. This can lead to shortages of certain mineral raw materials (which are difficult to substitute only by recycling) and/or a significant increase in prices. The results of recent surveys on the availability and supply risk of minerals/metals that are important for the economic development of EU countries are shown in Fig. 3. The figure shows that mineral raw materials can be classified into three groups (ISWA, 2011):

1. Mineral raw materials of low economic value and with low supply risk (marked in green). These materials do not have a significant impact on industrial development.

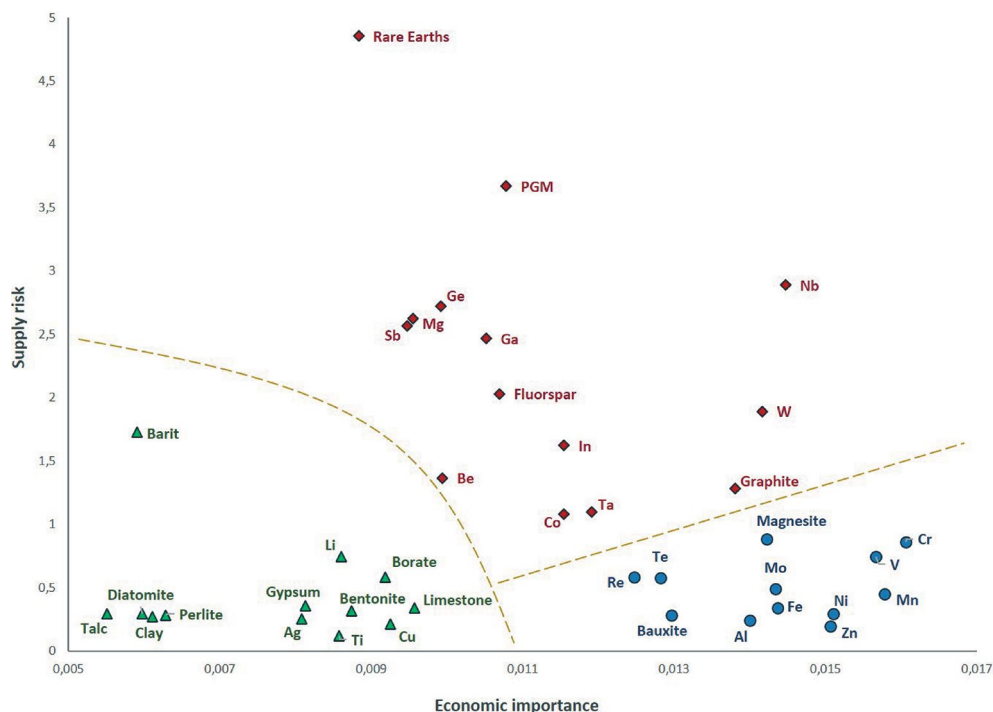


Fig. 3 – Mineral raw materials: economic importance and supply risk (ISWA, 2011)

2. Mineral raw materials of relatively high economic value but with low supply risk (marked in blue). There are mainly sufficient quantities of these materials, or they can be easily replaced with other materials, so that they also have no significant effect on industrial development.
3. Mineral raw materials of high economic value and with high supply risk (marked in red). There are about 14 materials that are considered critical for further industrial development.

Certain mineral raw materials from the last critical group are produced in only a few countries of the world (about 90% of rare earths and antimony, and about 75% of germanium and tungsten are produced in China, about 90% of niobium in Brazil and 77% of platinum in South Africa).

In Croatia mainly hydrocarbons and non-metallic mineral raw materials are exploited (Vrkljan, 2017). These are mainly mineral raw materials for industrial processing, mineral raw materials for production of construction materials and dimension stone (group 1 in Fig. 3). Croatia does not possess any reserves of metal mineral raw materials or raw materials belonging to the group of critical minerals

(groups 2 and 3 in Fig. 3). This also means that for its sustainable development Croatia will lack mineral raw materials, which it will have to acquire on the global market, and at least partially secure from secondary sources by applying the concept of urban mining.

Urban mining

In the past several decades waste management strategies have been based on circular economy principles, replacing the previous linear economy principles. In the traditional approach to the extraction of mineral raw materials from natural deposits, in the exploitation phase mining waste (topsoil, overburden and waste rock) and in the processing phase tailings were created. In this process waste rock was usually inert for the environment, representing a problem mainly due to its large quantity and visual effects on the landscape. Tailings often belong to the category of hazardous waste and pose a threat to all components of the environment.

With the shift to circular economy, and due to the increase in the required quantities of mineral raw materials and the awareness of their limited supply in natural deposits, a completely new concept emerged called urban mining (Cossu et al., 2012a). Urban mining includes activities and technologies developed with the intent to recycle mineral raw materials and energy from so-called anthropogenic sources (products, buildings, landfills). Figure 4 shows the link between classical and urban mining and waste management. Also, Table 1 lists some waste streams (such as electronic waste, end-of-life vehicles, construction waste etc.) and landfill sites in general, useful components present in waste and ways that they can be re-used, as well as certain problems that could arise in the process or need to be solved in the future. Thus for example, quantities of waste of electrical and electronic equipment (WEEE) are constantly increasing, and in that waste stream there are some valuable mineral raw materials (rare-earth elements, precious metals and metals). Some of the mentioned mineral raw materials that can be recycled from WEEE- belong exactly to the group of critical mineral raw materials (see Fig. 3), which are low in supply in natural deposits, are available on a limited number of locations and are difficult to obtain, or are obtainable at very high prices on the global market. Similar conclusions can be drawn for other waste streams shown in Table 1, which suggests that urban mining as a new concept will definitely evolve in the future. This is certainly a major challenge for a large number of professionals involved in solving complex engineering, safety and environmental problems encountered when exploring, extracting and processing useful raw materials from “urban mines”.

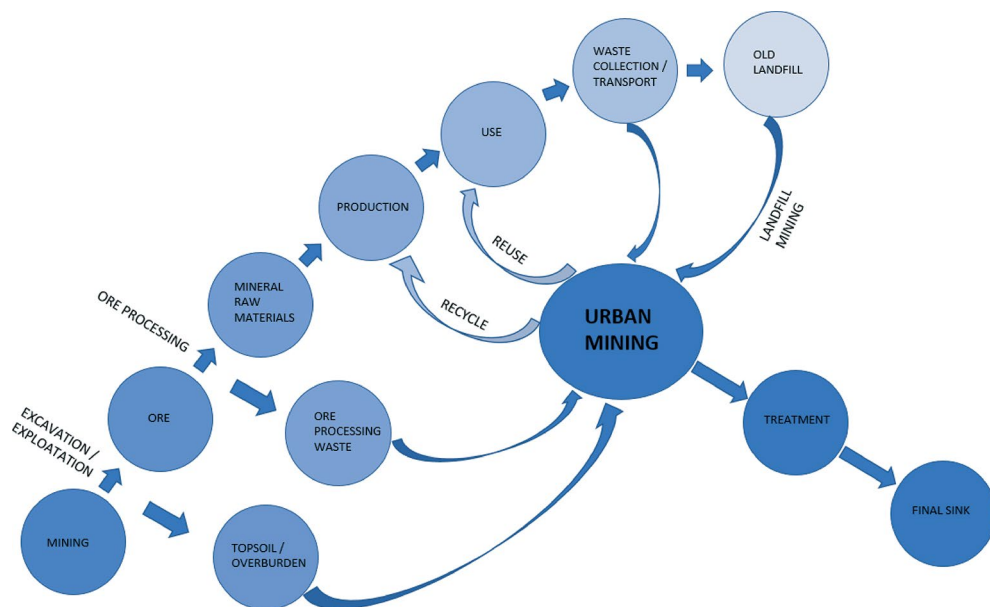


Fig. 4 – Correlation between waste management and mineral raw materials management (Cossu et al. 2012a, ISWA, 2014)

Today the demands for mineral raw materials by far exceed the possibilities of obtaining them from secondary sources i.e. recycling (Serranti et al., 2012). Nonetheless, this fact does not diminish the importance of the further development of recycling technology, since using secondary sources reduces the total quantity of mineral raw materials that need to be obtained from primary sources. The decision on whether it is profitable to recycle a certain raw material or not, or which is the best applicable recycling technology, should be made by applying LCA (Life Cycle Assessment). By such assessment waste management (through waste prevention and reuse/recycling/energy recovery from waste) is directly linked to mineral raw materials management. Certain experience with such a unique approach already exists (Franke et al. 2015). Accordingly, it is necessary to evaluate the available reserves of mineral raw materials (primary sources) at national level and then evaluate the needs and criticality of supply of certain mineral raw materials, depending on industrial development, energy consumption and standard of living of the population, as well as identify and evaluate the availability of secondary raw materials from anthropogenic (secondary) sources. By comparing the available reserves from primary and secondary sources with the needs that provide the desired development of society, conclusions can be reached as to whether the reserves of certain mineral raw materials are sufficient, or whether they will have to be obtained on the global market.

Table 1 – Urban resources for reuse of secondary mineral raw materials (adopted from Cossu et al. 2012a)

Waste stream/ Source of waste	Recovered materials	Products/ Applications	Possible problems
WEEE	Rare-earth elements (samarium, europium, yttrium, gadolinium, dysprosium, etc.)	Cathode ray-tube glass Electronic equipment	Hard to recycle Hazardous metals
	Metals and metalloids (copper, aluminium, iron, steel, lead, cadmium, tellurium)	Electronic equipment Semi-conductors	Implementation problems in the “waste chain” (devices remain in the household even after they are no longer used, there is no organized separate collection, etc.) Incomplete toxicological data
	Precious metals (gold, silver, platinum, palladium, iridium, ruthenium, indium)	Electronic equipment	High energy consumption at recycling Non-metallic and non-combustible slag Emission from thermal processes Economic viability only in large-scale recycling Multicomponent metal mixtures Precious metals are often coated with plastic or ceramic materials, high losses in the recycling process
	Cathode ray-tube glass	Ceramic products (bricks, tiles, stoneware) Lead alloys	Contains heavy metals, hazardous waste, limitations of recycling in the glass industry Requires special technology for separating lead-free and lead glass
End-of-life vehicles (ELV)	Metals (aluminium, copper, brass, iron, zinc)	Metal components, alloys Zinc coatings	Depends to a great extent on the secondary market Difficult recycling of materials
Construction and demolition waste (C&D)	Concrete	Road filling, railway subgrade, concrete production Piles Quartz sand	Regulations, dust and CO ₂ emission (processing and transport)
	Asphalt	Asphalt	Heterogeneous and variable composition
	Bricks	Road filling, railway subgrade, concrete production	

Waste stream/ Source of waste	Recovered materials	Products/ Applications	Possible problems
Combustion residuals	Bottom ashes (inert) Bottom ashes (metals)	Geotechnical materials, aggregates, fillers Concrete Secondary raw materials: titanium, copper, zinc	Limit values in leaching tests A need to improve the technical and environmental characteristics; different properties compared to conventional materials; The impact on the environment associated with the use of ashes; Lack of regulations The need for chemical and eco- toxicological analyses Insufficiently explored
	Fly ash	Preparation of mortar/cement	Seasonal production (heating season) Need for electro dialysis in order to decrease leaching of Ba, Cr, Pb, Zn, Na and Cl
	Slag (industrial incineration)	Filling material Reactive media in wastewater treatment Landfills cover	Potential pollution during the construction phase Insufficiently explored Heavy metals plant uptake
Waste from road sweeping	Inert materials (sand, gravel, fine gravel)	Concrete aggregate	A substantial quantity of water is required for washing/cleaning of the material
Sludge (industrial and sewage sludge)	Phosphorus (wastewater sludge) Inert material (sewage sludge)	Mineral fertilizer Concrete	Contains heavy metals Sludge content decreases compressive strength
Landfills	Ferrous metals	Reuse in metallurgy	
	Fine fraction	Landfill cover	Quality could be questionable due to heavy metals leaching
	Inert materials (non-ferrous metals, glass, stones)	Recycled glass Geotechnical materials, aggregates, filler	Not always in compliance with recycling standards Limit values in leaching tests

Landfill mining

Landfill mining (LFM) stands for the excavation of waste (or its useful components) from old (closed) landfills (ISWA, 2013).

Landfill mining was first introduced in Israel in 1953 as a way to obtain fertilizers for orchards (Krook et al., 2012). In the 1990s, however, it was more intensely used

in the USA, Europe and Asia. LFM was then used for the required expansion of existing landfills and lack of space due to public opposition to the construction of new landfills, as well as the growth of urban areas. The interest in LFM has diminished at the beginning of the 21st century, since the method did not prove successful in obtaining quality and economically viable materials through recycling processes. The method has since been applied in cases related to soil cleaning, urban space demands, and energy recovery from waste or increasing the capacity of existing landfills, i.e. when LFM is linked to additional needs and therefore economically justified at certain locations.

In the near future, landfills could be used for the management of all types of raw materials, including mineral raw materials (ISWA, 2014) in three ways, as follows:

- strategic storage (materials that currently cannot be recycled due to financial or technological reasons; separate disposal of waste components is preferred)
- as mines for secondary resources (of non-recyclable raw materials) and
- as permanent repositories i.e. sink of hazardous substances (if it can be ensured that they do not pose a threat to the environment and human health in the long run).

LFM represents a complex intervention on landfills, consisting of extracting and processing waste through material and energy recovery and/or site redevelopment. The rest of the waste that cannot be recycled is again disposed of in a controlled manner (Cossu and Raga, 2012b). Usually, such activities are carried out for one of the following reasons:

- Recovery of resources - for example recycling of metals or plastic, energy recovery from waste
- Recovery of the landfill volume through recycling and extending the lifetime of the landfill
- Remediation of contaminated sites of old landfills through excavation and processing of waste
- Reclamation of land enabling site redevelopment.

On the other hand, LFM is also associated with potential technical problems if the old landfills contain large amounts of biodegradable waste or high levels of leachate. In such circumstances, the use of mechanization and digging can be very difficult due to the mechanical instability of wet waste and the potential emissions of biogas components (some of which are hazardous, flammable or explosive, such as methane). It is clear, therefore, that the decision to launch mining activities on landfills will depend on a detailed analysis of economic, social and environmental impacts.

As already mentioned, LFM is a complex engineering procedure that encompasses the following phases:

- Preliminary works
- Waste extraction
- Waste processing
- Site remediation
- Site redevelopment.

In the preliminary phase, in addition to the usual activities of preparation and investigation, it is possible to find hazardous substances in the waste, which can jeopardize the initiation of further processes, or cause further increase in price of waste processing. After extraction, waste must be processed in accordance with the end user's requirements, or in case of energy recovery from waste, it must be prepared by grinding, removal of metal, drying and the like. In the final stage and depending on the future use of the landfill area, investigations are carried out on the site and air, soil and water quality is analysed in order to plan appropriate remediation and site redevelopment.

Based on the above, it can be concluded that these projects require detailed preparation and implementation of various preliminary works for the purpose of determining:

- the morphological and structural characteristics of the landfill
- the composition of disposed waste and the fractions that can be extracted
- biogas and leachate properties
- measures required to protect workers' health and safety
- technical requirements regarding excavation and separation of waste components
- economic justification of the procedure.

Landfills contain numerous materials that can become secondary raw materials. A number of factors affect the composition of waste in a given landfill, primarily the way waste collection is organized. One way is to separate waste into recyclable components (e.g. paper, aluminium cans, iron and steel, glass, plastic packaging) when collecting waste and put them into separate containers. Another way is to separate "wet" waste (organic waste, waste from green spaces etc.) from "dry" waste (all "non-compostable" waste). Municipal waste can be collected without separation (called mixed waste). The composition of waste is also dependent on demographic indicators, habits of the population, economic activities and many other indicators, so it is clear that the composition of waste will vary from site to site. Taking into account the demands of secondary raw material customers (quality of secondary raw materials), it is also obvious that there is no "universal" waste processing procedure. The technological waste processing scheme may vary to a

certain extent depending on the above-mentioned specifics and the required quality of secondary raw materials. Despite the mentioned differences and due to the cited factors, in waste processing almost identical methods are used as in mining: crushing, grinding, screening, separation (magnetic, gravity, dense medium separation, etc.). The three main processes - crushing, screening and separation - are carried out in the stated order (Figure 5), regardless of the type of waste.

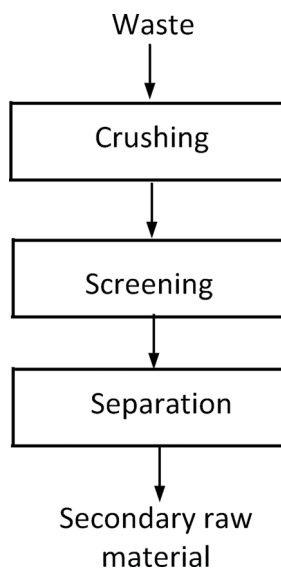


Fig. 5 – Waste processing

In the grinding process from larger pieces of waste smaller pieces are formed, whereby the bond between the various types of material is broken, i.e. there is a release of one from the other (liberation is achieved). Achieving an appropriate degree of liberation is crucial for later successful separation. Crushing is carried out in various types of crushers (jaw crusher, impact crusher, hammer crusher, crushing rolls, blade crusher etc.), which are selected depending on the characteristics of the waste to be crushed.

After crushing screening is carried out, i.e. grain groups of approximately the same size are separated (so called “classes”), whereby the grain size must be adjusted to the separator, in which separation is then performed. Waste classification is usually carried out by sieving, using different types of screens (vibrating screen, trommel screen, gyratory screen, flip flop screen etc.); the process may be “dry” or “wet” (with addition of water), depending on waste characteristics. Sometimes the crusher and the screen work in a closed circle, i.e. the material is cyclically crushed and sieved until it is small enough to be accepted by a particular separator. In this re-

spect, crushing and screening are preparatory procedures for the separation process, since it is impossible to carry out the separation without liberation, while screening (sieving) ensures the grain size at which the separation will be effective.

The third procedure that is used to obtain secondary raw material from waste processing is separation. There are several different separation methods, and which one (or more) of them will be used depends on the characteristics of the waste to be processed. In order to achieve separation, there must be a difference in some of the physical properties on which a particular separation method is based. One of the methods is gravitational concentration based on the difference in the density of individual waste components to be separated and it may be carried out in water or air as a medium. If it is carried out in a heavy medium, then it is called dense medium separation (DMS). These types of separation can be carried out for separating any type of waste in which there is a sufficient difference in density, and whether this difference is sufficient is determined by the concentration criterion. Magnetic separation separates materials based on the difference in magneticity (magnetic permeability and magnetic susceptibility) and is used to extract iron and steel from waste. In waste recycling eddy current separation is also used relatively often, to separate non-ferrous metals (mainly aluminium). Electrostatic separation uses the force of electric fields and separates conductors from non-conductors based on the differences in electrical conductivity. Froth flotation is based on the difference in surface properties (different wettability of surface material) and it separates materials into hydrophobic and hydrophilic, where surface features can be influenced by adding flotation reagents. Optical sorting is used to separate waste based on visual differences (e.g. colour, shine). The hand picking should also be mentioned, which is commonly used as a control method after mechanical sorting, which is not fully effective.

The assessment of cost effectiveness of LFM is also a complex task, where in addition to economic indicators all environmental indicators need to be considered. Initial investment in extensive research, excavation and processing of waste must be correlated with the assessment of the possibility of remediation and conversion of the landfill site, as well as potential long-term earnings. At the same time, it is necessary to reconcile the demands of different professions and regulations in the field of mining, construction, environmental protection etc.

In conclusion, LFM is a new concept that has been carried out on a limited number of locations. At this point in time it is impossible to claim that it can be successfully applied to each landfill and at any location. To facilitate the usage of raw materials from landfills, further research is required, which today is mainly focused on defining the methods for selecting the most appropriate old landfills potentially usable for LFM, developing innovative recycling solutions, applying LCA etc. Should urban and landfill mining prove to be cost-effective, safe and environ-

ment-friendly activities that will provide diverse resources needed for the development of society, after the intensive research phase the implementation phase will follow, which will require intensive co-operation between different sectors and stakeholders, and the adaptation of regulations.

Conclusion

In developed societies today, there are more and more discussions about sustainable development, protection of natural resources, circular economy, ecological design, ecological printing, zero-waste society etc. Such modern endeavours and concepts are in line with the concept of urban and landfill mining. The reason for such a paradigm shift lies in the increased awareness of the growing need for space, energy and raw materials, some of which, such as mineral raw materials, are non-renewable. This also leads to the need to link strategic documents in the field of raw material management and waste management. Croatia has limited quantities of some mineral raw materials, but also lacks some of them (e.g. metals and so-called critical minerals), that are necessary for the development of advanced technologies. For this reason, Croatia belongs to the group of countries that can obtain these mineral raw materials either on the global market or from secondary sources, where this potential is yet to be assessed.

For the sustainable development of societies and sustainable resource management, different interests and demands have to be harmonized. Apart from the necessary development of new technologies in the field of engineering, economic, political, ethical, social and environmental aspects must be taken into account in order to ensure the safe and cost-effective introduction of urban and landfill mining into strategic documents. This also opens up opportunities for cooperation between a large number of professions, as well as for developmental research and innovation. In such world-wide trends Croatia should also get involved.

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