Mining Waste Management in the Baltic Sea Region. Min-Novation project

Editor: Marek Cała

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1. Introduction

Mining waste and what to do about it is a common challenge facing companies, local authorities, environmental organizations, policymakers and increasingly other stakeholders in several countries of the Baltic Sea Region. From 2011 to 2013, a network of scientific and regional expertise brought together in the Min-Novation project has put this topic in the spotlight.

The importance of the management of waste from extractive industries is due to the substantial share this waste has in the overall stream of waste generated in the EU. In 2010, **672 Mt or 28.3% of the total waste generated in the EU was attributable to the mining and quarrying industry**, second only to construction (34.4%) and ahead of manufacturing (11.0%) and households (8.7%)[1]. Apart from this, mining waste is the raw material for one of the more visible man-made landmarks that surround us, with waste heaps of various shapes and sizes dotting the landscape up and down the Baltic Sea Region. Despite this dual prominence, mining waste is most often seen only as an environmental problem and in no way a resource. To move away from a one-sided view of mining waste, a life-cycle approach, which recognises that value can be recovered from waste and re-introduced into the product cycle is of the essence. It cannot be stressed enough that mining waste is a source of secondary raw materials, the use of which helps to protect the natural mineral deposits for future generations. Equally important is an appreciation of how the waste can be re-cycled in the excavation process (prevention

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[1] http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Waste_statistics, accessed 12 October 2013.

and recovery) and adapted to create value for local communities (reclamation and revitalisation).

However, for there to be effective mining waste management, both in the prevention stage, as well as in the recovery stage, and finally during land reclamation many conditions must be fulfilled. Of these the most important are access to appropriate technologies and methods and common sense legislation. Another condition not without importance is social acceptance for the recovery of waste located in old landfills.

The Min-Novation Network over a span of 3 years has worked to understand and appreciate mining waste both as a corporate, community, regulatory and strategic issue. Set against the background of mining activity and waste management in the partner countries: Estonia, Finland, Germany, Norway, Poland and Sweden, both good practices and problem areas, which need to be addressed have been presented in this monograph.

The purpose of this monograph is to show a cross-section of topics that affect how mining waste management works today, and which will play a decisive role in whether management of mining waste remains – an issue of primarily local relevance or whether it becomes a growth opportunity of national and EU-wide importance. The monograph focuses primarily on issues related to the management of waste from extractive industries in the countries whose representatives were involved in the Min-Novation project. Examples from outside the Baltic Sea Region of the use of waste heaps as an industrial heritage of the mining regions and also as attractions for local communities are presented as well. Indeed, every experience is valuable for the environment and socio-economic development of the Baltic Sea Region.

2. About the Min-Novation project

2.1. Origin

The main theme of project Min-Novation, which stands for the Mining and Mineral Processing Waste Management Innovation Network, was the management of mining and mineral processing waste (www.min-novation.eu). The idea for it was a direct spin-off from the Interreg IIIC project – The European Network of Mining Regions (ENMR). ENMR was carried out in the years 2005–2007. It formulated an interregional and cross-sector strategy on mining and its contribution to regional sustainability. One of its recommendations for future actions was to develop mechanisms for supporting growth of businesses throughout the mining lifecycle. Another was to develop and implement regional action plans on the issues of waste management and remediation. Min-Novation contributes to the EU Strategy for the Baltic Sea Region (BSR) by exploiting the potential of the region in research and innovation.

2.2. Assumptions

Each region represented in Min-Novation has a long history of mining, including present-day operating sites. Each region also faces key development questions when it comes to the future of mining and the role of sustainability in this context. The spectrum of issues addressed in the project covers rare earth metals through coal and oil shale all the way to oil.

The project's key phrase: waste management is understood to mean the process for handling waste in accordance with procedures described in the relevant laws, which covers:

- Prevention of waste generation.
- Minimization of the amount of waste produced.
- Waste recovery.
- Disposal of waste, including minimization of environmental impacts.
- Reclamation of waste site and remediation of polluted environments.

This broad approach to waste management is a reflection of the diversity of mining environments and mining community histories, which are represented in Min-Novation.

2.3. Objectives

The main idea of Min-Novation has been to empower stakeholders to get involved in topics of relevance to mining and mineral processing waste management, including the legal framework of mining waste management, the policy incentives (or disincentives) for waste management operations and the technological and scientific knowledge, which advances greater reuse/recycling/recovery/reclamation. In connection with this, the project created a trans-national network (the Min-Novation Baltic Network) that brings together universities and other research institutions with regional business development agencies.

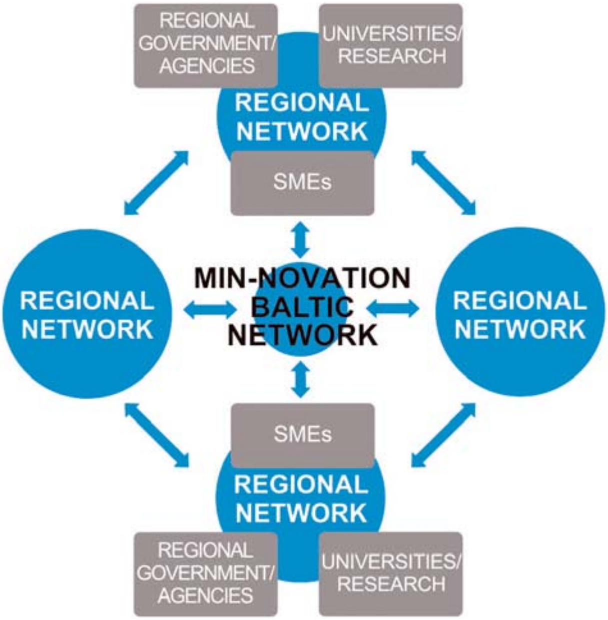
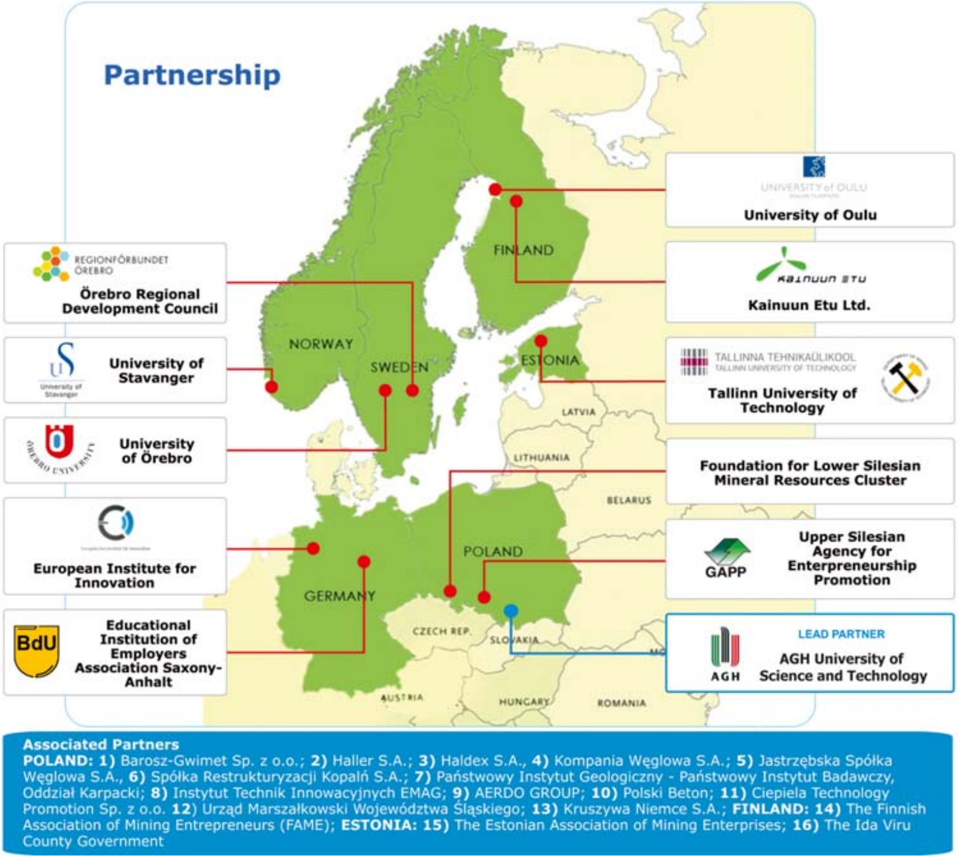


Figure 2.1. Min-Novations' networks

Small and medium enterprises have been the target stakeholder group to help increase the pace and volume of mining and mineral processing waste management innovation coming out of academic and research institutions into the private sector – especially small and medium sized enterprises (SMEs) (Figure 2.1).

2.4. Partnership

11 core partner organizations, which represented 5EU countries and Norway, and who included both local and regional businesses and innovation sources, participated in the project (Figure 2.2). The lead partner was AGH University of Science and Technology – Faculty of Mining and Geoengineering. Associated partners representing mining industry stakeholder associations and regional government bodies also took an active part in the project.



Associated Partners
POLAND: 1) Barosz-Gwimet Sp. z o.o.; **2)** Haller S.A.; **3)** Haldex S.A., **4)** Kompania Węglowa S.A.; **5)** Jastrzębska Spółka Węglowa S.A., **6)** Spółka Restrukturyzacji Kopalń S.A.; **7)** Państwowy Instytut Geologiczny - Państwowy Instytut Badawczy, Oddział Karpacki; **8)** Instytut Technik Innowacyjnych EMAG; **9)** AERDO GROUP; **10)** Polski Beton; **11)** Ciepiela Technology Promotion Sp. z o.o. **12)** Urząd Marszałkowski Województwa Śląskiego; **13)** Kruszywa Niemce S.A.; **FINLAND: 14)** The Finnish Association of Mining Entrepreneurs (FAME); **ESTONIA: 15)** The Estonian Association of Mining Enterprises; **16)** The Ida Viru County Government

Figure 2.2. Min-Novation Partners map

The Partnership met regularly at Min-Novation Baltic Network meetings to discuss important issues of consortium-wide relevance. The individual regions represented in the project organised Min-Novation regional network meetings.

3. Min-Novation project outputs

3.1. Introduction

The main outputs of the project have all been geared toward raising the level of awareness and knowledge about mining waste management and creating opportunities for stakeholders to voice their opinions and interact with government authorities on important topics that define how mining waste is dealt with in each region. The particular outputs described in this chapter are all related to the awareness raising and knowledge building efforts launched as part of Min-Novation, namely: the Baltic Mining Waste Management Business Database, the Compendium & State-of-the-Art and four pilot investments.

3.2. Baltic Mining Waste Management Business Database

The Baltic Mining Waste Management Business Database (the Baltic Business Database) was established to include small, medium as well as large companies that are active in the mining industry and mining waste management in the Baltic Sea Region. The Baltic Mining Waste Management Business Database provides insight into regional specificities and cross-regional similarities and gives a much better idea of the size of this segment of the mining sector.

The Baltic Mining Waste Management Business Database contains the following categories:

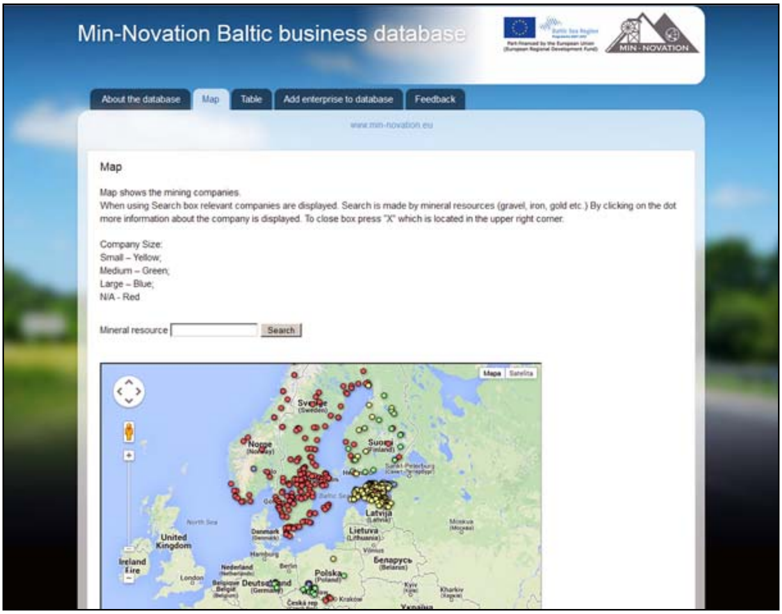
- Company – the name of the organization.
- Mineral resource – what mineral resource the company is allowed to mine.
- Field of activity – a short description of the organisation's main line of activity.
- Website – the organisation's website address.
- Country – where the organisation is located.
- Keywords – short words identifying the organisation's scope of activities.
- Year of operating – the year the organisation was established.
- Name – the full name of the contact person from the organization.
- Function in Company – the position of the contact person.
- E-mail, Telephone, Fax – contact details for the contact person.
- MRN membership – whether the organisation is a member of the Min-Novation Regional Network.
- Street, Index, City – is the address of the organisation's head office.
- Full address – for geocoding purposes.
- Company size – the size of the company in line with the European Commission.
- Recommendation of 6 May 2003 concerning the definition of micro, small and medium-sized enterprises.

The Baltic Mining Waste Management Business Database lists active enterprises in the mining sector. In addition to mining companies there are enterprises, which deal with mining waste, specialize in developing machinery to support waste management activities or provide R&D support to the mining industry. A total of 556 (as of 19 September 2013) enterprises are listed in the database. The database can be found free of charge at: www.min-novation.eu and http://mi.ttu.ee/db/. The data is presented in the form of a table and on a map. The database is searchable (Figure 3.1 and 3.2). It is possible to create own queries, graphs and maps online. The collecting of enterprise information has been carried out on two levels:

1) organisations that are based in the regions represented in the Min-Novation project;
2) organisations that are active outside these regions but within the Min-Novation partner countries.

Enterprises are welcome to provide their business details online for inclusion in the Baltic Mining Waste Management Business Database.

From looking at the statistics, we can see that the database includes enterprises from all project partner countries (Figure 3.3) and 9.4% of all (556) enterprises have participated in Min-Novation regional meetings.

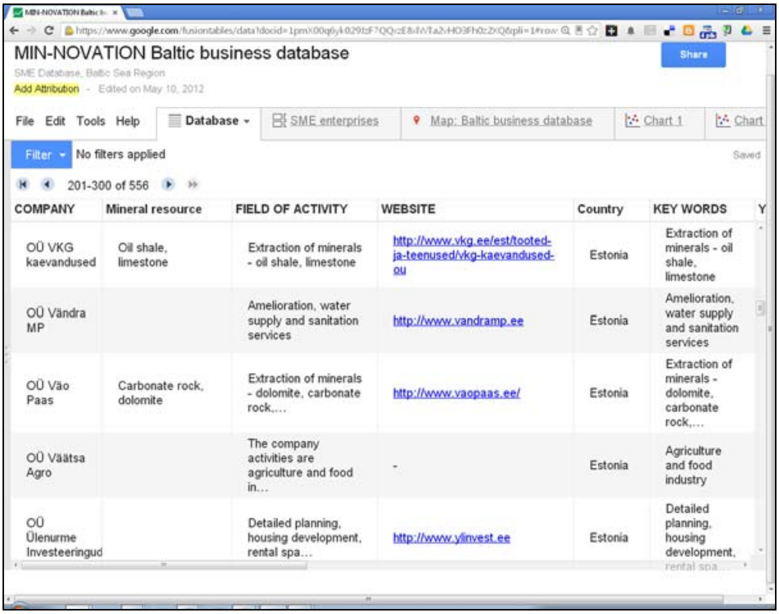


Map

Map shows the mining companies.
When using Search box relevant companies are displayed. Search is made by mineral resources (gravel, iron, gold etc.) By clicking on the dot more information about the company is displayed. To close box press "X" which is located in the upper right corner.

Company Size:
Small – Yellow;
Medium – Green;
Large – Blue;
N/A - Red

Figure 3.1. Examples of mining companies and locations
Source: www.min-novation.eu



MIN-NOVATION Baltic business database

SME Database, Baltic Sea Region
Add Attribution - Edited on May 10, 2012

No filters applied

201-300 of 556

COMPANY	Mineral resource	FIELD OF ACTIVITY	WEBSITE	Country	KEY WORDS
OÜ VKG kaevandused	Oil shale, limestone	Extraction of minerals - oil shale, limestone	http://www.vkg.ee/est/tooted-ja-teenused/vkg-kaevandused-ou	Estonia	Extraction of minerals - oil shale, limestone
OÜ Vändra MP		Amelioration, water supply and sanitation services	http://www.vandramp.ee	Estonia	Amelioration, water supply and sanitation services
OÜ Väo Paas	Carbonate rock, dolomite	Extraction of minerals - dolomite, carbonate rock,...	http://www.vaopaas.ee/	Estonia	Extraction of minerals - dolomite, carbonate rock,...
OÜ Väätsa Agro		The company activities are agriculture and food in...	-	Estonia	Agriculture and food industry
OÜ Ülenurme Investeeringud		Detailed planning, housing development, rental spa...	http://www.ylinvest.ee	Estonia	Detailed planning, housing development, rental spa...

Figure 3.2. Min-Novation Baltic Mining Waste Management Business Database
Source: www.min-novation.eu

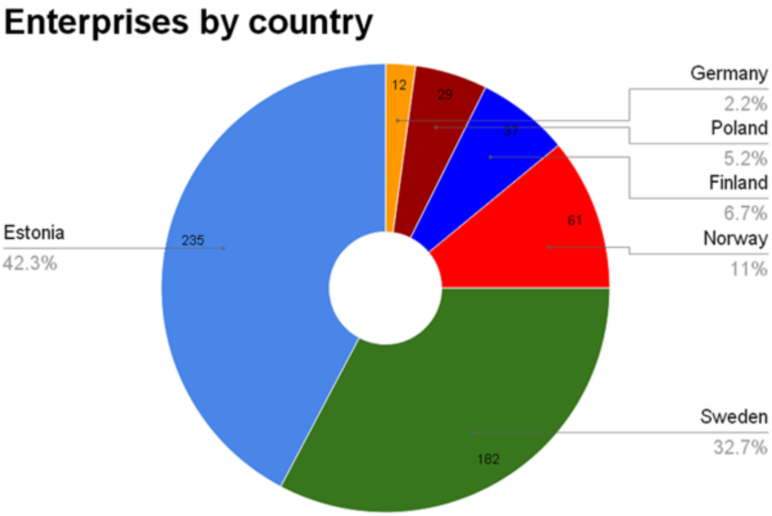


Figure 3.3. Database statistics

3.3. Compendium & State-of-the-Art of mining waste management technologies

The Compendium & State-of-the-Art seeks to bring together the current state of knowledge about management approaches and technologies. It contains current practice as well as approaches, which have been tested on a laboratory scale, while also introducing up-and-coming technologies (Bäckström et al. 2013).

The subject matter is very extensive, and reflects the diversity of mining waste management traditions and practices across time and place. The Swedish and Finnish case studies concern current and historical base metal mining waste; the Polish and German examples emphasize developments in coal and copper mining; the overview of Norwegian experiences focus on oil cuttings; while the Estonian case studies draw exclusively on that country's experience in limestone and oil shale waste rock management.

The State-of-the-Art report focuses on different mining wastes. **Waste prevention (minimization)** as a primary focus is described first, followed by different methods for waste recovery and finally approaches to **land reclamation**. What follows is a summary of the key processes and technologies for each of these management approaches.

Prevention is the first stage in the mining waste management hierarchy. This stage also includes waste **minimization**, which is the most cost effective way to handle the problems with mining waste. In the Compendium & State-of-the-Art presented case studies concern waste minimization underground, which include examples from Sweden, Poland and Estonia (Figure 3.4).

Recovery and **recycling** of elements and other useful materials from the mining wastes are becoming increasingly important from a societal, industry and environmental point of view. One of the best economic and environmental benefits of secondary raw material production is that it usually requires less energy to produce a specific quantity of raw materials. For example producing steel from primary ore consumes 3.5 times more energy as compared to the production of melted scrap; similarly copper needs 5 to 7 times more energy and for aluminum 20 times more energy is consumed.

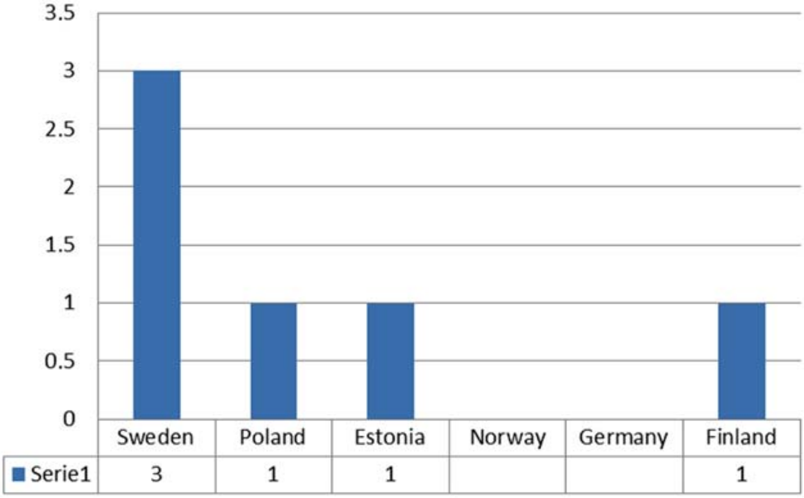


Figure 3.4. Number of cases in the Compendium & State-of-the-Art concerning waste minimization

Mining waste, especially waste rock, often has similar properties to rock used for aggregates. This means that portions of the generated waste rock can be substituted for rock from natural deposits. It is important to note that only waste rock with low concentrations of trace elements or other contaminants should be used. Also coal spoils have several usages as construction materials.

Historical tailing deposits and rock dumps may, in some cases, due to the less advanced techniques at that time, contain considerable amounts of certain valuable metals. The grades in these mine waste deposits might in some cases be high enough for economic metal recovery with today's technology.

Up-and-coming technologies, which are currently under development or not commercially available are also described. One of them is applied in the processing of iron oxides in mining waste from the abandoned Ljusnarsberg copper mine, Kopparberg, Sweden, which are recovered and used as a red pigment in outdoor red paint by a local company. The in-house developed method uses a dry process and has resources and capacity to become a major supplier on the Swedish and maybe European market.

Several case studies regarding waste recovery can be found in the Compendium & State-of-the-Art (Figure 3.5).

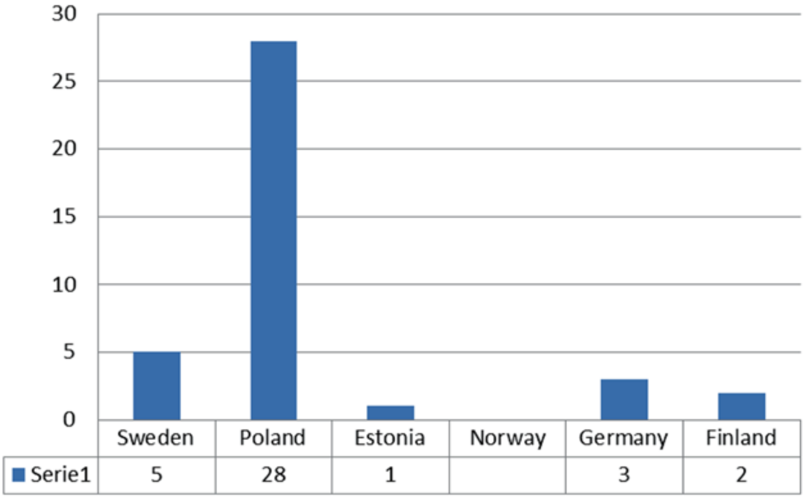


Figure 3.5. Number of cases in the Compendium & State-of-the-Art concerning waste recovery

Mining waste, depending on waste characteristics can affect the environment in different ways (acidification, toxicity to aquatic organisms etc.). In cases where it is not possible to reduce waste or recover it from waste heaps, land affected by mining activities is subject to **reclamation**. Mining waste varies considerably in chemical composition and physical properties. The finely ground material generated in the enrichment process is called tailings. Metal sulphides are stable in reducing environments and tailings generated in modern day processes (20th century) are therefore generally stored by being covered with water in order to minimize contact with oxygen. Generally, historical mine waste (waste rock and tailings) contains higher concentrations of metals than modern mine waste and is often more oxidized. Waste rock produced in operating mines contains low metal concentrations and can often be used for backfilling.

This section of the Compendium & State-of-the-Art illustrates several ways to handle the problems related to mining waste, both from a theoretical as well as a practical point of view.

It has for instance been shown how waste materials from other parts of the society can be used for mining waste reclamation. Alkaline materials can be tilled down or injected in a pile containing sulphidic mine waste. This will reduce the pyrite oxidation, neutralize the acid produced and immobilize metals (through sorption and/or precipitation) before it discharges. Also, reductive dissolution of secondary iron(oxy)hydroxides and iron(III) mediated weathering of pyrite can be avoided. Mixing can either be made by injection or by using heavy machinery. Injecting the material as a slurry may have the advantage that the landscape is preserved if this is desired.

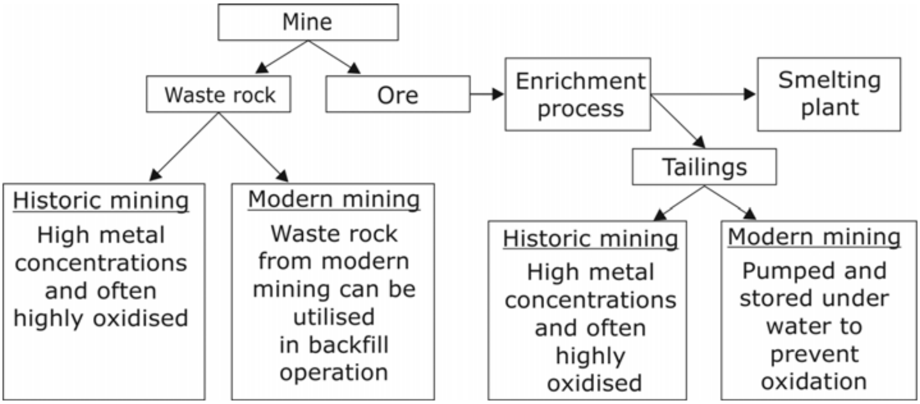


Figure 3.6. Principal mining schedule. Mainly two waste products are generated from mining activities: waste rock and tailings

Source: Sartz 2010

Stabilization experiments demonstrate the long-term changes (both chemical and hydraulic) taking place when a weathered and acidic historical mine waste is mixed with an alkaline material. Acid that is present and generated in the mine waste is neutralized, and trace metals are largely immobilized.

Many projects have focused on treating the source, e.g. the drainage prior to discharge, by means of covers and amendments to the waste. Another common approach is to treat the discharge by means of reactive barriers and filters.

Flooding of oxidized tailings/waste rock can lead to release of metals and acidity to overlying water. Addition of alkaline amendment before flooding could prevent this process. A remediation "tool-box", adaptable to different sites, is essential and needed for the choice of an efficient remediation strategy for historical mine sites due to the heterogenic character of these sites.

Several case studies from different countries are presented as well (Figure 3.7).

The Compendium & State-of-the-Art is a separate online publication, which is available free of charge on the Min-Novation project website www.min-novation.eu.

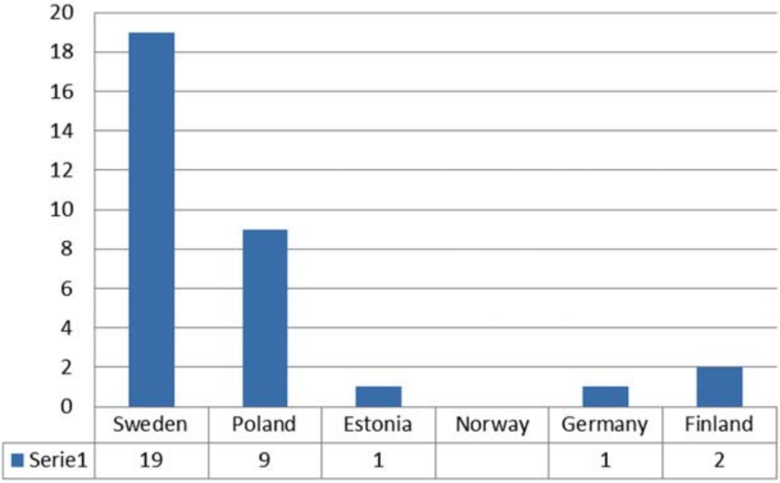


Figure 3.7. Number of cases in the Compendium & State-of-the-Art concerning reclamation

3.4. Pilot installations

The Min-Novation pilot installations were designed and set up to act as the testing grounds for creating value from mining and processing waste. Their role, during and beyond this project, is to provide the mining community but also the general public an opportunity to see waste management in action. The installations are thus an investment in industry support for and public education about the effective use and reuse of mining waste resources. There are a total of four pilot installations in place – in Estonia, Finland, Poland and Sweden – which taken together cover practically the entire spectrum of mining waste streams and build the potential for recovering value from secondary raw material feeds.

3.4.1. Estonia – Oil Shale Waste-to-Product Mobile Unit

The pilot investment in Estonia is located on the campus of the Tallinn University of Technology. It is operated by the University's Department of Mining. It is a mobile unit for producing aggregates from oil shale waste and other waste materials.

The installation consists of crushing, sieving and separation units (Figure 3.8). The input to the installation is waste rock with a grain size of up to 150 mm. The pilot installation consists of mini wheel-loader equipped with crushing bucket to crush material down to <40 mm (loading capacity 0.5 m^3, capacity 2–4 m^3/h; Figure 3.9), dry sieving unit with a set of 5 sieves (supplemented by drying oven), and separation unit for crushed oil shale waste rock, which uses a process of wet gravity separation. Inputs into the unit have to be of a certain aggregate class namely: 4–8 mm, 8–16 mm, 16–31.5 mm or

31.5–40 mm. The result of separation will be these aggregate classes along with lighter oil shale grains and heavier limestone grains. Photo analysis software for granulation analysis is also a part of the installation.

This mobile plant can be transported to different locations to process various mining and processing wastes. The installation is primarily designed to test oil shale waste rock (a mixture of oil shale and limestone), to extract oil shale for oil or electricity production, and limestone rock for aggregate production or backfilling. In such case, the difference in compressive strength between the oil shale (compressive strength 20–40 MPa) and limestone (compressive strength 40–80 MPa) is applied. Thus, the finer fraction is enriched in oil shale, while the coarser fraction in limestone. Moreover, the fine fraction is treated in the gravity separation unit for oil shale fines to increase oil shale content. This material can find use as fuel. The total expected recovery of the two products – oil shale and limestone aggregate – amounts to approx. 90%. The capacity of the installation can be as much as several t/a.

The installation allows one to test various mining and processing wastes, also from other countries. After the end of the Min-Novation project, the investment will be used in research related to the utilisation of various mining and processing wastes. The installation will be run for demonstration purposes during students' field classes (Galos et al. 2013).

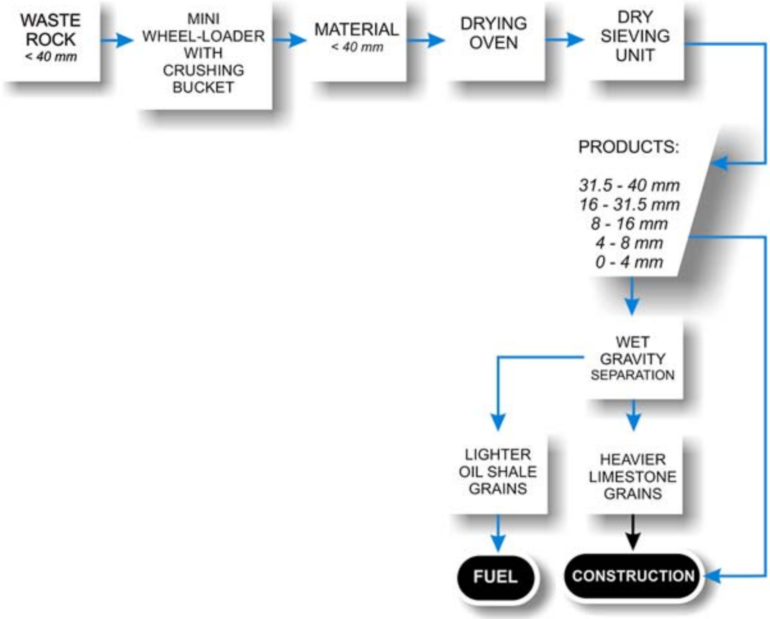


Figure 3.8. Scheme of mobile installation in the Tallinn University of Technology

Figure 3.9. Mini wheel-loader equipped with crushing bucket
Photo: Tallinn University of Technology

3.4.2. Finland – Mining Waste and Process Side Stream Assessment Lab

The Finnish pilot unit: the analytical laboratory of Kainuun Etu Ltd is located at the University of Applied Sciences KAMK campus in Kajaani. The pilot unit of Kainuun Etu Ltd & Min-Novation is part of a larger joint laboratory environment, having effectively been merged with the Kajaani University of Applied Sciences' mineral technology laboratory (Figure 3.10).

The KAMK mineral technology laboratory has been purchased for educational purposes by the Kajaani University of Applied Sciences. It consists of equipment for crushing, grinding, screening, sieving as well as for filtering, fine grading and flotation. The laboratory is a partially mobile installation housed in a container, which can be transported to other locations for environmental research on various mining and processing wastes. Likewise, if necessary, the portable elements of the sample preparation unit may be transferred to various mine sites along with the KAMK mobile laboratory for short periods of time. Mining and other process industry waste samples may be crushed, milled and then dry sieved to fractions between 8 mm and 32 μm in the mineral technology laboratory. Also wet and air classification is possible.

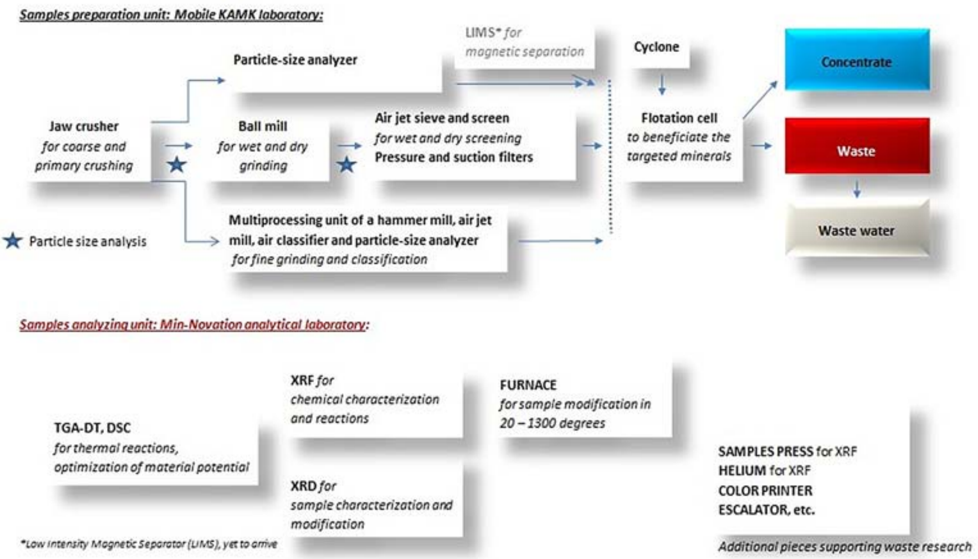


Figure 3.10. Composition of the Min-Novation & KAMK joint laboratory environment
Source: Kainuun Etu Ltd

The Min-Novation pilot investment includes the following analytical components that supplement the line of equipment of the mobile laboratory unit:

1. TGA-DTA-DSC analyzer (Thermogravimetry Analysis – Differential Thermal Analysis – Differential Scanning Calorimetry) for measurements of thermodynamic reactions of various waste materials – a capacity of 3 test runs per shift.
2. XRF (X-ray fluorescence) (Figure 3.11) MiniPal4 spectrometer for chemical characterization of the waste samples – capacity usually approx. 20 minutes per position (with max 12 positions per test run).
3. XRD (X-ray powder diffraction) for crystalline phase identification of the waste samples – capacity of 1 test run per shift, which lasts 2–13 hours depending on the intensity sought for a given material.
4. Chamber furnace (heating up to 1300 °C) for thermal treatment and material modification, also for preparation of fused samples for metals analysis – capacity of one heating per shift.
5. Sample press for preparing fine-grained samples into buttons for XRF analysis – duration of sample pressing around 15 min. per sample.

The laboratory environment is operated by Kainuun Etu Ltd in cooperation with University of Oulu and KAMK laboratory staff. The laboratory environment enables assessing chemical composition, mineral composition, thermal properties of various mining and processing wastes, as well as processing slurries and water from mining and processing. Overall, the joint laboratory environment of Min-Novation and KAMK may be used for material classification, characterization and modification of the stone and extractives sector as well as other industries. Expectations are that this may well encourage new product solutions and alternative material uses for mining waste and other industrial side streams. The whole laboratory can also be applied for demonstration purposes during university field classes.

Figure 3.11. X-ray fluorescence
Photo: K. Kanniainen

3.4.3. Poland – Coal-Derived Aggregate Production Line

The Polish pilot investment is located in the Central Laboratory of Blasting Techniques and Explosives in Regulice (near Alwernia – approx. 35 km to the west of Kraków). The laboratory belongs to the Faculty of Mining and Geoengineering of the AGH University of Science and Technology, Kraków. This investment's aim is to obtain crushed aggregates from coal processing wastes, which will be appropriate for road construction and to this end a stationary unit of crushing and screening of material has been designed.

The stationary installation is used for processing of wastes from coal processing plants (fraction size range: 20–150 mm), coming from the gravity beneficiation stage (washer in heavy liquids) of selected hard coal mines in the Upper Silesia region. This material is a mixture of sandstones, mudstones and shales (claystones). It exhibits the following properties: Los Angeles abrasion loss >35%, freeze resistance loss >30%, coal content >12%. The technological line consists of crushing and screening modules and allows one to obtain a 4–31.5 mm mix that can be used as road aggregate (Figure 3.12 and 3.13). Thanks to selective sieving of fine particles, fine-grained material enriched in clay minerals and organic matter is removed. The result is a 4–31.5 mm mix with the following minimal properties: Los Angeles abrasion loss <30%, freeze resistance loss <20%, coal content <8%.

The enrichment is done by means of impact crushing and sieving. Properties of the final product depend on properties of applied coal waste and process parameters. During impact crushing, weak rocks (shale, claystone, mudstone with coal particles) are shredded more intensively and then – largely – turned into fine fractions <4 mm. As a consequence, the coal content in a 4–31.5 mm product is diminished by min. 30–40% in comparison to its initial content in the original 20–150 mm coal processing wastes. In effect, there is a higher share of hard grains in the 4–31.5 mm product and some improvement of the basic physical properties of this aggregate. Oversize fractions (>31.5 mm) are re-cycled back into the crushing unit. The main process parameters are: velocity of impacts in impact crusher and lower mesh sieve size during classification. The aggregate product can be obtained by adjusting these two process parameters.

The pilot installation is located in a former garage, which was adapted for the purposes of the installation. The entire installation is located indoors, while stockpiles for coal processing wastes and for products are located nearby. Coal processing waste 20–150 mm is taken from the stockpile and put by loader into the hopper (3 m^3). From the hopper it is directed by belt conveyor into the impact crusher of the M5 type, which has a capacity of approx. 1.5 t/h. Then it is put through two-deck vibrating screens, with classification of 0–4 mm (fine-grained material), 4–31.5 mm (aggregate product), and >31.5 mm (oversize). The aggregate product 4–31.5 mm and fine-grained material 0–4 mm are put into 1 m^3 containers, the contents of which are periodically unloaded onto the appropriate stockpiles located outside. The entire installation is cleaned by means of a dedusting system, which is an integral part of the pilot installation.

The capacity of the pilot demonstration installation amounts to 0.6–1.5 t/h. The obtained aggregate product – 4–31.5 mm (or – alternatively – 4–16 mm) – should be of utility as the base material for certain layers of road construction, as well as for engineering works (e.g. embankments, dams). The recovery of aggregate product amounts to 50–70% (depending on type of waste used), while fine-grained material with a grain size of 0–4 mm constitutes the remaining 30–50%. This material is enriched in coal substance, so potentially it can be treated as fuel of low calorific value.

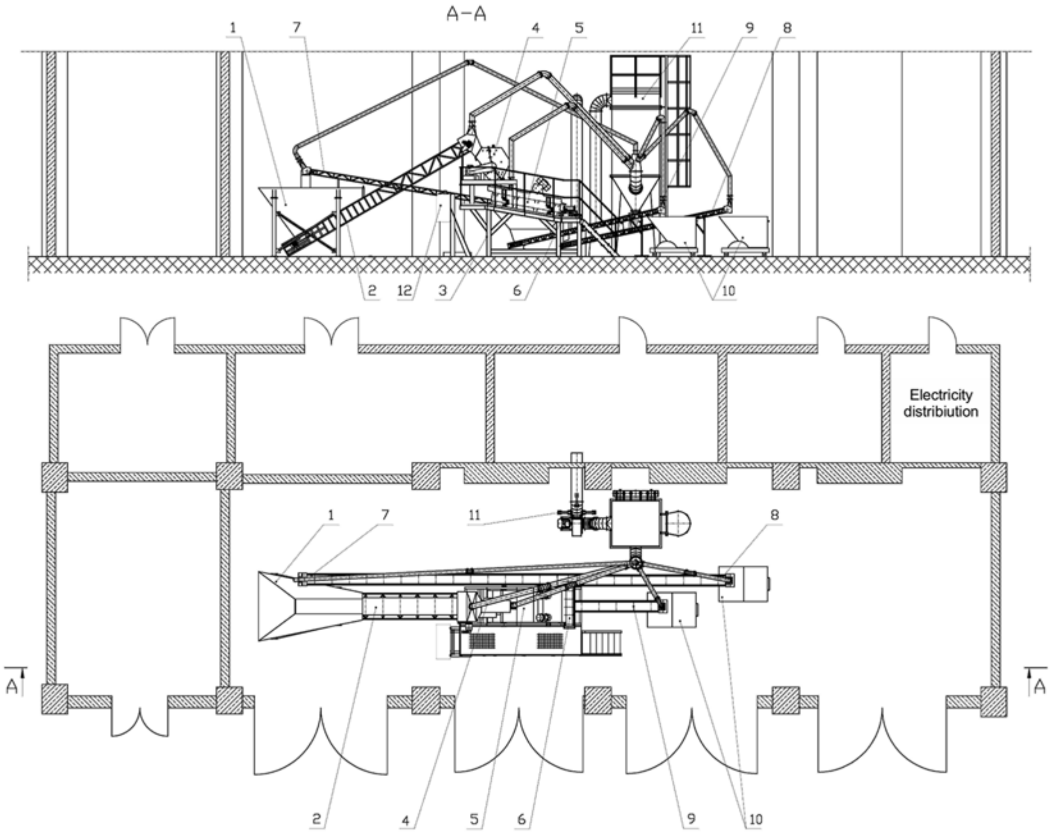


Figure 3.12. Schematic of installation for processing of wastes from coal processing plant:
1 – wastes charger (hopper); 2 – crusher conveyor; 3 – retaining construction; 4 – impact crusher; 5 – vibrating screens; 6, 7, 8, 9 – belt conveyors; 10 – product containers; 11 – de-dusting system; 12 – control box

Source: ORSTAL JSC

Figure 3.13. Installation for processing of wastes from coal processing plant
Photo: A. Ostręga

The installation allows one to test various coal processing wastes, but possibly also some other mineral processing wastes (e.g. oil shale wastes).

Post-project, the installation will continue as an educational tool for students and researchers alike (Galos et al. 2013).

3.4.4. Sweden – Mobile Metal Recovery Installation

The pilot investment in Sweden is located in Kvarntorp (20 km south of Örebro), at an old alum shale mine. It is a mobile pilot unit for element extraction and recovery, which has been developed by the Man-Technology-Environment Research Centre, Örebro University, Sweden.

The mobile unit covers three stages: 1. crushing/milling, 2. leaching, 3. recovery of elements from solution (Figure 3.14 and 3.15). All three stages are installed in two conventional 20-foot shipping containers, making it very easy to move them using a truck, train or even container shipping vessels. Expected capacity for this pilot plant is only around 100 kg solid waste per hour (mainly due to the capacity of the crushers and the solvent extraction system). The first stage involves a jaw crusher and a disc mill, which are used to comminute the waste down to roughly 0.1 mm in order to increase the surfaces available for the leaching in the following stage. The second stage involves a leaching apparatus designed to leach solid waste using high pressure and different temperatures. The liquid phase (water solution) comes from several nozzles under high pressure (maximum of 25 bars). The nozzles are designed to create the right drop size able to transfer as much energy as possible to the solid material being leached. The solid material is placed on a stainless steel mesh (different mesh sizes available) and is there exposed to a bombardment of distinct droplets. During leaching, the solid material passes through the mesh and ends up in a plastic tub below the mesh. Pressure (up to 25 bar), temperature (between 25–85 °C) and leaching solution (pH 1–14 as well as additions of different complexing agents, especially organic ones), in addition to droplet size and flows, can be varied within the leaching zone. During the third stage, elements are recovered from the solution using liquid/liquid solvent extraction (based on kerosene) and electrochemistry. Electrochemistry is, however, not included in the pilot plant.

Figure 3.14. Scheme of mobile pilot unit for element extraction and recovery
Source: Man-Technology-Environment Research Centre, Örebro University, Sweden

Figure 3.15. Mobile pilot unit for element extraction and recovery
Photo: A. Ostręga

The entire system is untested both with respect to recovery of elements from different solid materials as well as the economics of such operations if carried out at full scale. The installation can test various metal-bearing wastes, including: oxidized sulphide ore wastes (source of e.g. Cu, Zn, Pb), flotation wastes (source of e.g. Cu) or weathered Linz-Donawitz (LD) slag from steel making (source of e.g. Cr, Mo, Ni, V). Recovery from the solid waste is likely to be below 100% since most solid materials are geological in origin and therefore have elements bound within their structure. However, it is expected to be over 50%. It is possible that solid materials with high surface concentrations will be washed/leached to a higher degree. Depending on the composition of the waste, the leached remains may be used for other purposes (if clean enough) or deposited as waste with lower toxicity (washing can turn hazardous waste into less hazardous waste with substantially lowered handling costs). It is possible that the method can also be applied to treat contaminated soils and street sweepings (recognized as hazardous waste).

The method should allow for extraction of elements from solid waste during reclamation, thereby reducing the cost of reclamation either through metal recovery or by reducing the handling cost during deposition.

Post-project, the unit will be used for research into various metal-bearing wastes. The installation will also be applied for demonstration purposes during university field classes and educational outreach events for the general public (Galos et al. 2013).

3.5. Conclusion

All project outputs enriched the knowledge and experience of the project partnership, as well as the potential users and end-users of the outputs. The outputs such as a Business Database and Compendium & State-of-the-Art will be updated and expanded. However the pilot investments will be expanded to include new elements and will be used for research and educational purpsoes. After the launching of all pilot installations, follow-up activities have started. Non-investment follow-up activities have concentrated on testing the possibilities of utilizing mining and mineral waste from different countries in the pilot installations. Copper ore processing wastes from Poland have been tested in the Swedish installation, coal processing wastes from Poland in the Estonian installation, oil shale processing wastes from Estonia in the Polish installation and Finnish laboratory, while polymetallic ores processing wastes from Sweden have undergone testing at the Finnish laboratory. The results of follow-up activities will be presented in separate publications.

4. General information concerning extractive waste management in Partner countries or regions

4.1. Introduction

The aim of this chapter is to give an overview about the mining activity and waste management in the countries and regions involved in the Min-Novation project, namely: Estonia, Finland, Germany, Norway, Poland and Sweden. In the above-mentioned countries, mining activity is a substantial sector of the economy. Despite the fact that the global economy is clearly moving towards the development of high technology, mineral resources are not replaceable and they are a foundation for economic and civil development.

At the same time, this sector of the economy generates a large amount of waste. Wastes from the extractive industry, both from current production and historical deposits have a wide range of applications. In this chapter the types of waste generated in mining and processing operations, their quantity and ways of dealing with them are presented.

4.2. Mining and processing waste management in Estonia

Estonia is rich in sedimentary deposits. The main mineral resource is oil shale and different types of industrial minerals (e.g. limestone, dolostone, sand, gravel, clay). The volume of extraction of energy raw materials: oil shale and peat, and that of industrial and construction minerals like limestone, sand, gravel is presented in the table 4.1.

Table 4.1. The main mineral resources and the amount of their extraction in Estonia in 2012

Minerals	**Units**	**Anticipated economic resources**	**Extraction in 2012**
		State as of 1 January 2013	
Energy raw materials	1000 t	6 380 067	15 570
Oil shale	1000 t	4 774 107	14 944
Peat	1000 t	1 605 960	626
Metallic raw materials	1000 t	0	0
Chemical raw materials	1000 t	2 935 735	0
Phosphorite rock	1000 t	2 935 735	0
Industrial and construction minerals	1000 t	5 868 013	16 871
Limestone	1000 t	2 204 368	4 720
Dolostone	1000 t	833 385	1 545
Sand and gravel	1000 t	2 175 280	10 464
Clay	1000 t	654 980	142

Source: Estonian Land Board 2012 – Mineral Reserves Balance Sheet of 2012

Phosphate rock and granite may – depending on the economic situation – be mined in the future. In comparison with large scale oil shale and phosphorite (formerly mined), limestone, sand, gravel and peat represent a fraction, both in terms of volume and technology used. Despite the different extractive environments for oil shale on the one hand and industrial materials on the other, they have many problems in common due to the similar structure of rocks. For both types of minerals, drilling and blasting or difficult mechanical breaking is needed to enable further processing.

Oil shale mining has a crucial meaning for the Estonian economy. The oil shale deposits are located in the north-eastern part of Estonia. They are the biggest in Europe and cover about 3000 km^2, of which 425 km^2 have been mined (Figure 4.1). There are 4.8 billion t of oil shale reserves in Estonia (1.3 billion t of mineable reserve; 1.3 billion t in protected areas and 2.2 billion t of submarginal mineral resource).

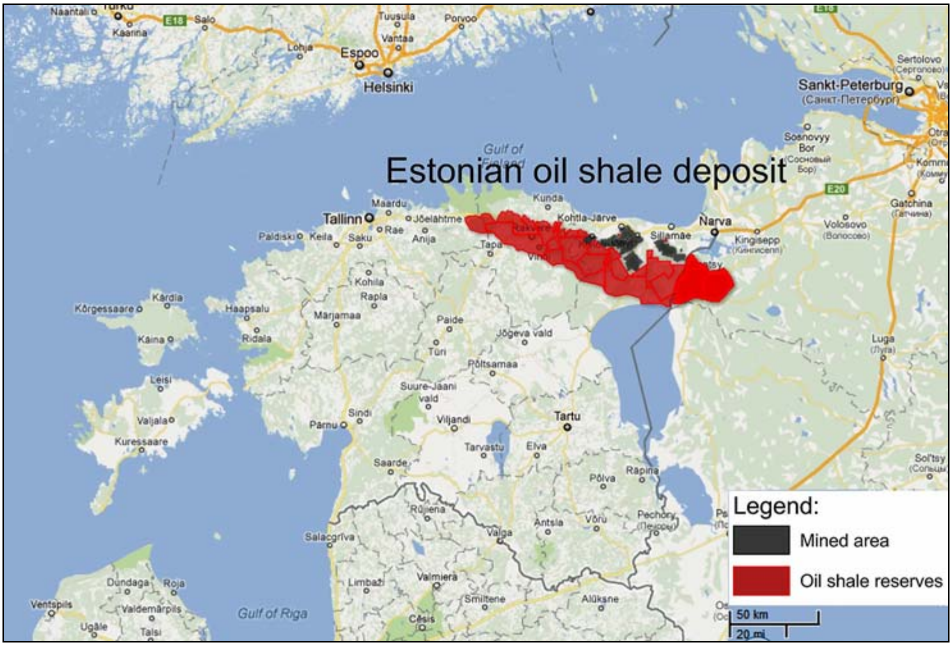
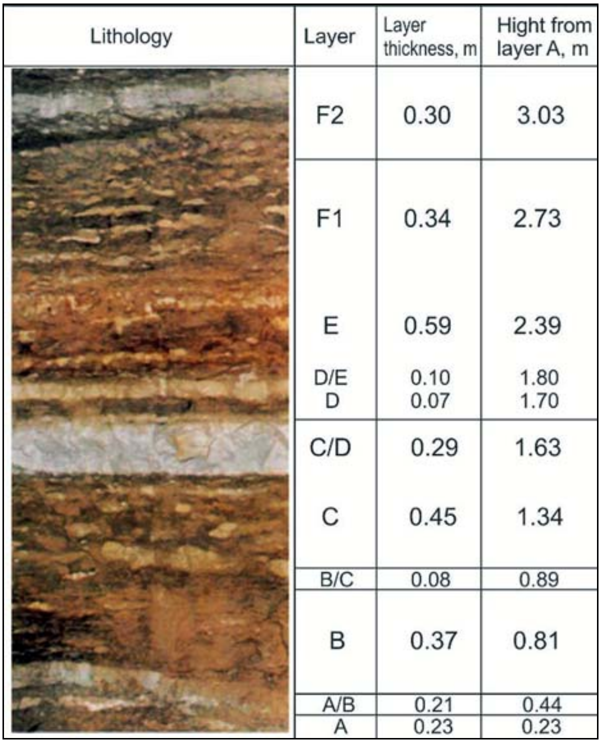


Figure 4.1. Location of Estonian oil shale deposit
Source: Estonian Land Board 2012

Oil shale has been mined for over 95 years with the total production to date exceeding one billion t. Annually 15 Mt of oil shale are extracted in Estonia, 50% is mined in underground mines (room and pillar mining method) and 50% is mined from the surface (open cast mining method). From extracted oil shale 85% goes for generation of electric power and large share of thermal power and 15% goes for shale oil production. More than 90% of electricity in Estonia is produced from oil shale. Power stations consume oil shale with net heating value $Q^r_i = 8.4 \ldots 11$ MJ/kg. The heating value of the oil shale deposit is fairly consistent across the deposit. There is a slight decrease in heating value from the north to the south, and from the west to the east across the area. The oil shale seam consists of interlayered limestone (Table 4.2), which is a waste rock stored in waste rock heaps. The quantity of mining and processing waste generated in the oil shale mines annually is 3–4 Mt.

There are two types of mining waste streams currently managed in Estonia: waste rock from oil shale separation and limestone mining fines (grain size 0 ... 4 mm) from crushing and screening operations. In addition, previously deposited phosphate rock, flotation sand and uranium ore processing wastes are handled. Estonia has a total of 43 waste heaps, the majority of which are oil shale waste rock disposal sites. Their locations are presented in figure 4.2 and one example in figure 4.3.

Table 4.2. Oil shale stratum



Lithology	Layer	Layer thickness, m	Hight from layer A, m
	F2	0.30	3.03
	F1	0.34	2.73
	E	0.59	2.39
	D/E	0.10	1.80
	D	0.07	1.70
	C/D	0.29	1.63
	C	0.45	1.34
	B/C	0.08	0.89
	B	0.37	0.81
	A/B	0.21	0.44
	A	0.23	0.23

Source: Kattai et al. 2000

In the Estonian mining and power industry, based on oil shale waste rock, material can be categorized as follows:

- Blasted and broken limestone removed during mining operations in order to expose the oil shale. The resulting material is not homogeneous, the size of the waste rock is variable, and pieces of rock can be up to 1.5 m in size.
- Waste rock material from separation of oil shale, composed principally of limestone, some sand and clay, and lesser amounts of oil shale, depending on the efficiency of the separation plant operation. Fractions of waste rock range from 25/100 and 100/300 mm in size. Fines are settled and then mixed with trade oil shale.
- Unwanted material from crushing and sizing operations in aggregate production.
- Flotation sand, obtained as a result of the separation process of phosphate rock, and in particular the flotation method.
- Oil shale ash and semicoke waste, which comes from the production of electricity, heat and oil by the energy sector. The oil shale ash is deposited in heaps as is semicoke.

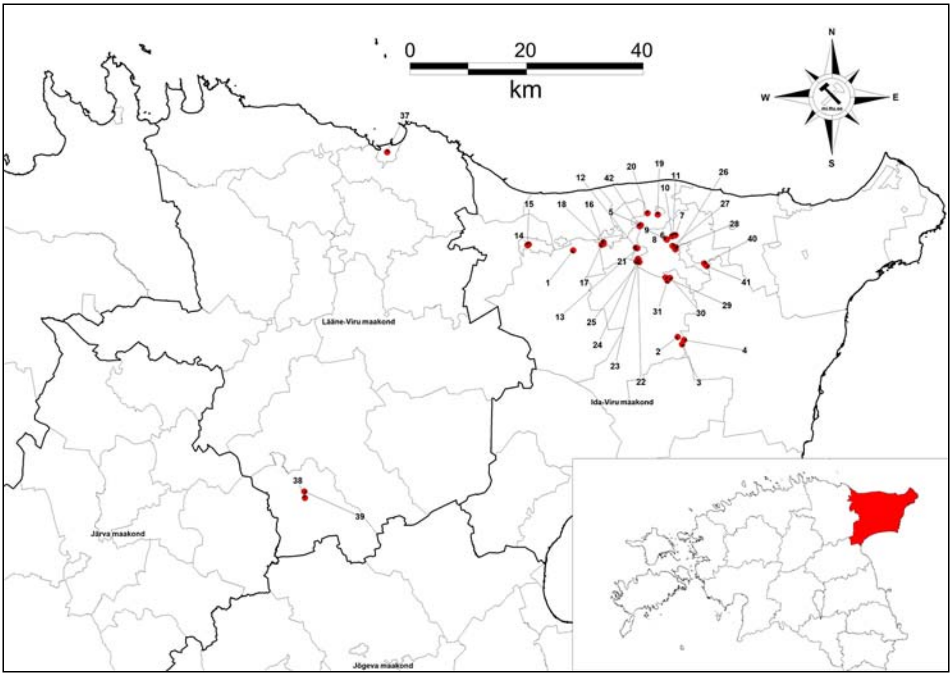


Figure 4.2. Location of waste heaps in Estonia. Details are provided in table 4.3
Source: Tallinn University of Technology, Department of Mining

Figure 4.3. Kukruse oil shale waste heap (waste heap no. 19); Estonia
Photo: Tallinn University of Technology, Department of Mining

Each of the 43 waste heaps in operation can be assigned to one of three levels of waste management, which are presented in table 4.3.

Table 4.3. Waste heaps in Estonia (numbers as in figure 4.2)

No.	Name	Type of Waste	Waste management level
1	Storage of Aidu waste	Oil shale waste rock	Waste prevention
2	Storage of Estonia waste	Oil shale waste rock	Waste prevention
3	Storage of Estonia waste	Oil shale waste rock	Waste prevention
4	Storage of Estonia waste	Oil shale waste rock	Waste prevention
5	Storage of Käva 2 waste	Oil shale waste rock	Waste recovery
6	Storage of Edise waste	Oil shale waste rock	Waste recovery
7	Storage of Edise waste	Oil shale waste rock	Waste recovery
8	Storage of Pauliku waste	Oil shale waste rock	Waste recovery
9	Storage of Pauliku wastes	Oil shale waste rock	Waste recovery
10	Storage of Edise waste	Oil shale waste rock	Waste recovery
11	Storage of Edise waste	Oil shale waste rock	Waste recovery
12	Storage of Rutiku waste	Oil shale waste rock	Waste recovery
13	Storage of Rutiku waste	Oil shale waste rock	Waste recovery
14	Storage of Kiviõli waste	Oil shale waste rock	Land reclamation
15	Storage of Kiviõli waste	Oil shale waste rock	Land reclamation
16	Storage of Kohtla waste	Oil shale waste rock	Land reclamation
17	Storage of Kohtla waste	Oil shale waste rock	Land reclamation
18	Storage of Kohtla waste	Oil shale waste rock	Land reclamation
19	Storage of Kukruse waste	Oil shale waste rock	Land reclamation
20	Storage of Sinivoore waste	Oil shale waste rock	Waste recovery
21	Storage of Sompa waste	Oil shale waste rock	Land reclamation
22	Storage of Sompa waste	Oil shale waste rock	Land reclamation
23	Storage of Sompa waste	Oil shale waste rock	Land reclamation
24	Storage of Sompa waste	Oil shale waste rock	Land reclamation
25	Storage of Sompa waste	Oil shale waste rock	Land reclamation

No.	Name	Type of Waste	Waste management level
26	Storage of Tammiku waste	Oil shale waste rock	Land reclamation
27	Storage of Tammiku waste	Oil shale waste rock	Land reclamation
28	Storage of Tammiku waste	Oil shale waste rock	Land reclamation
29	Storage of Viru waste	Oil shale waste rock	Waste prevention
30	Storage of Viru waste	Oil shale waste rock	Waste prevention
31	Storage of Viru waste	Oil shale waste rock	Waste prevention
32	Storage of Maardu flotation sand	Phosphate rock waste	Waste recovery
33	Maardu nort area of overburden dumps	Phosphate rock waste	Land reclamation
34	Maardu south area of overburden dumps	Phosphate rock waste	Land reclamation
35	Storage of Rummu limestone fines	Limestone waste	Land reclamation
36	Storage of Harku limestone fines	Limestone waste	Waste prevention
37	Kunda ash deposit	Waste from cement production	Land reclamation
38	Rakke lime waste deposit	Limestone waste	Land reclamation
39	Rakke lime waste deposit	Limestone waste	Land reclamation
40	Storage of Ahtme waste	Oil shale waste rock	Waste recovery
41	Storage of Ahtme waste	Oil shale waste rock	Waste recovery
42	Storage of Käva 2 waste	Oil shale waste rock	Waste recovery
43	Overburden of the Vasalemma quarry	Limestone waste	Waste prevention

Source: Tallinn University of Technology, Department of Mining Waste Facilities Database

Mining waste management – waste prevention

There are nine mining waste management sites that are designed for waste prevention, two of them being limestone (overburden dump of the Vasalemma limestone quarry, limestone landfill of the Harku limestone quarry) and the remaining seven oil shale landfills (Heavy Media Separation [HMS] waste rock of Aidu oil shale open cast mine and oil shale waste rock landfills belonging to the Estonia oil shale mine and Viru oil shale mine).

These waste management sites are designed for waste prevention. The material that would become waste is reprocesses by crushing, screening or cycloning. In this process additional raw material is produced, which decreases amount of waste.

Overburden of the Vasalemma limestone quarry and the limestone landfill of the Harku limestone quarry originate from the crushing process. The extraction technologies are drilling, blasting and crushing. The technology has been in use for 15 years. Alternative technologies for processing other types of mining waste are sand & aggregate washing plant or HMS.

Oil shale landfills of the Estonia oil shale mine and Viru oil shale mine hold mining waste that has been generated underground and as a result of the HMS process. The extraction technologies in which mining waste is generated are room-and-pillar mining, drilling and blasting as well as HMS.

Waste rock of the Aidu oil shale open cast mine has been generated by surface mining. The extraction and processing technologies, as a result of which the waste is generated are: bulldozer ripping, drilling and blasting as well as HMS. A sand & aggregate washing plant is a potential technological possibility for processing other types of mining waste. The technology is currently in production stage and has also been used for 15 years.

Mining waste management – waste recovery

There are 14 mining waste management sites that are designed for waste recovery from 11 oil shale, one flotation sand (from phosphate rock prosessing) and two limestone landfills. The technological lines are located in situ. The average annual quantity of mining and processing waste generated in the Estonia Mine and Aidu oil shale open cast is approximately 20 000 t/a. The waste recovered can be used as construction materials. The implemented technology is currently in production stage and has been used for 10 years.

The basic type of mining and processing waste from old oil shale mines originates from HMS and hand separation. The grain size is 0–125 mm and the content of organic material varies between 3–39%. The technological line is located in situ. Basic stages are crushing and screening. The technological scheme for HMS waste rock of the Aidu oil shale open cast includes two-stage crushing with an impact crusher and screening with vibrating screens. The other oil shale mines use an impact crusher and screening with a vibrating strainer. Possible uses of these waste materials following separation are as: aggregates for road basements, oil shale for electricity production and limestone sand for concrete.

In the limestone quarries, the mining or processing waste comes from drilling, blasting and crushing. The technological scheme for recovery is described by two stages: crushing with an impact crusher and screening with vibrating screens. The obtained products can be used as aggregates for road basements in different layers and limestone sand as above.

Potential technological possibilities for processing of other types of mining waste are crushing phosphate rock, gravel and dolomite. The obtained processing waste product from phosphate rock is flotation sand that has been produced in the separation process using the flotation method.

Mining and manufacturing waste management – land reclamation

There are 20 waste management sites that are destined for reclamation: 14 oil shale waste rock, two limestone fines, two lime plant waste heaps and two phosphate rock overburden dumps. The grain size is 0–125 mm and the content of organic material in the mentioned heaps varies between 0 and 60%.

The geomorphology of the sites is flat or convex. The basic risk is igniting in case of open fire but in the Maardu open cast there is also the danger of self-ignition resulting from oxidation. Waste dumps or land are reclaimed mainly for forestry but also for recreation. Land reclamation is being carried out at several oil shale waste rock sites. The oldest oil shale waste heaps are located in Kohtla-Nõmme. Those three heaps have been reclaimed for recreational uses and now function as ski-slopes.

Summary of possible uses of mining waste

The waste rock obtained from oil shale enrichment can be used as follows:

- Filler material for constructions.
- Splinters produced from the waste rock can be used as building material.
- The high-quality component of these splinters can be used to produce concrete.
- Reclamation using the waste rock together with overburden.

The oil shale ash obtained from the production of electricity, heat and oil can be used as follows:

- An ingredient in producing building materials.
- Backfilling of deserted mines. Concrete produced with oil shale ash can be used to backfill mines and to prevent ground subsidence. Mine backfilling allows one to extract most of the oil shale.
- In road construction for stabilizing boggy grounds and building foundations for highways, railways and pipelines.
- Expanding harbours and mass stabilization of contaminated areas.
- In agriculture to neutralize acidic soils and to fertilize fields and grasslands.
- Raw material for the plastic industry.
- As a binder of CO_2 and sulphur in ecological projects, for example in power plants.

4.3. Mining and processing waste management in Finland

There were 12 metallic mines operating in Finland in 2012. Industrial minerals were extracted from about 30 mines. Metal mines and new mine projects are located in Northern and Eastern Finland and industrial mineral mines are concentrated in Southern and Eastern Finland (Figure 4.4). The turnover of the mining industry was about 1.48 billion Euro, of which metallic minerals account for about 963 million Euro. The number of personnel employed by the mines is about 2700 and their subcontractors employ some 1900 people (Ministry of Employment and the Economy 2012).

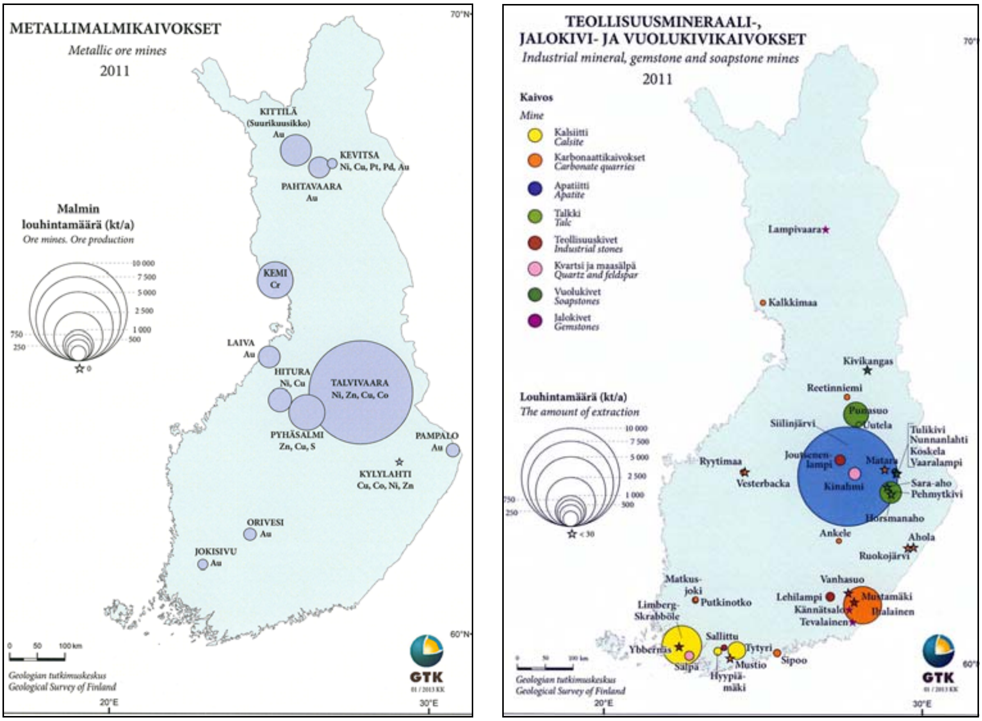


Figure 4.4. Operational and planned: metal ore (left)
and industrial mineral and gemstone mines (right) in Finland
Source: Geological Survey of Finland 2013

In 2008, the Finnish Council of State approved a National Waste Plan that is effective until 31 December 2016 or until the next waste plan comes into force (Ministry of the Environment 2012). The primary objectives of the new National Waste Plan are to promote sustainable use of natural resources, develop waste management as well as prevent dangers and environmental and health hazards caused by waste material.

The goals and primary management methods of the National Waste Plan are grouped under eight objectives:

1) Prevent formation of waste by improving material efficiency.
2) Enhance recycling.
3) Reduce hazardous chemicals in waste.
4) Decrease the detrimental effects of waste on climate.
5) Decrease the health and environmental hazards of waste.
6) Develop and clarify the organisation of waste management.
7) Develop new know-how in the waste material sector.
8) Ensure controlled, safe international transport of waste material.

These objectives apply to most sectors in waste management, such as municipal waste management as well as waste management in industry, mining, construction, agriculture, trade and services. The National Waste Plan specifies quantitative objectives for utilising industrial and mining waste in earth construction.

Mineral production and waste statistics from Finland

In 2011, a total of approx. 43.3 Mt of ore and waste rock was extracted from Finnish metal ore mines, of which over 17 Mt were ore and over 26 Mt constituted waste rock (Table 4.4). The decrease in quarried ore as compared with 2010 was attributable to one mine and the volume of waste rock decreased because the said mine completed the transition to underground operations. The volume of metal ores extracted has more than tripled from 2008 to 2011.

The most important metals mined in Finland are chromium, copper, nickel, gold and silver; their total volume in 2011 was approx. 1.73 Mt (Table 4.5).

Quarrying of industrial minerals includes quarrying of carbonate rock, other industrial minerals like apatite, talc, quartz-feldspar and gemstones, as well as commercial stone as a raw material of e.g. mineral wool. Altogether, almost 16 Mt of exploitable rock and over 12 Mt of waste rock were extracted from industrial mineral ores quarried in Finland in 2011 (Table 4.6).

Utilisation and management of mineral waste produced by the mining industry in 1995–2008 is presented in Figure 4.5. The volume of waste from mining production was about 32 Mt in 2008. Most of the waste came from overburden – 11.2 Mt, waste rock – 9.1 Mt and tailings – 11.4 Mt (Ministry of the Environment 2012). About half of the waste was utilised and half landfilled. Material used to backfill is not included in statistics.

Table 4.4. Quarrying of metal ores and waste rock in Finland in 2004–2011

Year	2004	2005	2006	2007	2008	2009	2010	2011
Volume of quarried ore, [t]	3 636 679	3 623 531	3 605 223	3 732 900	6 311 123	11 845 051	18 191 462	17 213 074
Volume of waste rock, [t]	4 468 049	1 184 134	1 335 217	3 198 445	7 608 208	14 795 402	27 590 444	26 113 162
Total volume quarried, [t]	8 104 728	4 807 665	4 940 440	6 931 345	13 919 331	26 640 453	45 781 906	43 326 236

Source: Mining industry: Sector report (Ministry of Employment and the Economy 2012)

Table 4.5. Production of metal concentrates in Finland in 2004–2011

Year	2004	2005	2006	2007	2008	2009	2010	2011
Sulphur concentrate, [t]	692 043	461 341	512 131	485 780	564 204	383 901	584 085	804 884
Chromium concentrate, [t]	580 000	571 100	548 713	556 101	613 544	246 818	598 000	692 527
Zinc concentrate, [t]	68 380	74 369	66 327	71 812	52 518	56 197	95 305	87 974
Nickel concentrate, [t]	45 914	39 854	40 474	44 824	43 038	11 413	43 151	91 196
Copper concentrate, [t]	52 179	51 379	44 663	46 325	46 096	50 876	50 709	48 668
Total, [t]	1 438 516	1 198 043	1 212 308	1 204 842	1 319 400	749 205	1 371 250	1 725 249

Source: Mining industry: Sector report (Ministry of Employment and the Economy 2012)

Table 4.6. Quarrying of industrial minerals, ore and waste rock in Finland 2004–2011

Year	2004	2005	2006	2007	2008	2009	2010	2011
Total volume of quarried ore, [t]	15 579 318	15 479 167	16 115 072	16 301 106	15 774 010	12 156 666	15 655 442	15 967 678
Total volume waste rock, [t]	6 079 003	8 088 644	8 542 847	8 569 253	8 019 771	6 771 364	9 242 542	12 117 724
Total volume quarried, [t]	21 658 321	23 567 811	24 657 919	24 870 359	23 793 781	18 928 030	24 897 984	28 085 402

Source: Mining industry: Sector report (Ministry of Employment and the Economy 2012)

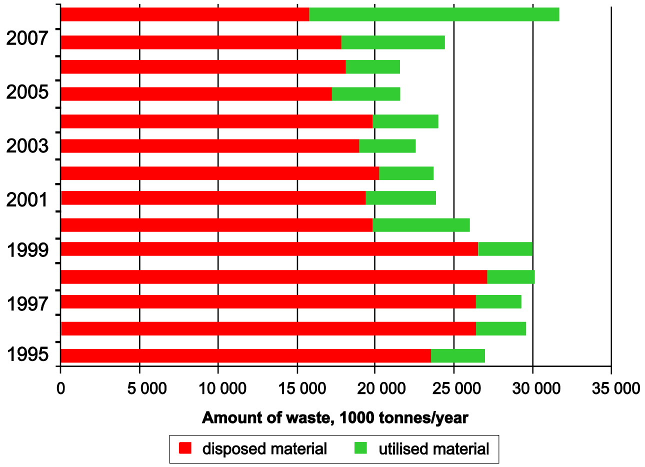


Figure 4.5. Utilisation and management of mineral waste produced by the mining industry in 1995–2008 in Finland
Source: National Waste Plan (Ministry of the Environment 2012)

The total volume quarried in 2011 was 71.4 Mt, of which waste rock, tailings and overburden accounted for about 50 Mt. Most of this waste is stored in the mine area. The mining industry accounts for approximately 53% of waste accumulation in Finland (Figure 4.6).

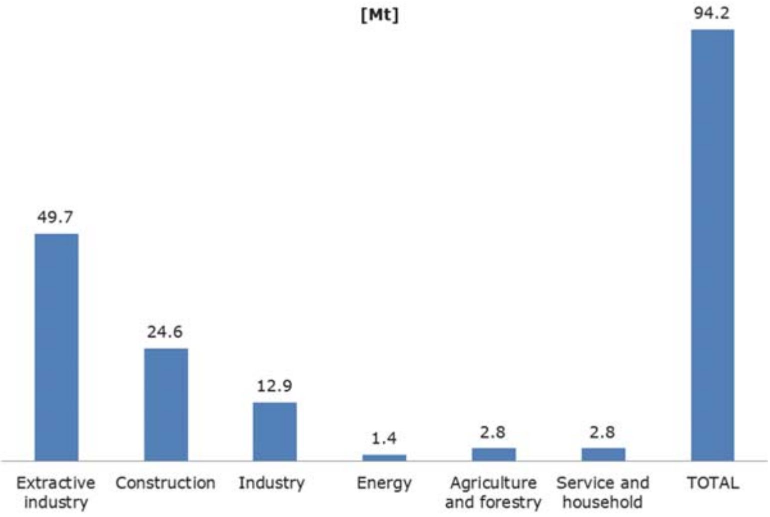


Figure 4.6. Amount of waste material by sector in Finland in 2010
Source: National Waste Plan (Ministry of the Environment 2012)

Reuse of mining waste in Finnish mines

At present, there are no systematic waste- and mine-specific utilization statistics with regard to tailings and mine waste in Finland. The main use for tailings and mine waste is in mine backfilling and tailings dam construction. Several mines in Finland, e.g. Pyhäsalmi Mine Oy and Outokumpu Crome Oy Kemi mines use up all of their waste rock and a remarkable amount of coarse tailings as backfilling material in underground mines (European Commission 2009). Waste materials used as backfill materials are not included in the annual waste statistics (see figure 4.5).Tailings from an apatite mine (Yara Finland Oy) are utilized in agriculture as soil improvement additives. Low sulphur tailings and mine waste are used in road construction as base and sub-base material. To avoid frost heave in frost susceptible soil conditions, construction layers have to be very thick in cold climate. Non-frost susceptible tailings have been used successfully in some pilot projects to prevent frost problems. Some tailings have also sorption capacity to bind contaminants like lead and other metals e.g. in contaminated soils.

4.4. Mining and processing waste management in Germany

General information about the mining sector in Germany

Securing stable growth in the German economy calls for sustainable use of natural resources. Substantial social efforts are required to implement the energy transformation, the sustainable strategy as well as the German resource efficiency program. Beside research and development, transnational cooperation is an important strategic element of the German Federal Government policy on securing a sustainable supply of raw materials. Germany as one of the world's leading industrial nations with its strong manufacturing sector and also strong export activities requires a reliable and continuous availability of raw materials. Especially mineral resources are limited and expensive. The importance of addressing resource efficiency will increase in the future. Hence new R&D initiatives should be focused on more efficient exploitation of primary raw materials as well as greater recovery of secondary raw materials. Metals and minerals for the technologies of the future have to be made available on the domestic market in a secure and sustainable way and in adequate volume.

In this context it should be noted that a large part of the nationwide need for mineral raw materials is covered by domestic deposits. In the sector of the pit-and quarry industry almost the entire demand is covered by local production. Apart from a large number of non-energetic raw materials, energy raw materials like hard coal, lignite, natural gas and crude oil are also extracted (Dera 2012).

Due to the legal regulations there are no standard guidelines for data acquisition, so the data material about all mining activities in Germany is non-uniform and imperfect. There is also no general obligation to report for mining companies not subject to the mining law.

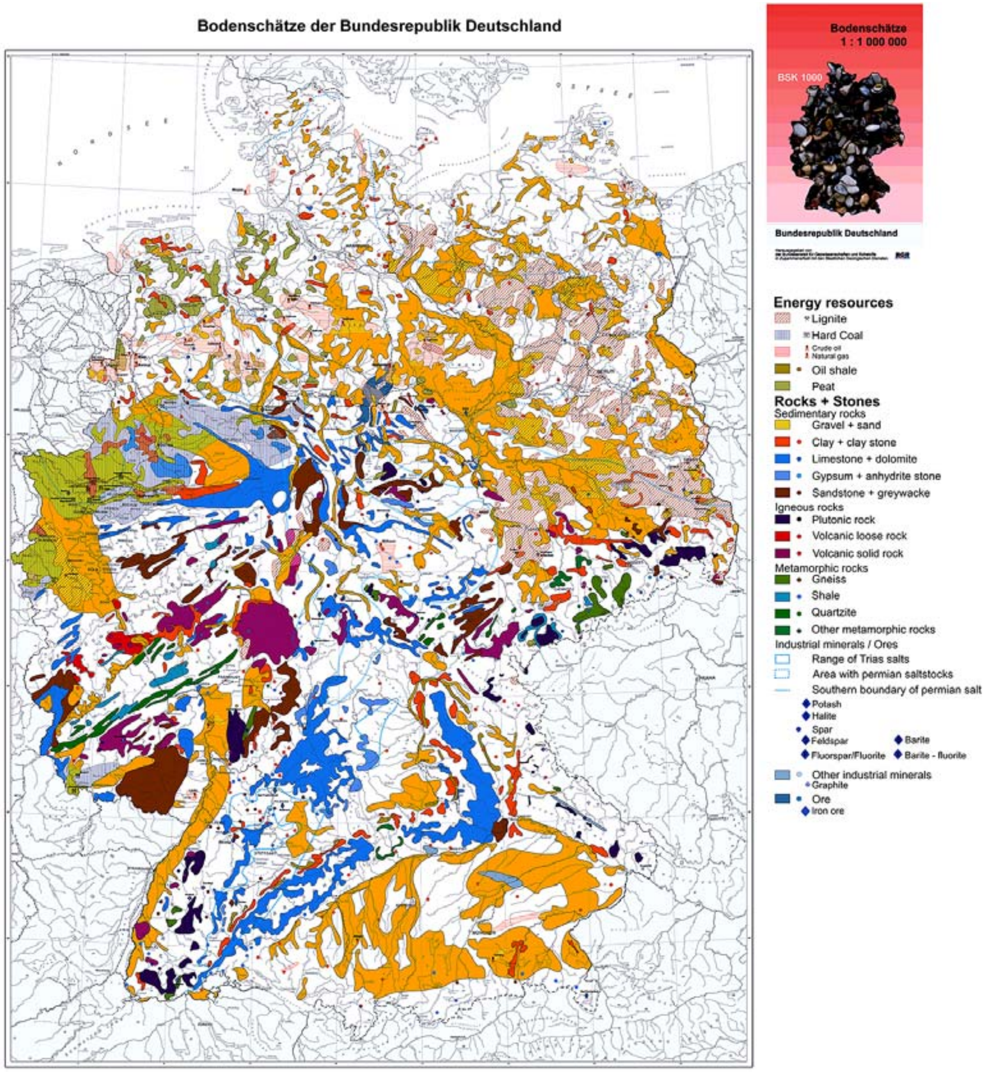


Figure 4.7. The map of mineral deposits in Germany
Sources: Bundesanstalt für Geowissenschaften und Rohstoffe 2007

On a global scale, Germany holds a position as an important mining country. In 2011, the country was the world largest producer of lignite, second largest of kaolin, third largest producer of halite and fourth largest producer of potash salt, the basis for essential fertilizer (3rd biggest in Europe) (Dera 2012).

The map of mineral deposits gives an overview of the spatial distribution of energy and metallic raw materials as well as rock industrial minerals in Germany (Figure 4.7).

In terms of quantity, gravel and sand are the most important industrial rock materials. Together with the second-ranked crushed natural stones they represent more than half of the extracted mineral raw materials. The third placed lignite is still the most important domestic energy source.

As far as the value of extracted raw materials is concerned, lignite is the most substantial local raw material, followed by natural gas, gravel and sand and crushed natural stone. The overall value of the extracted raw materials was around 20.8 billion Euro. The table 4.7 gives a review about the current mining activities in Germany (Dera 2012).

In the present subchapter, the situation regarding mining, mining waste and mining waste recovery is described in more detail for the region of Mansfeld/Südharz, situated in Central Germany. The mining of copper ore and its processing in smelting plants to cathode copper effectively ended in the region in 1990 after more than 800 years of mining activities (Jankowski 1995).

Between 1850 and 1990 alone, more than 100 Mt of ore were mined, from which 2.3 Mt of copper and 13 000 t of silver were extracted. The extraction of copper and silver was a multiple-stage technological process (Eisenächer and Jäger 1997). The copper ore, mined in shaft mines at a depth of 600 to 800 m, was processed to solid copper and silver in a two-stage smelting process (raw and refining smelters).

Beside the extraction of copper and silver, the poly-metallurgic character of the Mansfeld copper ore deposit allowed the production of a variety of high-grade metals, like molybdenum, germanium, selenium and others (Galonska 1997).

In the process of copper mining and processing, mining and smelting residues were accumulated, and today their exploitation is the focus of economic development efforts (Morgenroth and Schaefer 2011). In addition to this, two geologically developed, but so far not mined copper deposits exist: Heldrungen and Osterhausen copper deposit with a total of 17 Mt of ore, containing 425 000 t copper and 2000 t silver (ReSource 2012).

In the frame of the project ReSource in 2009/2010 a feasibility study regarding the mining of the Heldrungen deposit was developed. There were several inquiries by potential investors from 2010 to 2013 (ReSources 2012)[2].

Furthermore, a substantial potential for geothermal energy from mine water exists in the region, which should be included in any future exploitation activities (ReSource 2012).

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[2] Further activities on the level of the federal state government Sachsen-Anhalt and Thüringen are planned for 2013.

Table 4.7. Minerals extraction in Germany in 2011

Mineral	Unit	Anticipated economic resources		Extraction in 2011
		developed	of which were exploited	
Fuels (Energy raw materials):				
Crude oil	Mt	35.30	290	2.7
Hard coal	Mt	83 000		12.1
Lignite	Mt	36 500		176.5
Natural gas	billion m^3	133	987	13.0
Metallic raw materials:				
Iron ores	t as aggregate			489 000
Chemical raw materials:				
Potash	Mt			3.214
Halite	Mt			17.44
Feldspar	t			0.35
Bentonite	t			375 000
Fluorite	t			66 000
Baryte	t			55 000
Industrial and construction minerals:				
Gravel, sand	Mt			253
Crushed natural stone	Mt			229
Quartz sand	Mt			10.5
Lime, marlite, dolomite brick	Mt			66.4
Clay	Mt			6.81
REA-Gypsum	Mt			6.2
Kaolin	Mt			4.9

Source: DERA 2012

Waste from copper mining in the Mansfeld Region – volume of deposits and status of R&D with respect to recovery

The residues of copper mining (mine heaps) amount to around 105 Mt. Approx. 21 Mt thereof are available for exploitation. According to Schreck and Gläser 1997, the average metal content is:

Copper	:	0.25%,
Lead	:	0.31%,
Zinc	:	0.60%.

Currently, the only recovery and reuse option for the mine heap material is in road construction and improvement.

The recovery of non-ferrous metals from mine heaps was the focus of a R&D-project managed by the Martin-Luther-Universität (MLU) in Halle/Saale, University Halle-Wittenberg from 2009 to 2012, funded by the German Federal Ministry of Science. The main objective was to develop a suitable process for efficient extraction of the above-mentioned metals from mine heaps. The development of this process is still underway and will be continued in a follow-up project taking place in the 2013–2015 timeframe.

In addition, there are two residues from the first smelting process, which have been qualified for exploitation. One is a smelting works slag, which has a potential of around 50 Mt and contains non-ferrous metals and trace elements (Galonska 1997). Small amounts are currently used for road works. The other is "Theisenschlamm", the lead- and zinc--containing fine dust (Lorenz 1994), accumulated in the processing of copper in the period from 1921 to 1990 and deposited in a landfill, amounting to around 450 000 t. There is no current exploitation. Research into the possibility of recovering metals from the fine dust remaining from furnace processes were carried out by TU Clausthal-Zellerfeld and Helmholtz Centre for Environmental Research UVZ between 1992 and 1999 (Lorenz 1994). The research work however was not completed due to a political decision of the federal state government in Sachsen-Anhalt. Smelters and slag deposits and Theisenschlamm tailing in Mansfeld region are presented in figure 4.8.

Further activities at the level of the federal state government Sachsen-Anhalt and Thüringen are planned for 2013.

A final waste that represents exploitation potential is mine water. In the Mansfeld area there are around 120 km of drainage galleries with a depth between 20 and 150 m below surface and a flow rate between 2 and 25 m^3/min usable for geothermal energy production (ReSource 2012).

Currently a geothermal-energy pilot plant, which will use an underground drainage gallery to heat a mining museum, is under construction. Further projects are in preparation.

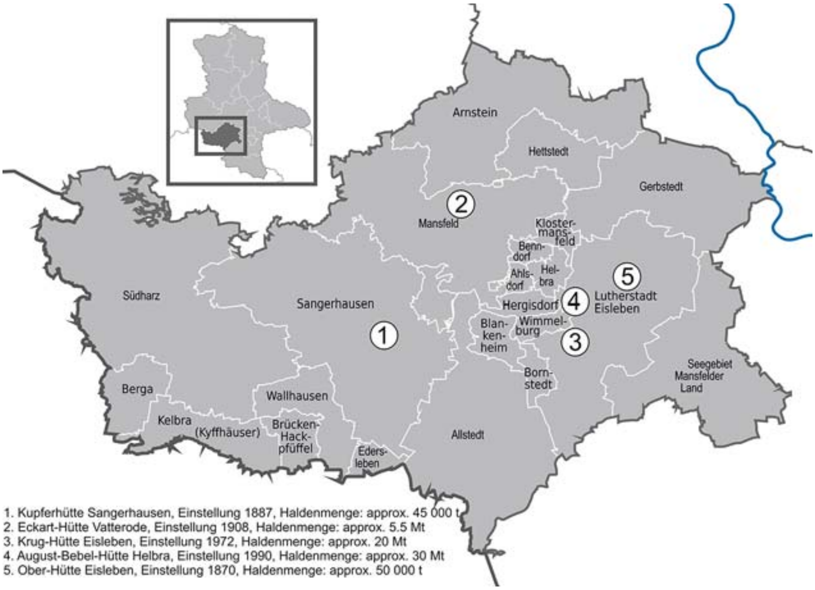

Figure 4.8. Smelters and slag deposits including Theisenschlamm tailing pond in Mansfeld region, Germany. Theisenschlamm deposit is located at no. 4, August-Bebel-Hütte, Helbra

Recommendations for action

The following actions promise to deliver opportunities in the Mansfeld region in the area of waste recovery:

1) Continuation of development of an economically efficient process for the reclamation of non-ferrous metals from mine heaps, supported by government funds.
2) Placement of a prospective usage of the copper ore deposits Heldrungen and Osterhausen into the structural political planning by federal state governments in the period 2013–2018.
3) Increased utilization of the energetic resource mine water by development of suitable processes and facilities in the scope of projects funded by the German ministry of economy and the federal state of Sachsen-Anhalt.
4) Implementation of a R&D-project regarding the exploitation of Mansfeld copper slag with two main targets:
   - Recovery of strategic metals from copper slag.
   - Application of copper slag for cement production.

4.5. Mining and processing waste management in Norway

Extraction and resources of Norway's main mineral and fossil fuel resources

Norway is the world leader in the extraction of olivine (43% of 2010 world production), and the leader in EU production of calcite and nepheline (Norwegian Ministry of Trade and Industry 2013). The country also boasts the largest titanium mine in Europe, which has a deposit of 400 Mt of ilmenite ore (making it the largest deposit of ilmenite in the world). The Titania company produces approx. 940 000 t ilmenite-concentrate per year.

Norway's non-petroleum mineral resources have only recently been re-assessed, and present a substantial potential for exploitation.

Of the 14 minerals determined to be critical to the European Union's economy, Norway is a key supplier of several of them, namely: flake graphite (only stable supplier in Europe) and niobium (the Sœteråsen deposit SW of Oslo contains 8 Mt of nobium; Boyd 2012). Norway likewise may have potentially substantial deposits of beryllium, cobalt, gallium, magnesium and rare earth elements, although the volume of the anticipated deposits has as yet not been determined.

The volume of mineral extraction in 2010 is presented in table 4.8.

As compared with the rest of the Baltic Sea Region, Norway's extractive sector is relatively small, with approx. 6000 people employed directly (Norwegian Ministry of Trade and Industry 2013) at some 790 companies (Thjømøe 2012). However, recent policy developments, capped off by the government's formulation of a strategy for the mining industry in 2013, and supporting research by the Geological Survey of Norway, which revealed substantial deposits of mineral resources in the country, indicate prospective growth. It should be noted however that geophysical mapping at present covers only 30% of Norway, which means that it is too early yet to tell, whether the extraction of the identified deposits will be economically viable.

Figures 4.9 and 4.10 show important metal as well as industrial rock deposits, the majority of which are unexploited.

Given that petroleum and natural gas make up a considerable share of Norway's economy, this subchapter addresses these particular fossil fuels alongside traditional mineral resources.

Table 4.8. Resources and extraction of minerals in Norway

Minerals	Unit	Anticipated economic resources		Extraction in 2010
		Existing	of which were exploited	
Energy raw materials				
Coal (all grades)	Mt	–	–	1 685
Petroleum	MSm^3 o.e.	7 048	3 812	225.14
Petroleum gas	MSm^3 o.e.	5 643	1 766	
Metallic raw materials				
Iron ore and concentrate	Mt			3 105
Copper, metal, primary and secondary refined	Mt			32 000
Cobalt, metal, refined	Mt			3 208
Nickel, primary	Mt			88 000
Titanium (Illmenite concentrate)	Mt			864
Zinc, primary	Mt			147 775
Chemical raw materials				
Nepheline syetite	Mt			327
Olivine sand	Mt			2 560
Feldspar	Mt			56
Rock raw materials				
Gravel, sand	Mt			13 011
Crushed natural stone: Dolomite	Mt			604
Quartz and quartzite sand	Mt			1 055
Limestone	Mt			6 129
Lime, hydrated, quicklime	Mt			100
Clay	Mt			230

Source: Norwegian Ministry of Petroleum and Energy & Norwegian Petroleum Directorate 2013, USGS 2011; MSm^3 o.e.: million standard m^3 oil equivalents

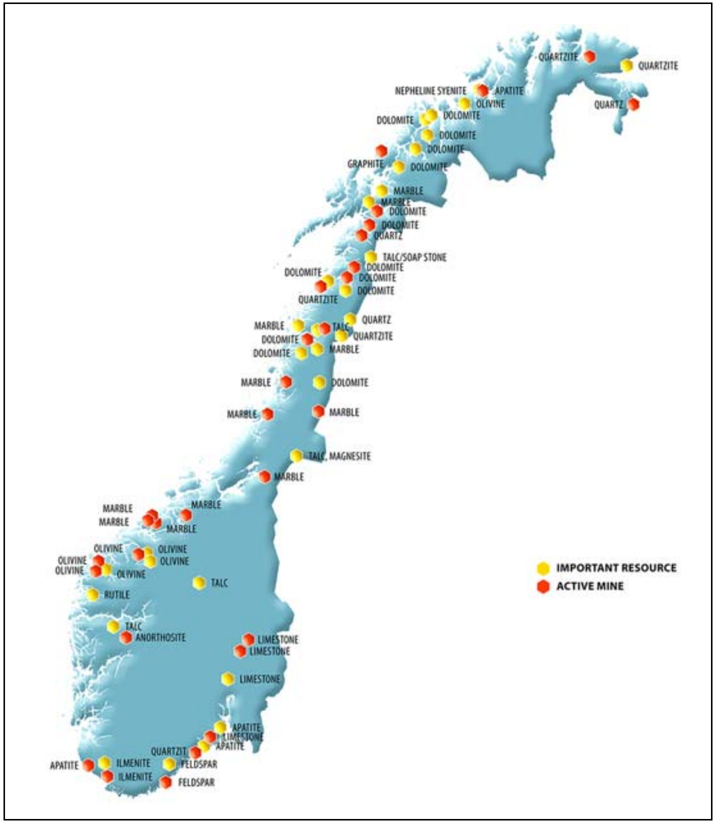

Figure 4.9. Industrial mineral deposits of national importance in Norway
Source: Norwegian Ministry of Trade and Industry2013

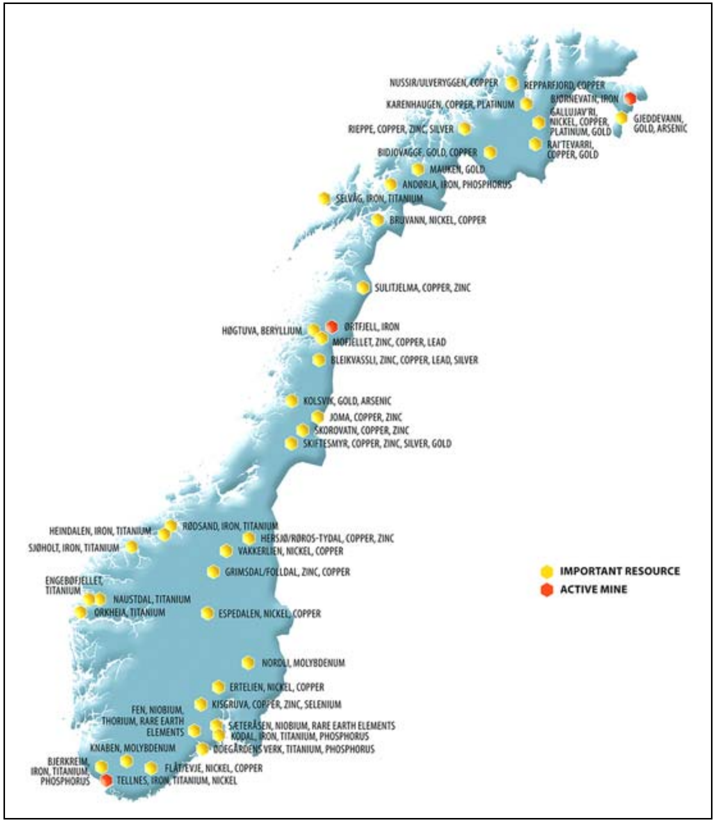

Figure 4.10. Metal deposits of national importance in Norway
Source: Norwegian Ministry of Trade and Industry 2013

The petroleum sector in Norway is by far the largest industry sector in Norway, representing more than 23% of the country's gross domestic product (Norwegian Ministry of Petroleum and Energy & Norwegian Petroleum Directorate 2013). Oil production is currently taking place on 76 fields on the Norwegian continental shelf, which in 2012 generated 1.9 million barrels of oil (including NGL and condensate) per day, and approx. 111 billion standard cubic metres of gas (Norwegian Ministry of Petroleum and Energy & Norwegian Petroleum Directorate 2013). Norway is ranked as the seventh largest oil exporter and the fourteenth largest oil producer in the world. In 2011, it was the world's third largest gas exporter and sixth largest gas producer.

Waste management of metals and other minerals

Unlike the Norwegian Petroleum Directorate, no Norwegian government agency or for that matter trade association representing the interests of the mining industry regularly gathers statistics on cumulative waste volumes produced or on the different modes of managing waste streams. A very rough estimate is that the Norwegian mineral sector generated approx. 57 Mt of waste in 2012[3]. Indicators on waste volumes are the hazardous waste disposal permits issued by the Norwegian Pollution Control Authority and non-hazardous waste disposal permits handled by county governments. For the latter, data specifically on iron ore and industrial mineral enterprises caps annual disposal at 6.8 Mt for submarine disposal and 3 Mt for land disposal[4]. No specific data on production of waste rock is available.

Further indication of the extent of waste deposits are the several sub-aquaeous tailings disposal sites located in Norway, which has a long history of disposal at sea-bottom of processed mining waste, making it unique when set against other European countries, including those represented in this publication.

The majority of mineral waste is deposited in 3 active sea-bottom disposal sites and 1 onshore disposal site. The only land disposal site is run by Titania mine. The sea-bottom disposal sites are located at Hustadmarmor AS (which receives <0.7 Mt/a of calcite tailings and has been in operation since 1982), Rana Mines (3 Mt/a of iron ore tailings) and the newly opened Sydvaranger (7 Mt/a) iron ore mine, giving a total volume of disposed waste at off-shore sites at around 10.7 Mt/a (Amundsen 2009). Lesser waste volumes are discharged in fjords in Skaland (20 000 t/a of fragmented granite) and Sibelco (unknown tonnage of nepheline syenite; Vogt 2012). The waste is disposed of by being discharged into the sea-bed of adjacent fjords.

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[3] Personal communication from Pål Thjømøe, Director, Magma Geopark AS, 17 September 2013.

[4] Personal communication from Glenn Storbråten, Senior Adviser, Section for Petrochemical and Mineral Industry, Norwegian Environment Agency, 30 August 2013.

Additional disposal sites are planned, which together will increase the disposal capacity in Norway by approx. 8.7 Mt/a, namely: Nussir ASA (2 Mt/a – copper, nickel and chromium) and Nordic Mining at Engebo AS (6 Mt/a – titanium dioxide).

The environmental impact of sea-based mineral waste disposal has been the subject of many studies, both in Norway and abroad[5]. The rationale for sea-bottom waste disposal relates to both the abundance of appropriate marine sites and the lack of appropriate onshore sites, and the fact that such disposal inevitably slows down the weathering process, with water acting as an oxygen barrier. On the other hand, this form of mining waste disposal has been found to cause damage to the surrounding ecosystem. The answer on whether the environmental impact is acceptable or not depends on several factors, including: the intensity and concentration of disposal, the methods of disposal and the biological characteristics of the area receiving the waste (tolerance level for the given waste type).

Scarcely any data is publicly available on the extent of waste reuse and recovery in the Norwegian mining sector and the research work done in this area is by and large confidential.

Waste management of petroleum production

Petroleum production involves the production of produced water, oily water (drilling slop), drill mud, drill cuttings (water-based and oil-based) and small levels of radioactive substances. The principal methods of disposing of the waste is to either discharge it into the sea (sea-bottom), inject it into a special disposal well off-shore or send it ashore where it is subjected to processing (4–5 major processing sites) before either being disposed of in landfills, discharged into the sea or converted into a product.

Produced water is by far the largest category of waste. The majority of it is discharged into the sea on the Norwegian Continental Shelf, with approx. 131 MSm^3 disposed of in this way in 2010 (INTSOK 2013). A considerable amount of hazardous waste is generated by the petroleum sector in the form of oily water and drill mud and drill cuttings. The Norwegian Oil and Gas Association in its Environmental Report (2013) concludes that a total of some 314 000 t of hazardous waste was produced, the majority of it drill (rock) cuttings and oily water (Norwegian Oil and Gas Association 2013).

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[5] Some recent research projects and studies on this topic include: Scottish Academy of Marine Science (2010): Independent Evaluation of Deep-Sea Mine Tailings Placement (DSTP) in PNG Project Number: 8.ACP.PNG.18?B/15; Søndergaard J., Asmund G., Johansen P., Rigét F. (2011): Long-term response of an arctic fiord system to leadezinc mining and submarine disposal of mine waste (Maarmorilik, West Greenland), Marine Environmental Research 71, pp. 331–341; Daniel M., Franks, David V. Boger, Claire M. Côte, David R. Mulligan (2011): Sustainable development principles for the disposal of mining and mineral processing wastes, Resources Policy, Volume 36, Issue 2, pp. 114–122; Evan Edinger (2012), Gold Mining and Submarine Tailings Disposal: Review and Case Study, Oceanography 25(2), pp. 184–199.

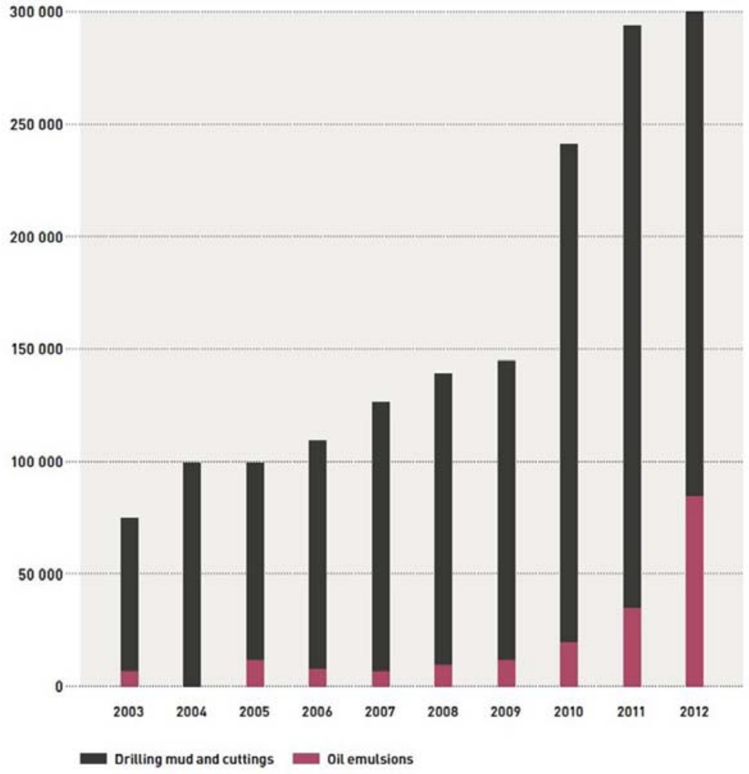

Figure 4.11. Oil-contaminated waste sent ashore [t]
Source: Environmental Report (Norwegian Oil and Gas Association 2013)

In the past 3 years there has been a substantial change in the management of drill mud and cuttings, with the amount taken ashore for processing increasing by more than twofold between 2009 and 2012 (Norwegian Oil and Gas Association 2013). The major reason for this was a number of identified leaks from injection wells on several oil fields, which led to a halt in further injection. The oil industry however is pushing to resume injection, arguing that new safety measures have been introduced that will reduce even further the risk of leaks and emphasizing the uneconomical nature of transport and treatment on land.

4.6. Mining and processing waste management in Poland

Poland is an important producer of hard coal and lignite, copper and zinc-lead ores, rock salt, sulphur and numerous rock minerals.

Table 4.9. Extraction, reserves and resources of the main minerals in Poland

Mineral	Unit	Measured and indicated resources (end of 2012)	Anticipated economic resources (end of 2012)	Mining extraction in 2012
Energy raw materials				
Crude oil	Mt	24.96	16.29	0.66
Hard coal	Mt	48 225.61	4 210.59	71.34
Lignite	Mt	22 583.83	1 219.12	64.30
Natural gas	Gm^3	137.84	66.43	5.62
Metallic raw materials				
Copper ores	Mt gross Mt Cu kt Ag	1 792.53 34.36 104.90	1 235.57 24.25 72.47	30.18 0.48 1.34
Zinc-lead ores	Mt gross Mt Zn Mt Pb	77.15 3.42 1.45	9.62 0.41 0.17	2.33 0.07 0.03
Molybdenum-tungsten-copper ores	Mt gross Mt Mo Mt W Mt Cu	550.83 0.29 0.24 0.80	– – – –	– – – –
Chemical raw materials				
Potassium-magnesium salts	Mt	669.84	2.74	–
Rock salt	Mt	84 952.77	1 442.33	3.92
Sulphur	Mt	511.15	24.91	0.70
Industrial and construction minerals (main)				
Dolomite, industrial	Mt	336.74	81.99	2.92
Feldspar	Mt	172.24	39.07	0.85
Gypsum and anhydrite	Mt	257.12	110.42	1.23
Kaolin	Mt	212.91	72.19	0.25
Limestone, industrial	Mt	18 439.73	3 115.77	41.05
Refractory clay	Mt	54.65	2.71	0.09
Sand, foundry	Mt	314.29	34.71	1.21
Sand, glass	Mt	621.69	153.65	2.15
Sand and gravel	Mt	17 735.14	3 496.20	184.74
Stone, crushed and dimension	Mt	10 509.15	3 392.33	64.01

Source: Polish Geological Institute 2012

In 2012, over 4900 mineral deposits were extracted in Poland, including 295 deposits of hydrocarbons, 63 deposits of coal, 9 deposits of metallic ores, 10 deposits of chemical raw materials, and over 4500 deposits of rock minerals (Polish Geological Institute 2013). Presently 7124[6] mines are active, including 40 underground, 6999 open casts and 77 borehole mines (WUG 2013).

Total extraction in 2012 amounted to 484.45 Mt of solid minerals and 6.56 Gm^3 of natural gas and crude oil, coal-bed methane (Polish Geological Institute 2013). Mines occupied an area of 38 065 ha (data for 2011, Environment 2012), while providing employment to 175 600 people (data for 2011, Statistical Year Book 2012). The amount of mineral extraction for the four main groups: energy, metallic, chemical, industrial and construction minerals, their proved and probable reserves as well as measured and indicated resources are presented in table 4.9.

Maps illustrating the distribution of selected Polish natural resources are presented in figures 4.12–4.15.

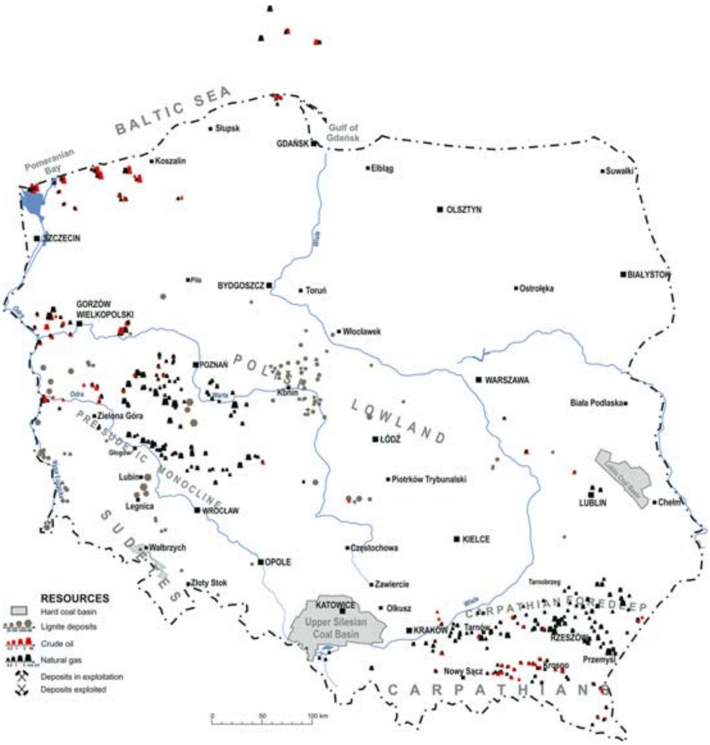

Figure 4.12. Map of energy resources in Poland
Source: own study based on the http://geoportal.pgi.gov.pl/surowce/mapy

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[6] Facilities included within mining supervision, and thus also mining facilities under liquidation, underground gas storages, underground landfills, and facilities conducting geological works.

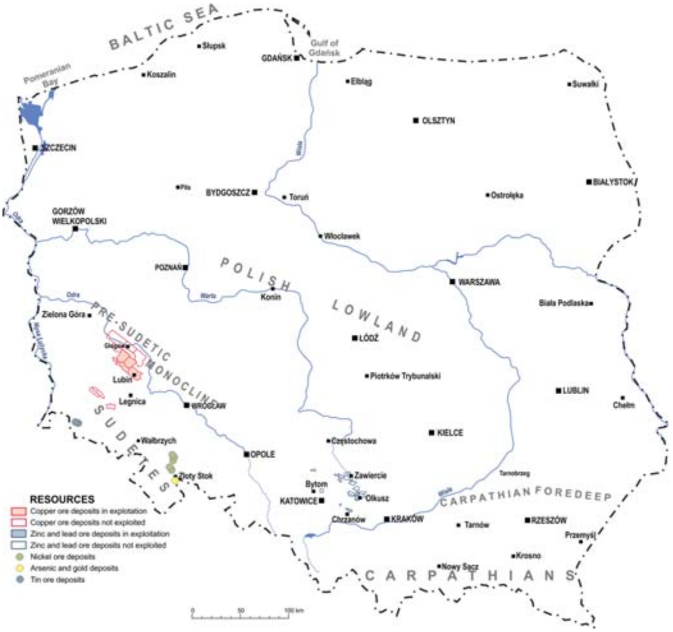

Figure 4.13. Map of metallic raw materials in Poland
Source: own study based on the http://geoportal.pgi.gov.pl/surowce/mapy

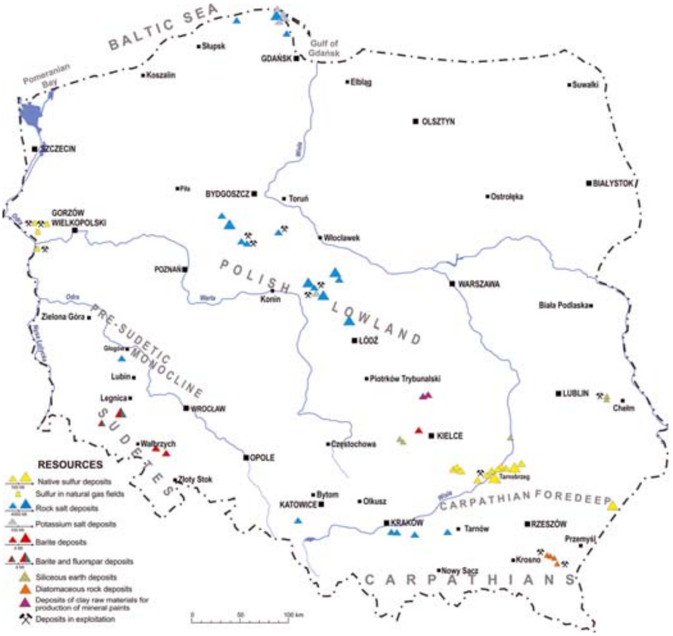

Figure 4.14. Map of chemical raw materials in Poland
Source: own study based on the http://geoportal.pgi.gov.pl/surowce/mapy

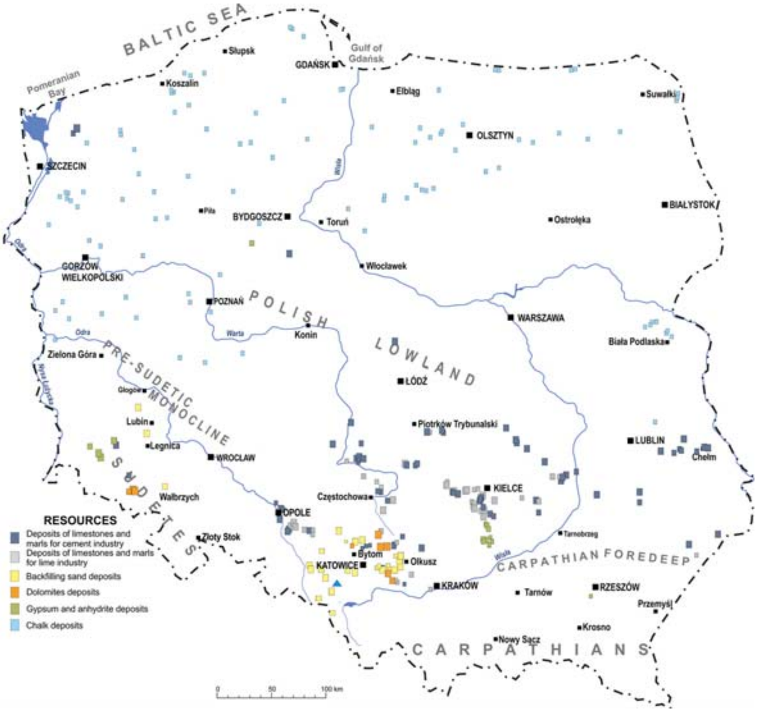

Figure 4.15. Map of industrial and construction minerals in Poland (selected)
Source: own study based on the http://geoportal.pgi.gov.pl/surowce/mapy

The total amount of industrial wastes generated in Poland declined from 143.9 Mt in 1990 to 125.5 Mt in 2000 and 115.9 Mt in 2011. The quantity of utilised wastes grew from 77.1 Mt (53.6%) in 1990 to 81.2 Mt (70.1%) in 2011. The majority of these wastes are generated in the three southern voivodeships: Śląskie (28%), Dolnośląskie (28%) and Małopolskie (5%) (Environment 2012).

According to official data of the Polish Central Statistical Office, wastes from mining and processing (waste code 01) are the largest group of wastes generated and deposited in Poland. In 2011 approx. 60.9 Mt of mining and processing wastes were generated, which constitutes approx. 53% of total amount of industrial wastes generated. The three main types of such wastes in Poland are (Environment 2012, Galos et al. 2009):

1) wastes from mining and processing of hard coal,
2) wastes from mining and processing of non-ferrous metals ores,
3) wastes from rock minerals extraction.

Mining and processing of chemical raw materials (salt, sulphur) currently generates only negligible amounts of waste: <2000 t/a (details see subchapter 6.6).

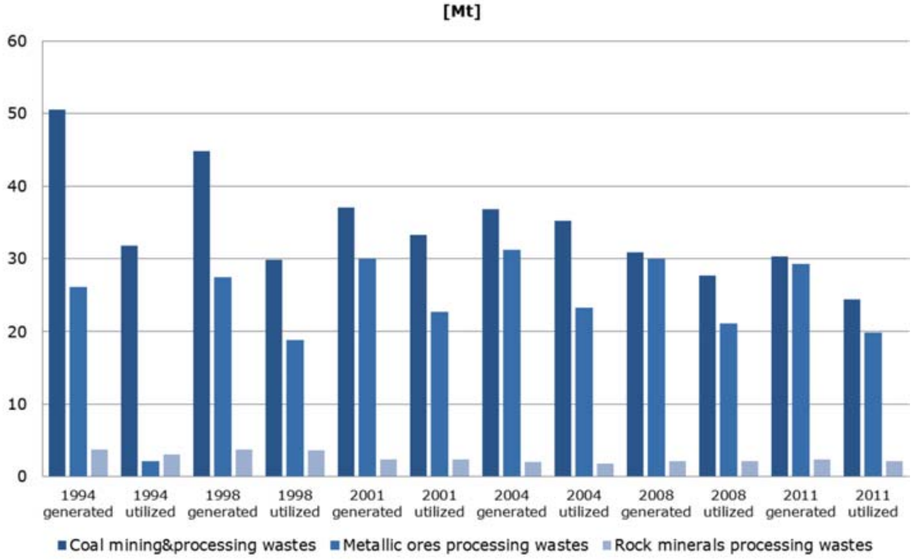

Figure 4.16. Mining and processing wastes generation and utilization in Poland between 1994 and 2011

Source: Environment 1995, 1999, 2002, 2005, 2009, 2012

Wastes from mining and processing of hard coal

In the hard coal industry, amounts of waste generated have been gradually declining, from 50–60 Mt/a over 20 years ago to approx. 40 Mt/a in 2000 and approx. 30 Mt/a in recent years. In 2011, 30.3 Mt of hard coal wastes were generated and 24.5 Mt of them were utilised (Figure 4.16). Approx. 4.1 Mt of such wastes were generated in 2011 due to activity of the only mine in the Lublin Coal Basin (Bogdanka Mine), while the rest in the mines located in Upper Silesia Coal Basin. The majority of the waste (approx. 93%) arises during processing in heavy liquids, jiggers, and slurry circulation. Flotation wastes make up 6% of the total amount, while mining wastes account for the rest. Statistics point to a high level of economic utilisation of hard coal industry wastes (80–90%). However, only approx. 30% of the waste is utilised in industrial applications, while over 70% is applied in ground levelling and other engineering works. According to official data, over 500 Mt of historical hard coal waste is deposited in numerous dumps in Upper Silesia and Lower Silesia[7] (the hard coal production in Lower Silesia was abandoned in the 1990s).

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[7] Dumps are defined as "earth structures", "landscape structures" or "reclamation structures" which are built for different purposes e.g. to serve as recreational sites, be integrated within the existing landscape or be reclaimed as woodlands.

Wastes from mining and processing of hard coal come from barren sedimentary Carboniferous rocks, which are extracted together with hard coal seams. Additional amounts of such materials come from preparatory mining works. These wastes, in general, can be divided into two main groups:

1) mining wastes from preparatory mining works, possessing very variable quality and properties, depending on the geological conditions of the extracted deposits, their granulation reaching even 500 mm;
2) processing wastes obtained as a result of hard coal processing; depending on the stage of processing and type of equipment they can be further divided into:
   - coarse-grained wastes from heavy liquids separators – uniform mineral composition, granulation 20–200 mm, coal content 5–15%, sulphur content <1%, humidity 4–6%;
   - fine-grained wastes from jiggers – uniform mineral composition, granulation <20 mm, higher coal content, sulphur content and humidity;
   - flotation wastes – very fine-grained, high content of coal, sulphur and moisture, presence of remains of flotation reagents and flocculants (Galos et al. 2009, Galos and Szlugaj 2012).

Regarding their petrographic composition, these wastes represent various proportions of claystone, mudstone, sandstone and rarely conglomerates, with a dominant share of claystone. Presence of sandstone is much less common than claystone or mudstone.

From a market utility perspective, the most promising varieties of hard coal wastes are coarse-grained mining wastes and coarse-grained processing wastes from heavy liquid separators. Their main current uses are:

- engineering, hydrotechnical and road construction, including aggregate production for such purposes;
- production of mineral raw materials for construction materials manufacture (cement, building ceramics);
- coal recovery and production of low-energy fuels for power plants;
- filling material for hydraulic filling of underground excavations.

Mineral aggregates can be produced from unburnt coal wastes and from burnt (oftentimes self-burnt) coal wastes. Haldex JSC. of Katowice is the main Polish producer of aggregates from unburnt coal wastes. Currently, the company has four aggregate production plants with total throughput capacities of 13 400 t/d. The next plant is under construction. In 2008, aggregates production from these plants amounted to approx. 1.8 Mt, while in 2012 it rose to over 3 Mt. Moreover, the company commenced two crushing and sorting units near the Knurów and Rydułtowy Hard Coal Mines (total throughput capacities

4000 t/d). Their combined aggregate production should reach 0.7–0.9 Mt/a. Various aggregates are produced in Haldex's plants: 0–31.5, 31.5–63, 40–90, 10–31.5, 0–63, 0–200 and 63(100)–150(200) mm (Galos and Szlugaj 2012). Mineral aggregates are also produced on the basis of self-burnt coal shale. Their total production varies between 0.5–1.0 Mt/a (Galos and Szlugaj 2012).

The cement industry is an important consumer of one type of coal processing waste, the coal shale obtained in Haldex plants. This material is used by cement plants (mainly plants located in Upper Silesia and in Opole region) as low component, silica-bearing and alumina-bearing material (0.15–0.25 Mt/a; Galos et al. 2009).

Coal shale obtained in Haldex plants is also used as a complementary raw material in production of ceramics for building materials, being used in the amount of 20–30% in several building ceramics plants in Upper Silesia (up to 0.1 Mt/a). Likewise, coal shale from the Bogdanka Mine near Lublin (granulation 20–80 mm) is used in an auxiliary, state-of-the-art plant as the main raw material for the production of building ceramics (Galos et al. 2009).

Coal wastes are also used in increasing amounts for coal recovery. Haldex JSC (throughput 1–2 Mt/a, coal recovery 0.1–0.2 Mt/a) and several minor companies, e.g. Gwarex Polska of Świętochłowice, Polho of Czerwionka are at the forefront of these efforts. These wastes are also the basis for the production of low-energy fuels for power plants. Usually, such products have calorific values of 10–18 MJ/kg. Since 2005, Haldex JSC. has set up such plants in a few locations (Koperski et al. 2008). The Southern Coal Concern (PKW) has also started to produce such fuels near its Janina and Sobieski Hard Coal Mine but with lower calorific values 5–9 MJ/kg (Galos et al. 2009).

Substantial amounts of coal processing wastes are used as filling material for hydraulic filling of underground excavations in Upper Silesian coal mines. They partly substitute filling sand, constituting up to 50% of filling mix. The amount of coal waste used for this application varies between 1 and 3 Mt/a at the Upper Silesia Region (Galos et al. 2009).

Wastes from mining and processing of non-ferrous metals ores

In non-ferrous metal ore mining and processing, the amount of waste generated has varied between 30 and 35 Mt/a, with some reduction in volume in recent years (Figure 4.16). In 2011, approx. 29.3 Mt of such wastes were generated, and approx. 68% of them were utilised, according to official data (Environment 2012). Flotation wastes from copper ore processing of KGHM's ore processing plants constituted the majority (approx. 27.8 Mt in 2011, e.g. 95%). Flotation wastes from Zn-Pb ores processing made up 4%, while mining wastes only 1%.

Economic utilisation of these wastes substantially rose, but this was primarily due to formal reasons, which are described further below.

65–75% of the flotation wastes from copper ore processing has recently started to be used as material in hydrotechnical engineering, i.e. for construction of barriers and sealing of the Żelazny Most tailings pond (Jasiński et al. 2003). Very small amounts of these wastes were utilised for the neutralization of contaminated sulphuric acid in copper smelters of KGHM Polska Miedź (Polish Copper) JSC. Use of flotation wastes from copper ore processing as a component of solidified filling material is anticipated in the coming years. The level of utilisation of this type of waste in such a way could involve as much as 7 Mt/a (Dębkowski et al. 2007). In the distant future, flotation wastes from copper ore processing will likely be treated as secondary materials for copper and silver recovery (Galos et al. 2009).

Flotation wastes from Zn-Pb ores processing in ZGH Bolesław (Mining-Metallurgy Plant) also started to be used as material in hydrotechnical engineering, i.e. for the construction of barriers and sealing of its tailings pond (approx. 60% of the total amount). They have also performed well as a component of hydraulic filling of the underground excavations at Olkusz mine (up to 0.2 Mt/a). Other processing waste from the ZGH Bolesław processing plant (dolomite rock waste from gravity separation of Zn-Pb ores) has traditionally been used for the production of dolomite crushed aggregates (up to 1.0 Mt/a; Galos et al. 2009).

Wastes from mining and processing of rock minerals

Wastes arising from rock minerals extraction and processing constitute the third most important source of mineral waste in this group. The volumes of these wastes generated and utilised, as reported by the Polish Central Statistical Office, are substantially underestimated. According to this official information, generation of wastes from rock mineral mining varies between 2.3 and 3.6 Mt/a (2.4 Mt in 2011, Figure 4.16), and the majority of them are utilised (Environment 2012). However, it is estimated that the total volume of these wastes varies between 8 and 11 Mt/a, while the level of their utilisation does not exceed 30%. There is a lack of detailed information, and estimates are based on information from the Polish Geological Institute's MIDAS database. The following types of wastes are classified in this group: wastes obtained during extraction and processing of compact rocks (limestone, dolomite, sandstone, magmatic rocks), as well as of clays, sand and gravel.

The most important applications of wastes in this group are (Galos et al. 2009):

- Civil engineering (road construction, ground levelling and other engineering works) – processing wastes from crushed aggregates and sand & gravel aggregates production.
- Use of wastes from dimension stone dressing as raw material for crushed aggregates production.

- Recovery of lower quality kaolin raw materials from glass sand washing and their use in the ceramic industry (ceramic tiles production).
- Application of fine-grained granite processing wastes as lower quality feldspar-quartz raw materials for ceramic tiles production.
- Use of fine-grained chalcedonite wastes in the ceramic industry and cement industry.
- Application of fine-grained limestone wastes from limestone rock production for lime production, for the purposes of cement industry.
- Use of lower quality industrial dolomite for crushed aggregates production.
- Application of fine-grained limestone and dolomite wastes as Ca and Ca-Mg fertilizers.

4.7. Mining and processing waste management in Sweden

Sweden has four major mining districts; Norrbotten, Skelleftefältet, Bergslagen and Gotland. Currently, iron, apatite, copper and gold is mined in Norrbotten; copper, zinc, lead, silver and gold is mined in the Skellefteå area; iron, zinc, lead, silver, dolomite, feldspar and slate are mined in Bergslagen, while dolomite is mined on the island of Gotland (Table 4.10 and Figures 4.17–4.20).

Table 4.10. Extraction, reserves and resources of the main minerals in Sweden

Mineral	**Unit**	**Mining extraction in 2011 (*2009)**	**Non classified estimated resources ******
Fuels (Energy raw materials)			
Crude oil	m^3	0	100 000
Oil in oil shale	Mt	0	452
Uranium	t	0	10 000
Energy peat	Mm^3 MWh	2 139 1 926 000	5 150 000 000
Natural gas	Gm^3	0	***
Metallic raw materials			
Iron ores	Mt gross Fe	26.1	670
Copper ores	Mt Cu	0.083	1.8
Gold ore	kg Au	5994	188 000
Silver ores	kt Ag	0.302	5.25

Table 4.10. cont.

Metallic raw materials cont.			
Zinc ores	Mt Zn	0.194	2.6
Lead ores	Mt Pb	0.062	1
Molybdenum	Mt Mo	0	0.204
Tellurium	t	0	**535
Graphite	Mt gross	0	**2.6
Heavy Rare Earth Elements	Mt		**0.172
Light Rare Earth Elements	Mt		**0.167
Zirconium	Mt		**0.988
Industrial and construction minerals (main)			
Dolomite, industrial	Mt	0.483	***
Feldspar	Mt	0.080	***
Quartz	Mt	0.163	***
Quartz sand	Mt	0.143	***
Slate	Mt	0.008	***
Talcum	Mt	0.004	***
Crushed industrial dolerite	Mt	0.664	***
Clay	Mt	0.402	***
Limestone, industrial	Mt	7.317	***
Dimension stone dolerite, gabbro	Mt gross	0.264	***
Dimension stone gneiss	Mt gross	0.159	***
Dimension stone granite	Mt gross	0.491	***
Dimension stone marble	Mt gross	0.053	***
Dimension stone other	Mt gross	0.047	***
Crushed rock, aggregate*	Mt	*57 470	***
Sand and gravel*	Mt	*14 377	***
Morane/till*	Mt	*2 361	***

Sources:
* The Geological Survey of Sweden (2010),
** Summary of available company reports 2011–2012,
*** Present, but numbers not available,
**** The Geological Survey of Sweden (2008).

In 2012, Sweden's 13 metal mines produced 32.198 Mt of iron ore, 40.284 Mt of sulphide and gold ore and had approx. 6000 direct employees. The ores exploited had a metal content of 26.5 Mt of iron, 64 000 t of lead, 188 000 t of zinc, 83 000 t of copper, 309 t of silver and 6 t of gold. A summary of the reserves and resources present in Sweden are provided in table 4.10 and figure 4.17.

In 2011, the production of 68 Mt of ore yielded 53 Mt of waste rock and 41 Mt of waste sand. Of the total 94 Mt, an estimated 2.2 Mt of waste rock and 1 Mt of waste sand was used for backfilling and 0.4 Mt of waste rock was used for constructions (such as dams) on site, the balance being stored in dams and piles. In addition to this, LKAB Berg och Betong AB (subsidiary of Sweden's largest producer of iron ore) produced 0.8 Mt heavy concrete ballast from 2nd class iron-ore pellets, 0.3 Mt ballast from waste rock and gained another 3 Mt iron ore by reprocessing 10 Mt of more than 100 year old mining waste.

The amount of mining waste produced from metal mining in Sweden 2011 (94 Mt), according to the Swedish Environmental Protection Agency, accounted for more than 75% of all waste produced in Sweden 2011 (Naturvardsverket 2013).

Generally, all operations (metal mines, industrial mineral mines and quarries as well as quarries producing crushed rock) recover better qualities of waste rock for on-site crushing to be used as road material in the mine and the industrial area that surrounds it. Sometimes the waste is free from potential environmental pollutants and can thus be sold outside the company.

Mines also store waste in heaps for backfilling of the quarries after mining has finished and some heaps will also be reshaped as part of a "new" landscape. Large amounts (here, the statistics are incomplete) are also stored "for the time being", waiting for new markets or ideas for possible use. While temporary storage is a practical option for companies, the 2006/21/EC Directive has imposed a restriction on such practices by adding a new 2-year time limit, after which the storage may be reclassified as permanent disposal.

Mining waste is normally not allowed to be used outside of the operational area (e.g. as a material for construction of noise walls, in landfill for constructions). In order for this to happen a permit that certifies that e.g. the metal content is below a certain threshold is required.

The volume of ore, waste rock and waste sand from metal mining in Sweden 2011 is presented in table 4.11.

Table 4.11. Production of metalliferous ores, related waste and use of waste in Sweden in 2011

Mine (Operation)	Mining method	Metal	Ore production, (t/a)	Waste rock out of the mine (t/a)	Processed at	Amount of ore that after processing is classified as wastes sand in % of ore delivered to plant.	Annual output of wastes sand (t/a)	Amount of waste sand in storage at the end of 2011 (t)	Amount of waste rock that was used for backfilling in 2011 (t)
Kirunavaara (LKAB)	Underground	Fe	18 086 099	8 437 101	Kiruna	77%	4 100 000	Not reported	Not reported
Kirunavaara, Svappavaara, Malmberget (LKAB)	Reworking of waste and 2nd class pellets	(Fe)	3 000 000	7 000 000	Kirunavvaara Svappavaara Malmberget	NA	NA	NA	NA
Malmberget (LKAB)	Underground	Fe	10 233 796	6 632 934	Malmberget	82%	1 800 000	Not reported	Not reported
Gruvberget (LKAB)	Underground	Fe	1 529 128	405 472	Svappavaara			Not reported	Not reported
Garpenberg (Boliden)	Underground	Zn, Pb, Ag	1 440 870	952 329	Garpenberg	85%	809 000	Not reported	404 000
Aitik (Boliden)	Open pit	Cu, Au	31 541 127	29 580 290	Aitik	99%	29 284 000	400 000 000	1 000 000
Renström (Boliden)	Underground	Cu, Pb, Zn	275 412	53 990	Boliden	92%	50 000	0	0
Kristineberg (Boliden)	Underground	Cu, Pb, Zn	600 131	161 100	Boliden	92%	148 000	0	0
Maurliden (Boliden)	Underground	Cu, Pb, Zn	0	220 527	Boliden	92%	203 000	0	0
Maurliden Östra (Boliden)	Underground	Cu, Pb, Zn	590 203	545 636	Boliden	92%	502 000	0	0
Anrikningsverk (Boliden)	NA	Cu, Pb, Zn, Au, Ag	NA	NA	Boliden	NA	Reported on individual Boliden mines above	Reported on individual Boliden mines above	NA
Zinkgruvan (Lundin Mining)	Underground	Zn, Pb, Ag	1 131 872	459 348	Zinkgruvan	80%	367 000	Not reported	Not reported
Lovisagruvan (Lovisagruvan AB)	Underground	Zn, Pb, Ag	36 840	31 504	Garpenberg	85%	27 000	Not reported	Not reported
Svartliden (Dragon Mining Ltd)	Open pit	Au	169 706	3 129 170	Svartliden	100%	3 126 041	Not reported	NA
Bjorkdal (Bjorkdalsgruvan AB)	Open pit and underground	Au	1 090 847	1 780 440	Bjorkdal	100%	1 000 000	22 000 000	NA
Sum for 2011			69 726 031	59 389 751			41 414 041	422 000 000	1 404 000

Source: Bergskraft interviews with mining companies between December 2012 – February 2013

Table 4.11. cont.

Mine (Operation)	Amount of wastes that was used for backfilling in 2011 (t)	Amount of waste rock used for "on site" construction 2011 (t)	Amount of waste rock in storage at the end of 2011 (t)	Amount of certified waste rock in storage 2011 (t)	Reuse of waste rock, commercial products	Comments
Kirunavaara (LKAB)	Not reported	Not reported	Not reported	Not reported	Aggregates, crushed rock	
Kirunavaara, Svappavaara, Malmberget (LKAB)	Not reported	Not reported	Not reported	Not reported	0.500–0.8 Mt of heavy ballast produced annually from 2nd class pellets, 0.3 Mt aggregate produced annually from old waste rocks and 3 Mt of iron ore recovered by reworking of 10 Mt from >100 yrs old waste rock dumps per year	LKAB Berg och Betong AB are producing large quantities aggregate and crushed rock
Malmberget (LKAB)	Not reported	Not reported	Not reported	Not reported	Aggregates, crushed rock	
Gruvberget (LKAB)	Not reported	Not reported	5 095 000	Not reported		Started 2011, numbers not long-term indicative
Garpenberg (Boliden)	952 329	Not reported	Not reported	Not reported	Backfilling underground and backfilling of old open pit at Garpenberg Norra. Some sorted and certified waste rock sold externally.	Waste rock to be used for underground backfilling, never passes the surface and is not included in numbers
Aitik (Boliden)	Not reported	Not reported	Not reported	85 000 000	Certified crushed waste rock is put in separate storage for future sales	
Renstrom (Boliden)	Not reported	Not reported	Not reported	Not reported		Ore processed at central Boliden plant
Kristineberg (Boliden)	Not reported	Not reported	Not reported	Not reported		Ore processed at central Boliden plant
Maurliden (Boliden)	Not reported	Not reported	Not reported	Not reported		Ore processed at central Boliden plant
Maurliden Ostra (Boliden)	Not reported	Not reported	Not reported	Not reported		Ore processed at central Boliden plant
Anrikningsverk (Boliden)	NA	NA	NA	Not reported		Collects ore from all Boliden mines
Zinkgruvan (Lundin Mining)	450 000	225 000	Not reported	Not reported	About 50% of waste rock is used for backfilling underground and never reaches the surface. Is not included in statistics. Currently 50% of waste rock to surface is used for construction of sound barrier and construction of waste sand dam	
Lovisagruvan (Lovisagruvan AB)	26 800	4 704	Not reported	Not reported	About 15% of waste rock used for construction. The balance, 85% is used for backfilling	Waste rock not environmentally certified
Svartliden (Dragon Mining Ltd)	Not reported	Not reported	Not reported	Not reported	90–100% of waste rock goes to disposal. Some internal usage of crushed rocks	Waste rock not environmentally certified because of arsenic content. All waste rock stored underground in old historical voids
Bjorkdal (Bjorkdalsgruvan AB)	Not reported	25 000	40 000 000	Not reported	External aggregate company NCC has option to use all waste rock. About 100–200 kt/yr is sold externally and 20–30 kt/yr is used for own constructions. The balance is disposed	The waste sand is very clean according to the company and could very well be sold and used for construction purposes. However this is not possible because what is described as "bureaucratic reasons"
Sum for 2011	2 212 329	254 704	45 095 000	85 000 000		

Source: Bergskraft interviews with mining companies between December 2012 – February 2013

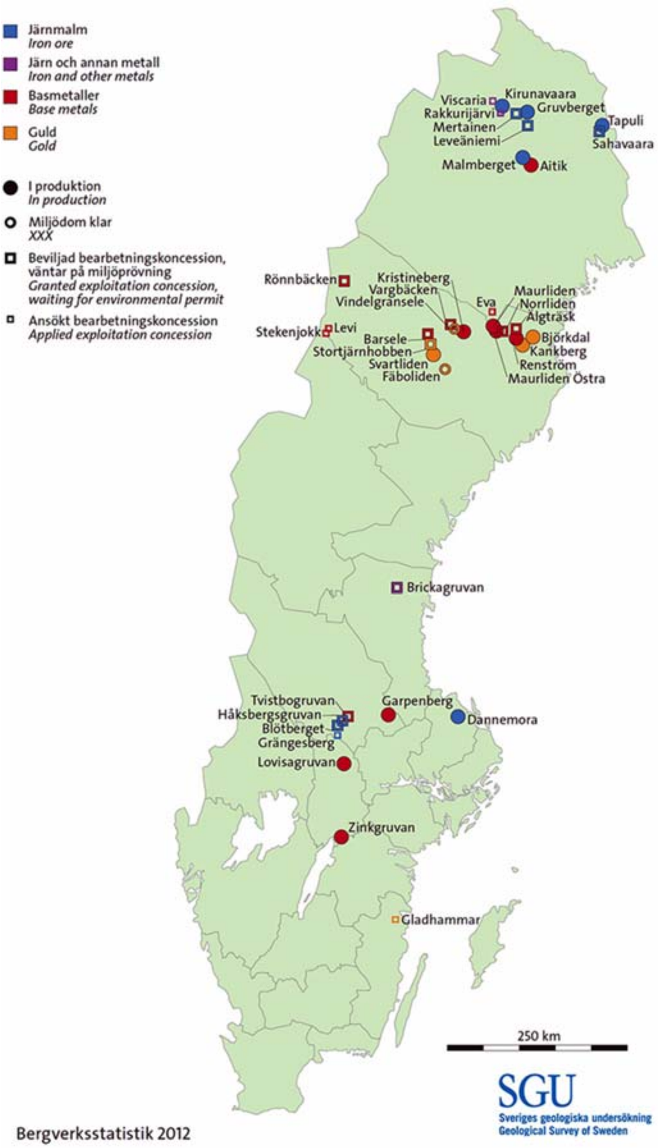

Figure 4.17. Operating metal mines in Sweden 2012
Source: Geological Survey of Sweden 2013

There are about 30–35 sites in Bergslagen (open pit and underground) with current production of carbonates (calcite/dolomite), marble, feldspar, slate and schist (Figure 4.18) and 57 quarries that secured permission to produce dimension stone in 2011 (Figure 4.19). The number varies due to market conditions. These quarries are regulated under a specific chapter of the Minerals Act and are not required to report sales in the same way as the metal producing mines. There is likewise no information on amounts of mining waste generated or reuse thereof from this segment of the minerals sector.

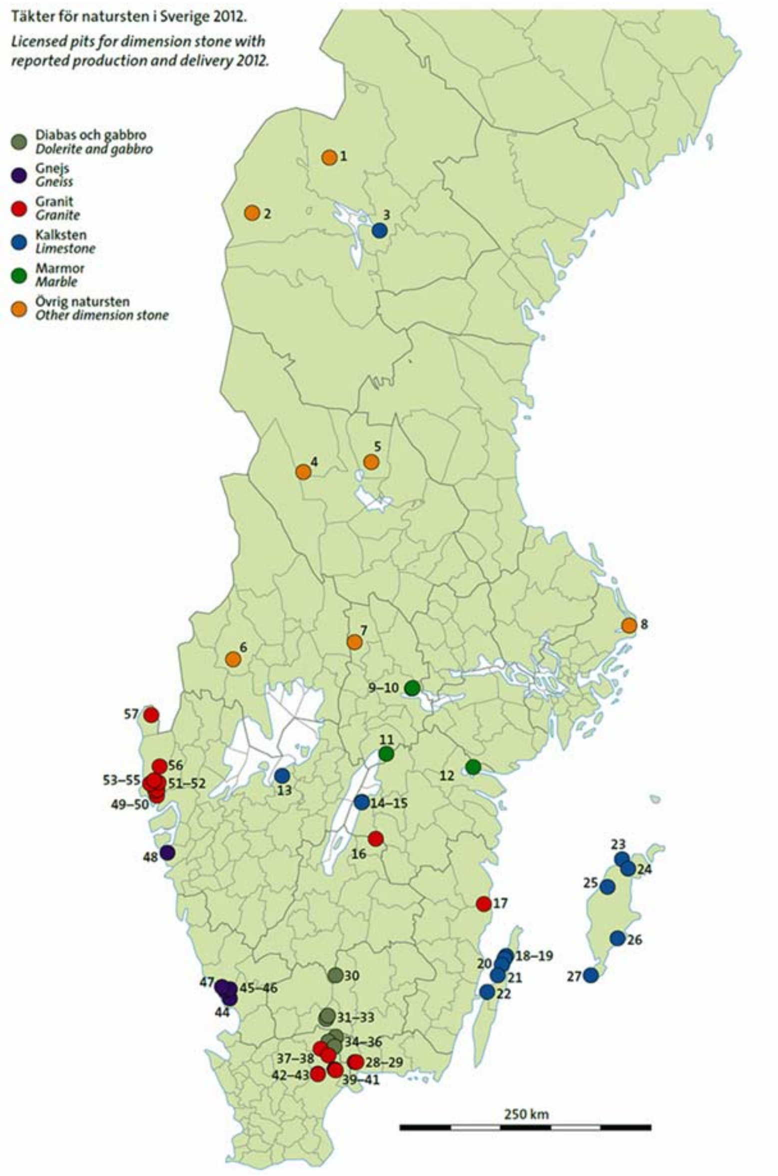

Figure 4.18. Operating industrial mineral quarries in Sweden in 2012
Source: Geological Survey of Sweden 2013

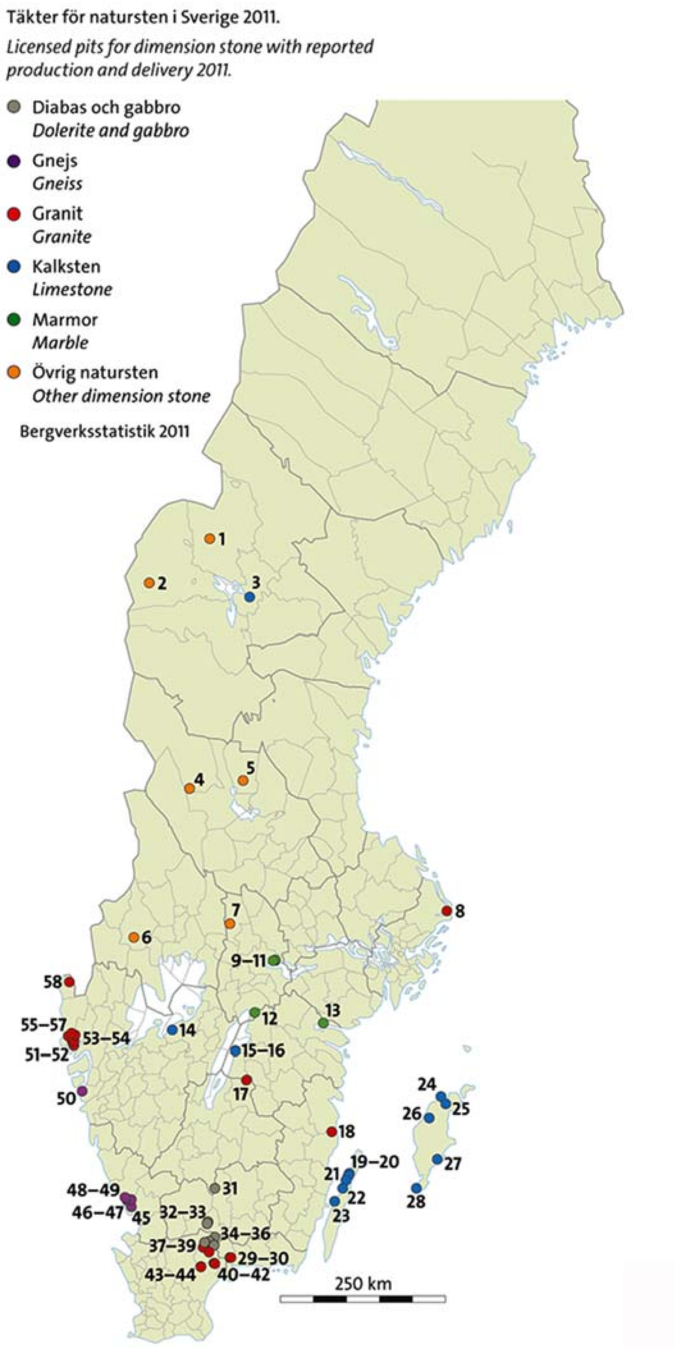

Figure 4.19. Operating dimension stone quarries in Sweden in 2011
Source: Geological Survey of Sweden 2012

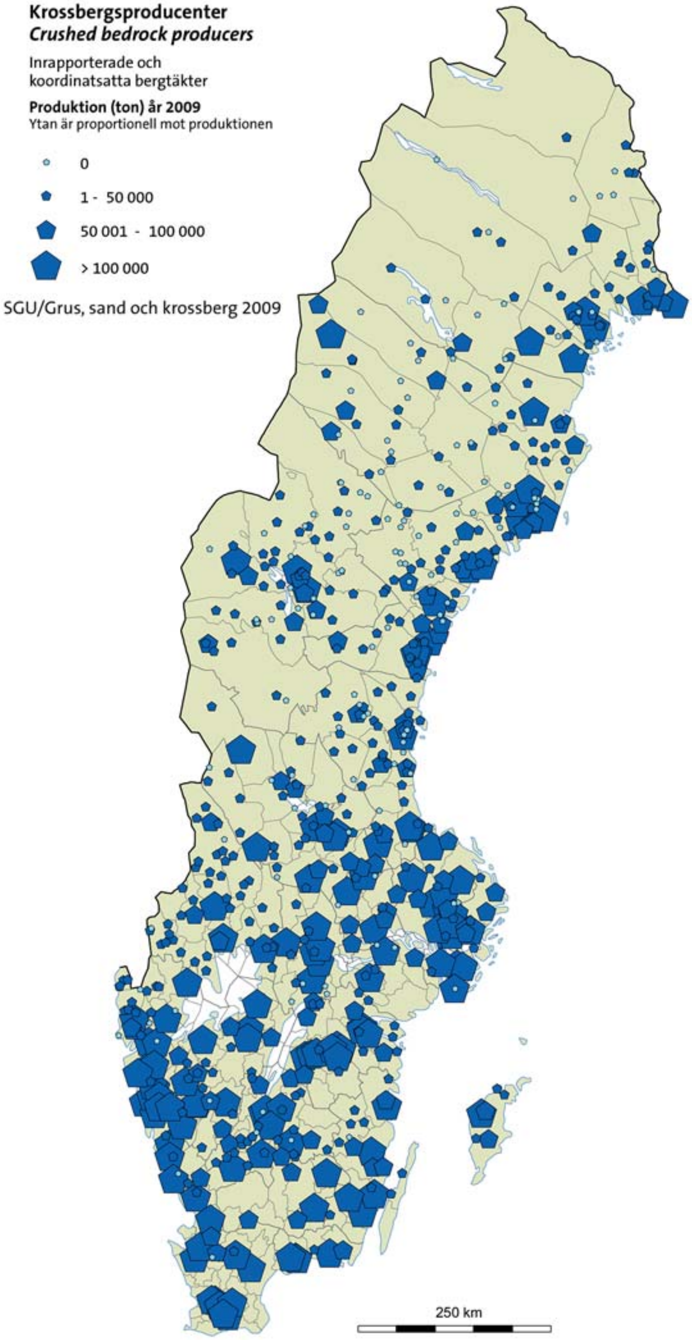

Figure 4.20. Operating aggregate/ballast quarries 2009
Source: Geological Survey of Sweden 2010

There are 1994 quarries with permission to produce crushed rock in Sweden (Figure 4.20). These quarries delivered 64.7 Mt of crushed rock in 2011. 64% was used for road construction, 6% in concrete, 16% in fillings, 0.3% as boulders and 14% for other purposes. The amounts of mining waste created from the extraction of these volumes has not been reported to the public, nor is there any information on reuse of mining waste from this industry.

Information from the branch organization shows that there are research efforts underway to minimize and find usage for drill dust, stone powder and mineralogically mixed materials.

Historical mines – estimated resources and recovery prospects

In the Bergslagen area, metal mining has been going on since medieval times, whereas mining on a larger scale started in the late 19th century in Norrbotten and in the Boliden/ Skellefteå area in 1920s.

There are no statistics for the total amounts of historical mining waste in Sweden. The earliest recorded mining in Sweden (Falun, about 500 AD) is from the Bergslagen area (surface area 62 000 km^2) where thousands of operations are recorded to have had some production over a more than 1000 year-long period.

Some estimation of volumes of mining waste from historical mining has been made. For instance, it is estimated that the Bergslagen mining district (62 000 km^2) has more than 10 500 historical mines. A more detailed inventory has been done in a subarea; the Dalarna county (15 000 km^2) where about 2000 historical mines are known to have existed. Of these 2000, the top 43 historical, base metal mines are estimated to have some 2.4 Mt of mining waste and about 7 Mt waste sand in disposal. Also more than 1.3 Mt of historical slag is recognized in the same county. For all of Bergslagen, the number of historic mines is in excess of 11 000.

Most of the knowledge about Sweden's and Bergslagen's metal mining waste has been collected for environmental monitoring purposes rather than mining. A consequence of this is that the information is not fully useful for estimates on quantities or estimations on extractable amounts of metals or minerals. It does however give an indication on what elements are present and where these elements are to be found. The before mentioned inventory concerned 43 historical base metal sites with mining waste, which have also been monitored to estimate the annual release of metals from the old mining areas. The 43 sites were estimated to, per year, release:

- 9 235 kg copper,
- 81 510 kg zinc,
- 107 kg cadmium,
- 509 kg of lead.

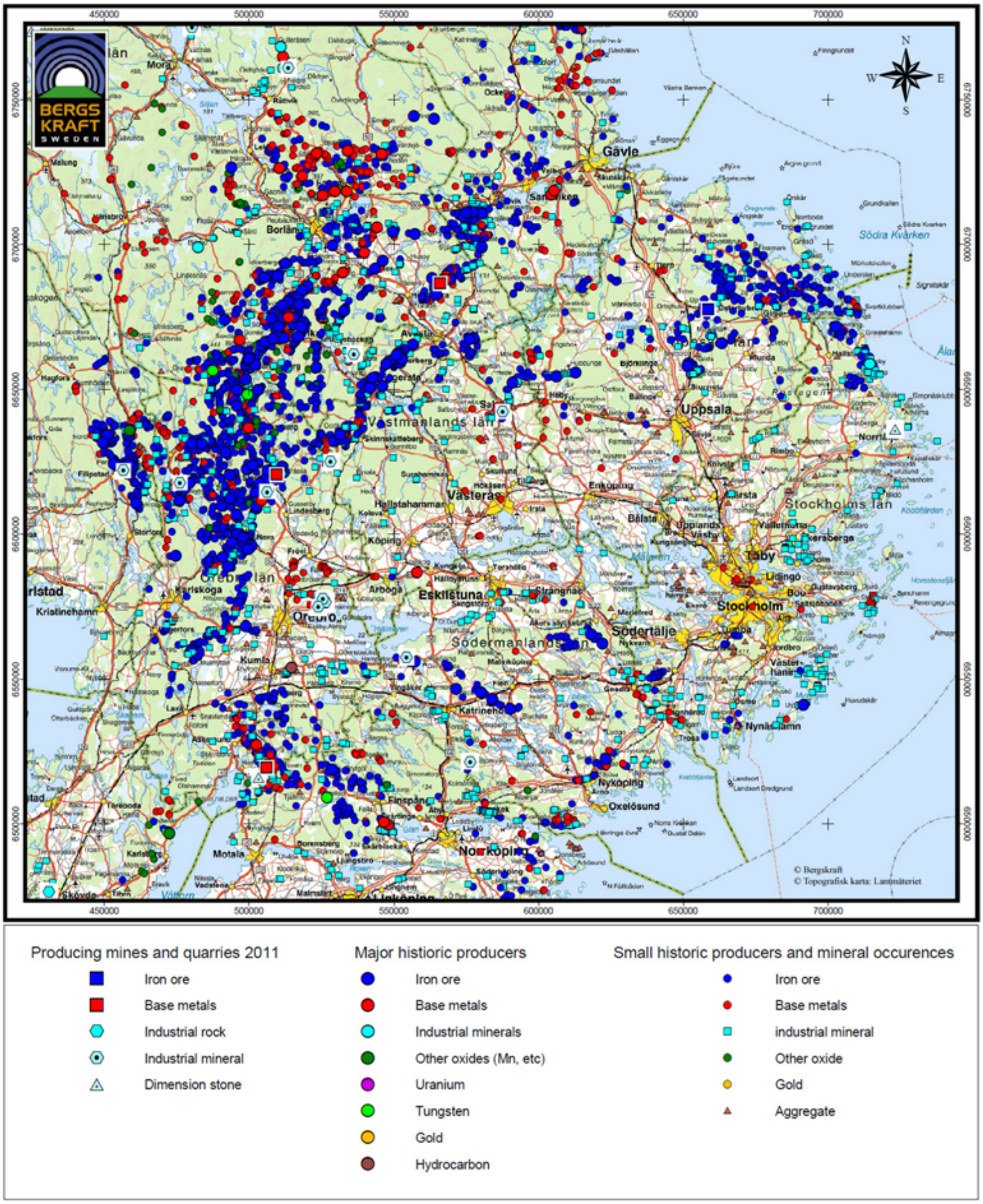

Figure 4.21. The Bergslagen area in Sweden – mineral deposits and producing mines (2012)
Source: Bergskraft

At historical as well as abandoned mine sites without links to an active mining company, responsibility for any environmental impact becomes a very complicated and challenging issue. A relatively recent change in the relevant legislation and its interpretation has forced landowners to accept the obligations for environmental and other hazards related to the old mine. This has caused many landowners to object, particularly those who have bought the property without the intention of making the old mining site a part of their business. Currently, the new interpretation is being implemented and so at the moment most mining waste sites are left unused and not rehabilitated, awaiting more promising developments in the legislation as well as the interpretation thereof.

Despite the uncertainty about how historical waste should be managed and what the responsibilities of landowners in this respect are, the reuse potential of mining waste has been and is well known in this region. In keeping with an age-old tradition, historical mining waste in the Bergslagen area is recovered from the Ljusnarsberg Cu-Zn-Pb mine in Kopparberg and the Falun Cu-mine for production of "Kopparberg Pigment" and "Falu Rödfärg". Both produce red pigment for paint manufacturing from Fe-oxide, and sulphide rich mining waste. Meanwhile, crushed rocks for gravel and construction are produced from historic mining waste at the old Ställberg iron ore mine, the Svartvik manganiferous iron ore mine, Haggruvan iron ore mine and the Stråssa iron ore mine.

Research on environmental aspects of mining waste

At the moment there is some research on methods to rehabilitate abandoned mine sites and treat acid rock drainage produced by sulphide mining waste. In Sweden, the most active research in this field is being conducted at the Universities of Luleå and Örebro and by the Bergskraft projects and organizations.

4.8. Conclusion

It is a challenge to present a uniform and easily comparable overview of mining and mining waste management in the countries involved in the Min-Novation project. There are several reasons for this:

- Differences between definitions concerning categories of mineral resources in particular countries and different methodologies of data collection.
- The diversity of definitions related to the management of waste from extractive industries and different approaches of data collection.
- The lack of an inventory of landfills, especially historical ones in most of the countries represented in the project.

Notwithstanding these limitations, the following observations can be made:

- In the countries, which took part in the Min-Novation project, mining activity continues to play an important role in their economies, albeit not as significant as was once the case. The mining industry in Estonia is focused on oil shale, in Finland, Sweden and Poland on metallic minerals. Poland continues to heavily draw on hard coal mining resources. Norway is world leader in oil extraction.

- Waste generated during extraction and processing activities is either stored on heaps or used for engineering work and sold as a valuable product. Some kinds of waste before use need to be processed (undergo recovery), while others can be taken up directly by end-users.
- The main applications of mining waste are: in civil engineering (e.g. road construction, dams building, technical reclamation including ground leveling or excavations filling) and in the production of e.g. aggregate, cement, pigment and fertilizers.

5. Legal framework of mining and processing waste management

5.1. Introduction

The policy shift towards greater support for raw material extraction in Europe in the last few years – best reflected in the Raw Materials Initiative and the subsequent European Innovation Partnership for Raw Materials, as well as a host of national initiatives such as Finland's Green Mining Programme, Sweden and Norway's Mineral Strategy, to name only a few – covers the entire life cycle of the mine. This has meant that secondary raw material recovery and mining waste management in general are gaining ground as legitimate policy topics. Even though mining waste management is already regulated by EU and national law, and performance standards are set forth in Best Available Technique (BAT) documents and various other guidelines, areas still remain within the legal framework, which are open to different interpretations.

The 2006/21/EC Directive on the management of waste from the extractive industry is the basis for the majority of measures, procedures and guidance to prevent or reduce as far as possible any adverse effects on the environment and any resultant risks to human health, brought about as a result of the management of waste from the extractive industries. As such, it is the main reference document in this chapter.

What follows is a concise description of the background to the current EU legal framework concerning mining waste and the degree of implementation of relevant directives into the laws of selected Baltic Sea Region countries. The final section reveals several challenges relating to mining waste management as a business activity, which are derived from the current set of mining laws, using Poland as a case study.

5.2. Past and present milestones in the development of EU policy on mining waste

The current EU legal framework for mining and processing wastes is strongly influenced by past overregulation as well as by the large-scale abandonment of geological sciences and mining in Europe starting in the 1980s.

For twenty years, the majority of EU Member States had been scaling back their geological surveys or focusing on exploration of other continents. At the same time, the fall of the "iron curtain" left Europe with the legacy of a large number of mines that had been opened and operated under the failed economic paradigm of soviet communism and which had quickly proven to be uneconomic when fully exposed to the rest of the global market. This, combined with final closures of hard-coal mines in France and Germany, tended to fuel the developing myth that Europe had exhausted its mineral wealth as a means of achieving its economic development and that its future now lay in becoming a specialised "knowledge-based" economy.

The EU that has resulted is a highly-regulated and ever-evolving jurisdiction that is the biggest single market in the world, but that also faces fierce and sometimes unfair competition at international level.

The properties of extractive wastes are site-specific. Depending on the type of minerals extracted and the local mineralogy there is a wide spectrum of materials ranging from inert to potentially acid producing rock with high levels of trace metals. On the other hand, it is possible to characterize the waste at a specific mine in great detail, something that is not possible at a landfill receiving waste from different sources.

The volumes of waste produced and managed within the mining industry, in combination with the fact that the potential impacts and possible solutions vary from site to site, makes it necessary to develop tailor-made technical solutions that meet high environmental standards without putting unrealistically high financial burdens on the sector. This in turn requires a legislation that is flexible enough to allow for site-specific solutions.

The initial focus of the EU on ensuring safe recovery or disposal of waste, without considering the specificities of extractive waste, led to application of EU legislation being costly and in some cases even detrimental for the environment[8].

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[8] SveMin (2000) personal communication.

The rise of the emerging economies (e.g. Brazil, Russia, India, China) since the turn of the century has triggered concern about secure supply of raw materials and a strategy re-think. Now, the EU faces the challenge of re-industrialising under a set of laws that does not encourage investment in heavy industry and having lost much of the considerable expertise that formerly existed in national geological surveys, mining inspectorates, ministries and universities. Additionally, the EU now faces a "transformation" of its economy in order to free-up the management of waste streams for maximum resource efficiency.

Current challenges related to raw-materials and waste include meeting the "base-load" demand for minerals, remaining relevant in a global economy – e.g. having something to sell to the world, increasing competition for resources and therefore increasing supply risks, further de-coupling of economic growth from resource and energy use (producing more value from the material used).

Meeting the "base-load" involves supplying the minerals required to upgrade and maintain infrastructure (health, transport, energy), to accommodate increased urbanisation, to deploy new sustainable technologies, to share equitably the benefits of new technologies across the whole of the Union and to re-balancing lifestyles and employment across the different regions of the Union (Euromines 2011).

A number of major accidents (Aznalcóllar, Spain in 1998; Baia Mare, Romania in 2000; Ajka, Hungary in 2010) have further hampered investment in the mining sector in Europe, but have also helped to trigger modernisation of the legal framework. Shortly after the accident at Baia Mare, the European Commission published a "Communication on the Safe Operation of Mines". The communication announced two substantial new regulatory actions:

1) The development of a Best Available Techniques document on the management of tailings and waste rock (European Commission 2009).
2) The development of a European Directive on the management of waste from the extractive industries (Directive 2006/21/EC).

Then, facing a tightening of the global market for metals and minerals during the first decade of the 21st Century, the European Commission launched the EU Raw Materials Initiative in 2008. The Raw Materials Initiative sets out three pillars of a comprehensive response: the first two pillars seek to diversify the EU's sources of raw materials and to replenish stocks and the third seeks to maximise the efficiency with which raw materials are used within the EU.

Recognising that innovation is the indispensable and fundamental basis of growth in the EU, a European Innovation Partnership on Raw Materials was launched at the end of 2012 to bring together raw-material suppliers and raw-material users and to ensure that innovations with a societal benefit get to the market more quickly.

The European mining sector currently comprises large and small companies that provide jobs to more than 350 000 people and extract more than 42 different metals and minerals. A large number of valuable raw material deposits remain to be exploited in Europe and the mineral supply industries of the EU have a strong growth potential. The sustainable exploitation of Europe's own mineral resources can ease its supply constraints, foster the socio-economic growth of its poorer regions and provide support that is now acknowledged as crucial for the competitiveness of European industry generally (Euromines 2012).

5.3. EU-level directives and their impact on regional policies

A number of European environmental directives have been put in place in reference to the extractive industry (Table 5.1).

Table 5.1. EU directives relevant to the extractive industry

Directive	Number
Major Accidents Involving Dangerous Substances Directive	Directive 2012/18/EU (4 July 2012)
Environmental Impact Assessment (EIA) Directive	Directive 2011/92/EU (13 December 2011)
Water Framework Directive	Directive 2000/60/EC (23 October 2000)
EU Environmental Liability Directive	Directive 2004/35/EC (21 April 2004)
Management of Waste from Extractive Industries Directive	Directive 2006/21/EC (15 March 2006)
Integrated Pollution Prevention and Control (IPPC) Directive	Directive 2008/1/EC (15 January 2008)

The Major Accidents Involving Dangerous Substances Directive (Directive 2012/18/EU) sets forth the rules for operators of facilities where dangerous substances are present so that all necessary safety systems, emergency plans and other precautions are in place, and the facility knows what it is obligated to provide to public authorities in case of an emergency. The Directive does not cover the exploitation of minerals, with one exception: where chemical and thermal treatment operations and storage connected with such operations lead to the presence of dangerous substances.

The Environmental Impact Assessment (EIA) Directive (Council Directive 97/11/EC, amended in 2003 and 2009, codified as directive 2011/92/EU in 2011) requires that public authorities carry out an assessment of the direct and indirect impact that a given project has on the environment. The assessment applies *inter alia* to all quarries and open-cast mine sites where the surface of the site exceeds 25 ha or, in the case of peat extraction, exceeds 150 ha. The EIA however leaves it to the Member States to decide whether it is mandatory for other types of facilities to undergo assessment. This concerns *inter alia* facilities producing and processing metals, quarries/open-cast mines and peat extraction facilities with a surface area below the threshold provided above and underground mines. The Directive obligates the developer to provide the appropriate information to interested parties prior to the decision on whether the project is to proceed. The opinions of the interested parties have to be taken into account in the approval procedure.

The Water Framework Directive (Directive 2000/60/EC) sets down the framework for protecting surface, groundwater, coastal and transitional waters. Member States are required to identify and list all river basins within their jurisdiction, and carry out an analysis describing the key characteristics of each river basin district, impact on the water of human activities or the economic aspects of water use. Management plans are to be prepared for each river basin district. These management plans shall contain information of relevance to a variety of mining and extraction activities. The Member States may under certain conditions (apart from geothermal purposes) allow for reinjection of pumped groundwater from mines and quarries. There are six daughter directives under the Water Framework Directive, which have relevance to mine drainage and some of these set environmental quality standards for specific pollutants.

The Environmental Liability Directive (2004/35/EC) focuses on setting up a framework for environmental liability, using the ‘polluter pays’ principle as a reference point with the goal of preventing and mitigating environmental damage. Management of extractive waste is subject to this Directive. Mine operators or owners of extractive waste disposal sites are obligated to take any necessary preventive measures to avoid environmental damage, carry out restorative actions when environmental damage has already occurred, and undertake remedial actions that will decontaminate the area affected and, in the case of water, protected species and natural habitats, restore and replace the affected resources at the site or, if necessary, at an alternative site.

The Integrated Pollution Prevention and Control (IPPC) Directive does not apply to the extractive industry, although some member states have applied their corresponding legislation to mines (e.g. Ireland’s national legislation covered mining before the IPPC Directive was adopted at EU level).

A final act directly addressing the environmental performance of the extractive industry is the Management of Waste from the Extractive Industries Directive (called

“Mine Waste Directive“) (2006/21/EC). This directive applies specifically to waste resulting from the extraction, processing (treatment) and storage of mineral resources, and the working of quarries. The Mine Waste Directive provides for measures, procedures, and guidance to prevent or reduce as far as possible any adverse effects on the environment brought about as a result of the management of waste from the extractive industries.

According to the Mine Waste Directive, no extractive waste management installation, other than certain installations containing non-hazardous waste from prospecting, inert waste, unpolluted soil or waste resulting from peat extraction can operate without a permit issued by the competent authorities. Member states must ensure that operators of the mining waste facility draw up a waste management plan with the objective to prevent or reduce the generation of waste and its negative impact and to encourage waste recovery through recycling, reusing or reclaiming. Waste facilities may be of two types according to their potential risks: a waste facility whose failure or incorrect operation would present a substantial accident hazard (category A), and all other waste facilities (not category A). For facilities in category A, the competent authority must compile an external emergency plan for the measures to be taken off-site in the event of an accident. The operator must provide a financial guarantee before the beginning of waste processing operations so as to ensure that the provisions of the Directive are complied with and that the financial resources for restoring the site are always available. A mining waste facility is regarded as finally closed when the competent authority conducts a final inspection, studies the reports submitted by the operator, confirms that the site has been reclaimed and gives its approval. After closure, the operator must maintain and monitor the site for as long as the competent authority considers necessary. One of the documents intended to guide the regulation of waste management as provided for in the 2006/21/EC Directive is the BAT (Best Available Techniques) reference document for Management of Tailings and Waste Rock in Mining Activities (EC 2009), which was adopted in January 2009. The BAT Reference Documents (BREF) represent a snapshot of BAT, which necessarily lags behind the industry’s innovative project plans and this could lead to lengthy permitting and regulatory negotiations between updates of the BREF (Drielsma and Cambridge 2007).

Though, traditionally, mineral planning policies and mine and quarry permitting are controlled by Member States of the European Union, the growing number of EU-wide environmental regulations has increasingly impacted national legislation. National mining codes have, in many cases, been revised to take into account such regulations. For example, mining companies in some of the newer Member States had the design standards for hazardous waste landfills temporarily imposed upon tailings management facilities, even as the current Directive specific to mine wastes was being drawn up in Brussels (Drielsma and Cambridge 2007).

According to the EU Treaty, certain areas of law, such as land-use and taxation must be regulated at the most relevant administrative level. Mining law is therefore formulated mostly on the national and provincial level. The European Commission (EC) is responsible for proposing EU legislation, under which the EU member states need to operate. European legislation is decided together with the European Parliament and the European Council in a "co-decision" procedure. Whilst some acts and regulations are put in place by the EC, each EU member state is expected to develop, manage, and incorporate its own environmental protection rules and regulations on mining.

While transposing EU directives into their own national legislation, the member states are free to include additional requirements (e.g. regulate additional substances relevant within their own territory or set higher standards). The member states are not permitted to set standards lower than EC standards because the minimum level of protection afforded should remain the same across the whole EU.

5.4. Legal regulations as incentives or disincentives for mining waste management

5.4.1. Implementation of EU level directives and decisions in Baltic Sea Region countries

As was mentioned in the previous part of this chapter, EU countries are obligated to implement to national legislation Directives of European Parliament. The crucial act, which defines mining waste management in EU is Directive 2006/21/EC of the European Parliament and the Council on the management of waste from the extractive industries. This act has been the basis for issuing four decisions by the European Commission:

1) Commission Decision 2009/335/EC on the Technical guidelines for the establishment of the financial guarantee, adopted on 20 April 2009.
2) Commission Decision 2009/337/EC on the Criteria for the classification of waste facilities in accordance with Annex III adopted on 20 April 2009.
3) Commission Decision 2009/359/EC on the Definition of inert waste in implementation of Article 22 (1)(f) of Directive 2006/21/EC of the European Parliament and the Council concerning the management of waste from extractive industries, adopted on 30 April 2009.
4) Commission Decision 2009/360/EC completing the technical requirements for waste characterisation, adopted on 30 April 2009.

The process of implementing the above-mentioned acts and decisions into the national law of several countries of the Baltic Sea Region is uneven.

All the Baltic Sea Region except Norway adopted the Directive 2006/21/EC. The way of implementing this Directive into national legislation varied from country to country:

- In Germany, the implementation of the Directive 2006/21/EC into legislation was carried out by completing and supplementing both the Federal Mining Regulation and the Directive on the Environmental Impact Assessment, which were originally issued for the purpose of implementing and adopting European directives on national level. As a result, the original national directives were adjusted to new European guidelines.
- In Sweden, the directive has been implemented as a new act called Utvinningsavfallsförordningen (SFS 2008:722). Commission decisions shall be applied in Sweden as well, however the Swedish Environmental Protection Agency does not yet know if the decisions will lead to further changes in the regulation or regulations.
- In Poland, the Directive was implemented as a new act, called Ustawa o odpadach wydobywczych (Act on Waste from Extractive Industry), which was passed on 10 July 2008. In consequence, several other acts were amended, introducing proper regulations coming from the new Act.
- The situation in Finland resembles that in Poland, where mining waste handling is regulated in several acts:
  - Valtioneuvoston asetus kaivannaisjätteistä / Government Decree on Extractive Waste (190/2013) issued on 14 March 2013.
  - Valtioneuvoston asetus kaatopaikoista / Government Decree on Landfill (331/2013) issued on 5 May 2013.
  - Government Decree on Mining Activities (391/2012) – Chapter 1 §3 waste management plan for extractive waste in the exploration area.
- Norway, as a signatory to the European Economic Area Agreement is obligated to implement directives of the European Union, including Directive 2006/21/EC. Norway's Minerals Act (2009) provides the essential framework for mineral exploration, extraction and decommissioning. Mining waste management is not addressed specifically in the Act, but is determined by guidelines and rules, which are set forth in several laws, the most important of which are:
  - The Pollution Control Act (1981).
  - The Product Control Act (1976).
  - The Greenhouse Gas Emission Trading Act (2000).

  Moreover, there is a strong conviction among Norwegian authorities that the country has a considerably different topographical, hydrographical and geographical setting from the rest of Europe, and even if Norway implements legislation from the European Union or elsewhere, it is imperative that such regulations must be adapted to reflect the country's specific conditions (SAFEMANMIN – Safe Management of Mining Waste and Waste Facilities 2007).

The degree of implementation of Commission Decisions in BSR countries is differentiated. The most advanced in this respect are Germany and Finland, which adopted all Decisions connected with the Directive.

It is, however, also the case that regulations concerning mine waste management included in these Decisions are already reflected in the national legislation. This is the case of Sweden.

In Estonia and Poland, two decisions connected with the main directive on extractive waste management are already implemented into national legislation. The remaining two are being incorporated into law, and the timelines for the completion of this process have been defined.

5.4.2. Legal regulations as incentives or disincentives for mining waste management. Case study from Poland

The 2006/21/EC Directive and European Commission decisions connected to the directive determine the general rules of waste management and are of great interest to mine waste owners (mines and processing plants) and operators of extractive waste facilities.

The activities of the main actors of the Min-Novation project, small and medium businesses, which deal with extractive waste recovery, are however constrained by many more regulations and obligations, stipulated in laws on plant exploitation, environmental protection and waste management in general. These regulations, established on the European level, are listed in subchapter 5.3.

In the case of Poland, the acts concerning mining waste management are not always transparent or consistent, sometimes containing both incentives and disincentives for mining waste recovery and reuse. The topics below illustrate the extent to which the laws support or restrict the growth of a smoothly operating internal market for mining waste-derived products.

Statutory hierarchy of waste management

The most stimulating regulations, promoting activity on the field of extractive waste management are found in the Act on Waste from Extractive Industry (2008). The statutory hierarchy of mining waste management places waste recovery higher than storage, which means that waste producers are strongly encouraged to consider this management option, especially if it is economically feasible. When applying for (obligatory) approval of a waste management plan, they need to propose ways to manage their waste stream other than by storage. The permit for mining waste storage is issued only when it is shown that there is no other way of mining waste management.

At the same time, recovery of waste from the extractive industry is not eligible to receive public funds, which are otherwise ensured for recycling processes and preparatory activities preceding waste reuse activities[9]. The problem lies in the fact that the processes of waste recovery cannot be classified as preparations for reuse or recycling. Given the commitments by countries to sustainable development practices and the ever growing need for protection of natural resources, holding back economic incentives for mine waste recovery activities is groundless.

Special permission for recovery of certain waste streams from extractive industry

According to Polish legislation, to control the environmental impact of waste, its recovery is performed in plants. However, certain kinds of waste recovery processes can be performed outside of plants. Up until the time that the Ministry of Economy determines the new rules[10] of recovery outside of plants, it is possible to run the recovery of mining waste (e.g. waste rock) in areas, where other forms of waste recovery are forbidden, which means, beyond plants[11]. There are six main possibilities for direct (without prior processing) mining waste recovery:

- Filling the unfavorably changed areas (like hollows, not exploited opencast workings or parts of them).
- Hardening the surfaces, for which the owner has a title deed.
- Usage in underground mine techniques.
- Usage for protection from water or eolian erosion of embankments and surfaces of closed waste deposition facilities.
- Construction of road/railway embankments, road bases, impermeable paddings and ground settlers, cores of hydrotechnical constructions and other constructions, including foundations.
- Elimination of fire hazards like spontaneous ignitions on heaps from coal mining.

This regulation promotes the use of mining waste, even though a proper permit has to be obtained before recovery can take place. It is to be hoped that the expected regulation coming from the new Act on Waste (2013) will maintain this incentive.

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[9] According to Article 19 of the Act on Waste (2013).

[10] According to Articles 30 and 232 of the Act on Waste (2013).

[11] Plant as defined by Environment Protection Law (unif. text 2013, as amended).

Classifying the waste rock from mining activity as a waste

According to the Act on Waste (2013), waste rock extracted together with basic minerals (e.g. coal or metal ore) is classified as waste. Such classification causes a lot of problems with the management of waste rock, among which the most troublesome concern:

- The necessity of obtaining several permits.
- The limitations on how it can be used (e.g. material with the status of waste tends to have many fewer applications than material without that status).
- The lack of social acceptance for products from waste material.

According to the entrepreneurs, waste rock is a pure mineral material, which because of its composition and qualities is comparable with minerals extracted from natural mineral deposits for similar purposes. That is why classification of waste rock as waste was pointed out as the most problematic aspect of the current legal framework during a series of Min-Novation regional meetings in 2011–2013.

Waste deposition at waste facilities free of charge

In accordance with The Act on Waste from Extractive Industry (2008), the storage of the mining waste in the mine premises is free of charge. As a result, the producers, who usually bear the costs of maintaining a storage facility onsite, are not motivated to find another way to develop the waste. Indeed, recovery of waste is usually connected with fixed costs such as costs of obtaining different kinds of permits, taxes, maintaining equipment or media. In the situation, where storage (landfilling) is the cheapest form of waste management, the producers choose the easiest and most affordable disposal route instead of exploring the possibilities of reuse or recovery.

Legal requirements for mining waste recovery

One of the most limiting factors affecting efforts to find applications for mining waste resources is a long and often multi-staged procedure of obtaining permits to conduct such an activity. Recovery of mining waste, as for every type of waste, requires the appropriate permits. The obligatory sequences of actions needed to legalise the use of mine waste is given in figure 5.1.

Obtaining such permits requires time and (often) funds for preparing documentation. In the end, then, it is much easier and cheaper to use material from natural resources, bought from their producers.

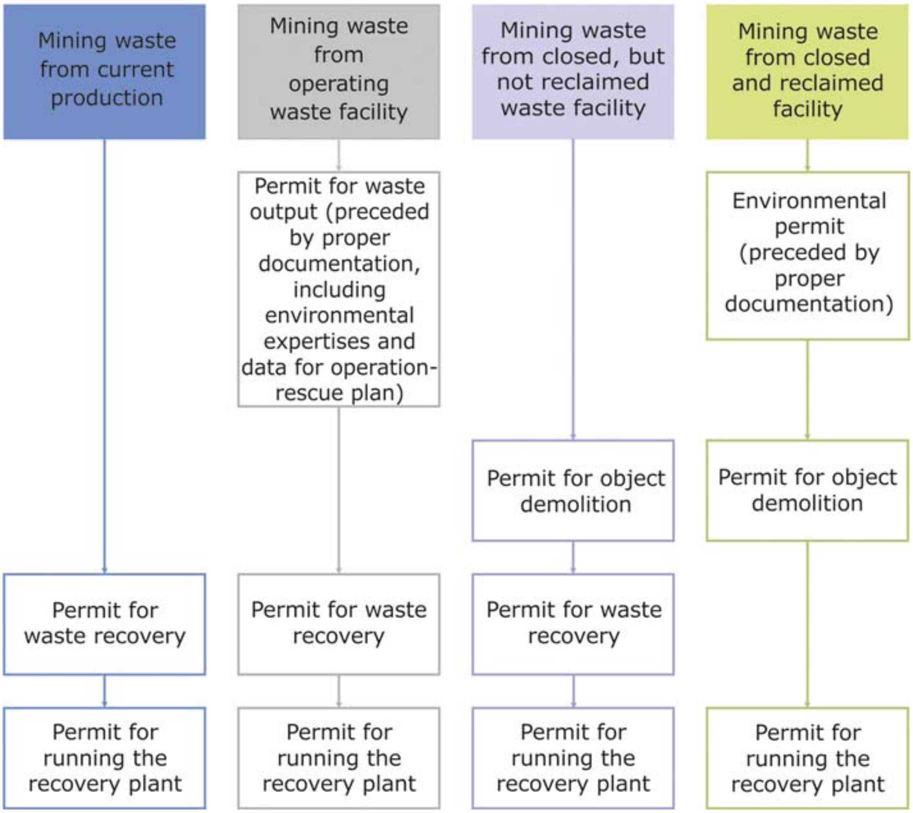

Figure 5.1. Scheme of obligatory permits for mining waste recovery in Poland
Source: after Kotarska 2013

Constantly changing legal framework

Since 2004, the year Poland joined the European Union, Polish legislation and the legal framework of mining waste management have been changing constantly, mainly because of the need to conform with European legislation. The implemented acts and regulations have been permanently amended, which has brought new requirements for entrepreneurs, as well as new, often more difficult conditions for obtaining obligatory permits and conducting waste management operations. Very often, this makes it all but impossible for businesses to plan their economic activity and development over the long term.

In summary, it should be stated that a certain degree of incoherency and inconsistency can be observed between the specific regulations concerning mine waste management, especially on issues concerning mine waste recovery. While the main acts promote using and reusing waste instead of drawing on natural resources, more specific laws and regulations complicate the process of recovering and reusing waste. Moreover, there are so many requirements, which should be fulfilled by entrepreneurs who deal with mine waste, that the legal framework turns out to be one of the major factors slowing down growth in the extractive waste management business.

5.5. Conclusion

Although mining waste management in the Member States of the European Union countries and in Norway is based on the same directives and regulations, their implementation into national legislation and subsequent interpretation is different. As the Polish case described above clearly shows, mining regions in the Baltic Sea countries face unclear and sometimes contradictory legal provisions governing how they handle waste. As will be seen in chapter 7, the legal framework of mining waste management can extend to cover priorities such as heritage protection, which may well be an additional factor limiting reuse and recovery of secondary mineral resources.

To ensure a sustainable and clear approach to mining and processing waste management and a level playing field for all EU Member States, there is a need to vet the legal framework for clauses and conditions, which run counter to the general policy of fostering reuse of mining waste. As part of the Min-Novation project, the most important legal issues, which are disincentives for entrepreneurs dealing with mine waste, were identified. This process got underway especially in the work of the Swedish and Polish partner organizations and memoranda detailing comments and concerns have been sent to the appropriate authorities.

6. Mining and processing waste management methodologies and technologies

6.1. Introduction

Mineral deposits, energy and metallic minerals as well as industrial minerals and chemicals are mined from the surface in open pit mines or from underground workings. Independent of the mined mineral or produced material almost all mines follow the mine life cycle, which is defined by the following stages:

1) Exploration and studies related with feasibility.
2) Major plan and construction.
3) Mining operations.
4) Mine closure and reclamation.

During every step of the mine life cycle, waste is produced and handled. The type and amount of waste produced during each step is largely dependent on, first and foremost, the geological, mineralogical, geochemical and geotechnical characteristics of the ore deposit.

Minimization of waste during every step of the mine life cycle is a way of saving energy and also a way to minimise the negative impact on the environment by introducing less amount of waste. It is important that generated waste is not mixed, but instead handled separately in different categories (e.g. waste rock, tailings, overburden, coal spoils, shale ash, limestone) at the mine. If waste is divided up into several different categories at the mine site, recovery or direct reuse is made much easier. Waste rock can for instance be used to replace aggregates if the concentration of sulphides is low enough. Also refined coal spoils can be used as aggregates. Tailings can be used for backfilling operations in underground workings and oxidized sulphidic mine waste can be starting material for production of pigments.

This chapter indicates that there is a multitude of different mining wastes being generated that either can be reused as is or sometimes contain high concentrations of valuable metals, which are recoverable after processing. Mining waste is divided into waste generated in the mine, during excavating and processing works, metallurgical waste at old slag heaps and shale ashes as well as coal spoils and oily drill cuttings from offshore oil production. In the chapter, ways of minimizing generation as well as recovery of mining waste are described in several case studies.

The present chapter will focus on different methods to increase recovery of mining waste for both direct use as well as metal recovery.

6.2. Waste from metal mining

Metal mining

Mineral deposits, containing metals like copper, zinc, lead or nickel are mined from the surface in open pit mines or from underground. This introduction describes some of the current issues related to metal mines exploitation, including the potential environmental impacts, which arise at different stages of the life cycle of the metal mine.

Metallic ore deposits extracted for metal concentrate production or advanced processing are usually classified according to the main metals of the commodity. The Canadian Public and Resources Sectors Directorate (2009) "The Environmental Code of Practice for Metal Mines" (ECPMM) presents the following classification for metal mines:

- Base metals, primarily copper, zinc, lead and nickel.
- Precious metals, primarily gold, platinum group metals and silver.
- Uranium.
- Iron ore.
- Other metals, including titanium, tantalum, tungsten, niobium and magnesium.

Environmental concerns with respect to metal mining concern in the first order waste water from site runoff, mining and ore processing, mine wastes and their effects on terrestrial and aquatic ecosystems, local and regional surface water and groundwater flow. Hudson et al. (1999) have summarized the following environmental issues related to metal mining:

- Physical disturbance of landscapes as a result of mine workings, waste rock and tailings disposal areas and facility development.
- Increase in the acidity of soils; such soils can be toxic to vegetation and a source of metals released to the environment.
- Degraded surface and groundwater quality as a result of the oxidation and dissolution of metal-bearing minerals.
- Increased air-borne dust and other emissions, such as sulphur dioxide and nitrogen oxides from smelters, which could contaminate the atmosphere and surrounding areas.

Each of the four stages of the mine life cycle mentioned in the introduction is associated with a set of environmental risks, the presence, absence or degree of which depends first and foremost on the geological, mineralogical, geochemical and geotechnical characteristics of the ore deposit. Typically, the base metal ore deposits contain sulphide minerals in their host rock, in the ore body itself and often in the overburden covering the deposit. The fast kinetics of oxidation of sulphide minerals pose the main environmental threat which could frustrate efforts to fully utilise metal ores. From an environmental perspective among the most harmful compounds in metal mining tailings are typically Pb, Cu, As, Cd, Cr, Zn, Ni, Co and Hg.

Oxidation of sulphides and acid drainage

In the presence of water and oxygen, iron sulphides (mainly pyrite (FeS_2) and pyrrothite (FeS)) oxidize and create acidic drainage. The pH decrease related to the alteration of the primary sulphide mineralogy has consequences for the environment in all phases of the mining activities.

Oxidation rates vary among sulphide minerals. Oxidation kinetics are case sensitive as there are several factors to control those reaction mechanisms. Jambor (1994) has suggested that the relative resistance of sulphide in oxidizing tailings environment is the lowest for pyrrhotite and increases in order; sphalerite-galena, pyrite-arsenopyrite, chalcopyrite and magnetite. Excluding magnetite, sphalerite and galena, of which the two last mentioned are classified as non-acid processing sulphides (Dold 2005), the above mentioned sulphides have a major role in acid production in the metal mining environment. See chapter 9 for additional information regarding environmental problems and reclamation methods.

The oxidation rate of pyrite by oxygen decreases along with a pH decrease. However, it has been reported (Williamson and Rimstidt 1994) that the overall abiotic rate increases as pH decreases into a range where ferric iron becomes the dominant oxidant. Nordstrom (1982) has found that when pH decreases to 4.5, ferric iron, liberated from sulphides, becomes more soluble and starts to behave as an oxidizing agent, thus speeding up the pyrite oxidation at low pH conditions (see also Lapakko 2002).

Alkaline effluents

Sulphide flotation is mainly carried out at alkaline pH. Flotation is typically favored for the recovery of sulphide minerals of lead, zinc, copper, molybdenum, silver, nickel and cobalt. In targeting to improve the conditions for mineral separation in the beneficiation processes, pH is typically adjusted to alkaline conditions. These circumstances may result in alkaline effluents to waste water.

Concern exploration and feasibility

Exploration activities in most cases have fairly short-term impacts on the environment, particularly, when compared to the other phases of the mine life cycle. In most areas, the main environmental consequences associated with early exploration are the side effects caused by diamond drilling, e.g. preparation of drill sites, transportation, drilling waste. The risk of environmental impact increases as exploration reaches an advanced stage.

Ore extraction

The environmental impact of extraction of metallic ore deposits is strongly related to the characteristics of the ore deposit itself. Open pit mining has more prominent consequences on surface conditions due to connection with ground and surface. On the other hand the extraction typically requires large volumes of waste rock and overburden removal, both of which may carry sulphides and thus accerelate acid production.

The principal environmental concerns related to ore extraction activities are the disposal of waste rock and the harmful discharge from the mine itself. Furthermore, ore extraction activities, loading and transportation can result in dust problems and affect the environment.

Transport and beneficiation

Ore is transported from the mine to stockpiles for homogenization or further storage. Homogenization is not necessarily required, in which case the feed continues in a straight line to crushing and milling processes, where the grain size is optimized for benefaction processes like leaching, tabling, flotation, high intensity magnetic separation, and other kinds of processes. Selection of the proper grain size distribution is essential for optimizing the mineral liberation and controlling the ore feed flow. Nowadays, the mineral liberation analytical (MLA) methods provide a comprehensive account of the physical and chemical properties of the ore and gangue mineralogy needed for planning the beneficiation process. Base metal ores are ground fine to achieve the best liberation conditions in the flotation process: typically the final grain size is less than 0.1 mm. Gold is recovered by some of the gravitational methods or it is leached with cyanide and sulphuric acid, respectively. For iron ores the beneficiation proceeds from crushing and milling to magnetic separation. For chromite ore beneficiation there are a number of applications in use. Depending on the ore source and the end usage requirements, chromite is gravity separated e.g. by shaking table or spiral. Alternative methods are heavy liquid and magnetic separation. The environmental footprint of processing iron and chromite ores is typically negligible in comparison to that of base metals. The quantities of residues involved also include the amount of overburden and rock that has to be removed to get access to the mineable ore.

Tailing site design and deposition techniques, wastewater contamination

The most widely used technique for tailings deposition is wet deposition. Water-sediment slurry is pumped in topographic depressions, constructed dams or waste rock dumps. In Nordic countries, like in Finland and Sweden, tailing ponds are typically constructed in marshland. The advantage of this practice is that peat, whilst it is compressed under the tailings material and shapes the bottom layer for the tailing pond, effectively starts to restrict seepage and at the same time acts as an adsorbent for a number of elements and compounds, which might be risky to discharge to the environment. The semi-dry subaerial tailing method is implemented by thickening the discharge and deep-water disposal (Robertson 1994, Ritcey 1989). In countries with large topographical variations (mountain areas) the tailings structures are commonly sited in valleys. The most common dam construction methods are the downstream and the upstream methods (Robertson and Mac 1984, Robertson 1994). In the wet deposition method, the tailings slurry is thickened to and discharged by either point or line discharge. The discharge point is changed in intervals resulting in a gravimetrical grain size separation, coarse grain size being deposited closer to the discharge point.

Metal mine waste management technologies

The Reference Document on Best Available Techniques for Management of Tailings and Waste-Rock in Mining Activities (prepared by the European Commission pursuant to Article 21(3) of the Directive 2006/21/EC) gives comprehensive insight into the subject area.

In relation to metal mining, the report emphasizes the weight of conditioning the tailings and waste-rock to minimize any environmental or safety hazard, such as de-pyritisation or addition of buffering material. As a prevention technology for Acic Rock Drainage (ARD) the report portrays the minimization of oxygen transport to the sulphides. As a solution for that, the report suggests an oxygen transport barrier (cover). The covers are normally variations on two basic concepts: (1) 'water covers', otherwise known as 'wet covers' (e.g. flooding) or (2) 'dry covers' (see chapter 9 for additional information).

Need for innovation

The ongoing boom in the mining sector has increased concerns for the environment. The recent metal mining related environmental problems have resulted in changes in legislation for mining and for handling of waste rock, tailings and waste water. There are tens of thousands of abandoned metallic mines in the European countries, which were exploited when the legislation with respect to environmental protection was more liberal. However, a major part of the players in the mining sector have implemented environmental protection measures in a responsible way and have avoided the undesired environmental consequences, which metal mining operations involving acid processing materials may have had.

Technical and scientific advances and new innovations have been put to use and have increased understanding and concern over the condition of the environment within the whole mine life cycle. However, there still is a lot of work to be done.

The recent advances in resource and reserve estimation and modeling ensure greater accuracy in mine optimization and for mining operations. The chemical composition of the waste rock material to be dumped and the online follow up of the composition of feed and its mineralogy have made it possible to manage the material flow from the mine to the tailings site. In regard to tailings, the special concern is how to stabilize the metal-bearing soils and prevent the seepage of contaminated water to the surrounding environment as well as how to clean the waste water discharged into the waterways.

The waste rock and the tailing material often contain acid drainage processing sulphide phases. The interaction of those phases with biological processes and, if neutralization is performed, with the neutralizing agents often is a condition that is not properly understood prior to operation. To ensure that this interaction and its consequences are understood and controlled, scaled piloting of the beneficiation process and simulation of environmental conditions in advance should be the main focus during the feasibility stage of the mine life cycle.

Following the initiative of the European Technology Platform on Sustainable Mineral Resources, the improvement of technological parameters, especially complete utilization of the ore material, decreases the irrecoverable loss and promotes the improvement in recovery rate. In the case of metal mining this objective is a positive outcome for the environment because by improving the recovery rate, the load to tailings and waste water is minimized.

Recycling and finding new usage for the mining residue and by-products are issues that must be approached from a scientific point of view hand in hand with empirical testing and an enthusiastic stance best described as: "someone's waste can be a desired raw material for another".

6.2.1. Case study from Sweden – mine water treatment using mining waste

Lovisagruvan (proterozoic stratabound) is a mine located in central Sweden where sulphide ore (lead-zinc-silver) has been mined since 2004[12]. The ore consists almost entirely of galena and sphalerite. Every year around 40 000 t of rock (containing 50% ore) are mined. No acid producing minerals are found in the mine and original mine water is therefore near neutral. During the mining operation crushed limestone is used to differentiate between ore and waste rock when loading the ore on mine trucks. This results in a circumneutral mine water. Water is pumped up from the mine at the rate of 5 m^3/h and is first collected in three sedimentation ponds underground (at 145 m, 105 m and 55 m below the surface) before it is pumped to a sedimentation pond above ground where it stays for about three days. Surface water is then released. Circumneutral mine water from Lovisagruvan with a pH of 7–8 is mainly contaminated with lead (370 μg/L) and zinc (690 μg/L). Previous investigations have shown that the present treatment method does not lower the metal content enough and the water needs further treatment (Sartz et al. 2011). Filtration studies (unfiltered, 1.0 μm, 0.40 μm, 0.20 μm and 0.05 μm) on the mine water have also shown that the major part of the contaminants in the water is associated to small particles (mainly as sulphides).

In order to improve the water quality, several steps have already been implemented. For instance a roof was mounted on the surface sedimentation pond in order to keep metal containing dust from entering the pond. As the primary crusher was close to the sedimentation pond, moving the crusher to another location lowered the metal concentrations substantially (especially the particulate). After minimizing the influence from metal containing dust on the sedimentation pond, the average concentrations of lead and zinc were 180 and 400 μg/L, respectively, during the first six months in 2013.

Long term tests using magnetite tailings were performed in order to study the possibility of removing particulate contaminants from the mine water (Fahlqvist et al. 2012). Water

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[12] The description of the mine and the initial pilot experiments have been described in full by Fahlqvist et al. (2012).

from the mine was pumped from the sedimentation pond above ground into a 1 m^3 container and transported to the laboratory. Water was pumped from the container to the columns at a rate of approx. 20 L/d. Total volume through the filters was 1 300–1 600 L.

Initially the filtration increased the pH, but as more water passed, the values decreased to about the same as for the untreated mine water (pH 8.04). Zinc and lead concentrations decreased by 97.5% and 99.7%, respectively, through the magnetite filters (Figure 6.1a, b), indicating that physical filtration is the dominating process in the filters. Trace metal removal was higher in all columns compared to the filtration through polycarbonate filters with an exact pore size. This indicates that also some adsorption occurs in the columns. The results can be compared with the results from the similar filter in 1 m^3 scale that was tested by Sartz et al. (2011) in direct connection to the sedimentation pond where zinc decreased by 52% and lead by 68%. This difference in filter efficiency can be partly explained by the fact that the flow through the 1 m^3 filter was higher, especially at the beginning, which might have created preferential flow paths in the filters. Metal concentrations in the sedimentation pond were also higher during those tests which could have an effect on the filter efficiency

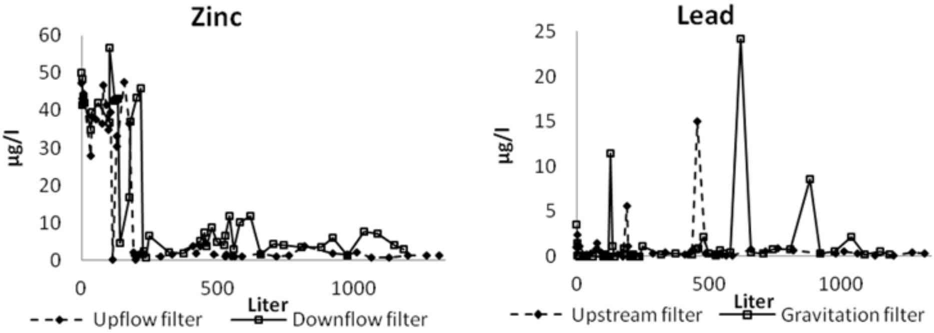

Figure 6.1. Zn in water filtered through the magnetite filter (Zn concentration in ingoing water: 690 µg/L) – left; Pb in water filtered through the magnetite filter (Pb concentration in ingoing water: 370 µg/L) – right

Source: Fahlqvist et al. 2012

Based on the positive results from both: the pilot scale test (Sartz et al. 2011) and the column test (Fahlqvist et al. 2012), the decision was made to construct a full scale filter and remove particulate metals from the mine water using another mining waste (magnetite tailings). The full scale filter will be divided into two subfilters in order to be able to run different filter materials and change the filter media without having to shut the filter down or by-pass it. The volume for treatment in each subfilter would be approx. 45 m^3.

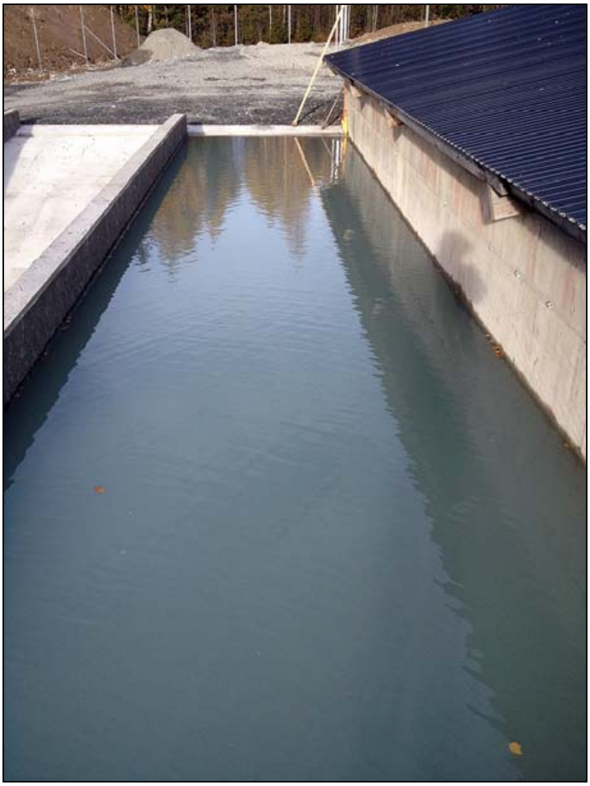

Figure 6.2. Foundation for the new filtration pond alongside the old sedimentation pond

Photo: M. Bäckström

6.2.2. Case study from Finland – Reuse of pyrite tailings from Pyhäsalmi Mine Oy

The case study described here focuses on reuse of pyrite rich tailings in pyrite production in Pyhäsalmi mine. Pyrite tailings contain over 40% sulphur and can be processed with flotation together with the ore's pyrite or in a separate flotation circuit. Pyhäsalmi Mine Oy, owned by the Canadian Inmet Mining Corporation until March 2013 and after that First Quantum Minerals Ltd., operates a copper, zinc and pyrite mine in central Finland. It is the oldest continuously operative mine in Finland and one of the deepest in Europe (Figure 6.3).

The Pyhäsalmi Mine is a modern and safe operation and one the best performing mines wordwide. The mine's production is currently about 1.4 Mt per year (Table 6.1). The mine's estimated lifespan is until 2019.

Table 6.1. Pyhäsalmi Mine in a nutshell

Orebody discovered	**1958**
Production started	March 1, 1962
Copper, t/a	14 000
Zinc, t/a	30 000
Pyrite, t/a	80 0000
Silver, kg/a	12 000
Gold, kg/a	260
Personnel	229

Source: Annual Report 2011

Figure 6.3. Aerial view of the Pyhäsalmi Mine
Photo: Pyhäsalmi Mine Oy

Geological Situation

The Pyhäsalmi ore is massive and coarse grained. The ore is hosted by felsic pyroclastic rocks and quartz-porphyries. The ore contains 75% sulphides on average, 3% chalcopyrite, 4% sphalerite, 2% pyrrhotite and 66% pyrite plus minor amounts of galena and sulphosalts. Barite and carbonates are the main gangue minerals.

At the end of 2008, mineable reserves amounted to 13.4 Mt with 1.11% Cu, 2.24% Zn and 41.4% pyrite. To secure future mining, Pyhäsalmi Mine Oy has made substantial investments in exploration on the mine site and in the region.

Mining

Since 1975, the Pyhäsalmi mine has converted entirely to an underground mine. Today, all underground operations are below the 1050 level reaching to a depth of 1410 meters (Figure 6.4). The mining method in use is benching. The slopes are approx. 25 m high, 15–25 m wide and 30–80 m in length. All openings are supported systematically by rock bolting and shotcreting. After blasting, the ore is mucked to the ore passes or tipped into the jaw crusher by loaders. The crushed ore is hoisted via the Timo shaft using a friction hoist. Finally, the ore is transported by conveyor belt to the mill[13].

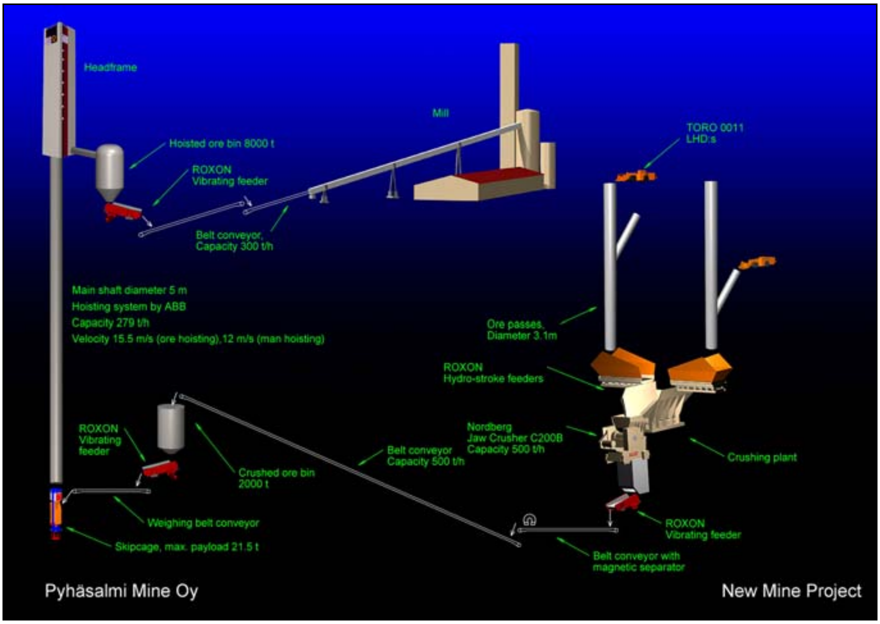

Figure 6.4. Crushing, hoisting and transportation
Source: Pyhäsalmi Mine Oy

Milling

Concentrator operations are divided into five stages: screening, grinding, flotation, dewatering and tailings disposal (Figure 6.5).

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[13] Personal communication with Pekkala T. – Pyhäsalmi Mine Oy, 2013.

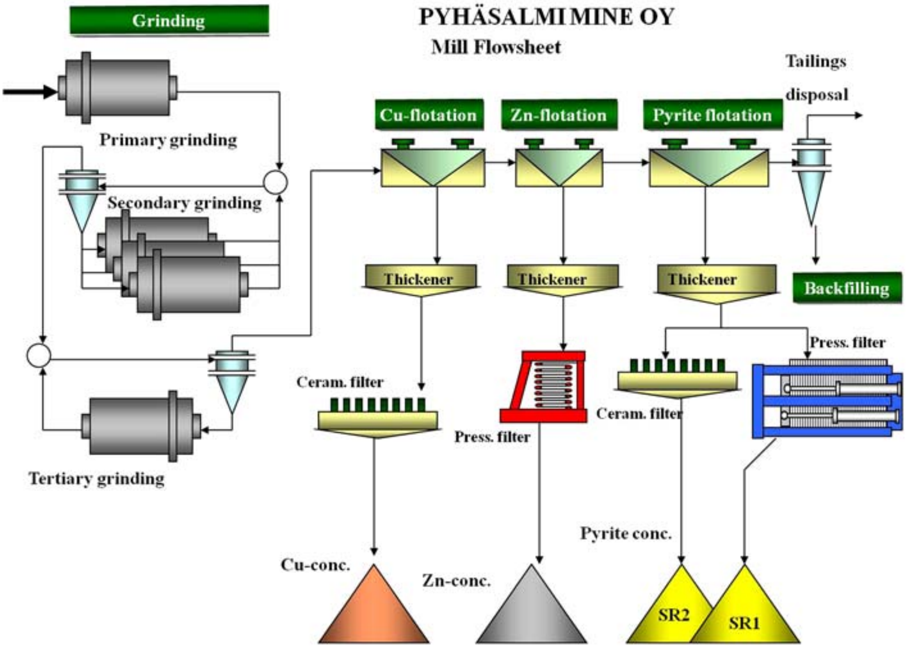

Figure 6.5. Mill flow sheet of the Pyhäsalmi Mine Oy
Source: Pyhäsalmi Mine Oy

Table 6.2. Pyhäsalmi Mine key operating data between 2010–2012

	2012	**2011**	**2010**
Mill Feed, 1000 t	1 384	1 386	1 401
Cu%	1.0	1.1	1.1
Zn%	2.0	2.6	2.4
S%	42	42	43
Cu recovery, %	96	96	96
Zn recovery, %	92	91	90
Cu production, t	12 600	14 000	14 700
Zn production, t	25 600	32 300	30 100
Pyrite production, t	858 000	804 900	584 100

Source: Annual Report 2011

The ore is screened into lumps, pebbles and crushed fine ore. In the Pyhäsalmi mill, the milling method in use is semi-autogenous grinding, where lumps and pebbles are used with steel balls as grinding media. The grinding fineness is about 65% below 0.074 mm. Part of mill tailings is used as fill material for cemented hydraulic backfill. Yearly, over 300 000 m^3 of backfilling material is required to fill the voids left from mining. Approximately 75% of the void is filled with waste rock and 25% with cemented hydraulic fill. Annually, about 40–45% of the total mill tailings are used in the cemented hydraulic fill production (Annual Report 2011).

The flotation consists of three sequential flotation circuits: copper, zinc and pyrite. Finally, the concentrates are thickened, filtered and dried to a moisture content of 5.5–8%. The annual production and grades are presented in table 6.2.

Environment

The mine area contains four tailings ponds (Figure 6.6). Fine-grained tailings slurry, drainage water from the mine, surface water from the industrial area and filter water from the tailings ponds are pumped into the tailings ponds. Filling of the 41 ha large Pond A was terminated in October 1997. Cover structures were constructed in 1999–2002. Tailings are pumped into Pond B or D. The approx. 31 ha large Pond B currently functions as a pyrite raw material stockpile into which tailings that still contain pyrite concentrate are pumped. The objective is to store pyrite-rich tailings in one pond for future additional refining. The current understanding is that all the pyrite-rich tailings in Pond B will be taken into production again before the mining activity ends. Pyrite material is dried by stacking before transportation to the mill (Figure 6.7). Pond D is the currently used tailings pond; slurry and water will be pumped there when the pyrite is concentrated. The pond's surface area is about 31 ha. The approx. 47 ha Pond C is a sedimentation pond and functions as the mine's water basin (Environmental permit 2004).

Filling of the pond B with pyrite rich material was started at the turn of the twentieth century. At the end of 2012, Pond B contained over 3 Mt of tailings with a sulphur content of 40–45%. During the last few years the mine has made multiple studies to make it possible to produce good quality pyrite concentrate out of this material. Processing of the material has been tested in mill scale in the summer of 2012 and 2013. Utilization will be possible in the near future, if annual pyrite sales exceed the ore's maximum pyrite content, 0.9–1 Mt. Mechanical and chemical properties of B pond material vary a lot. The oldest material has been oxidizing in the pond for over 10 years. The particle size distribution is coarser near the crest of dam and finer in the middle. Furthermore, material varies vertically as the dam has been raised multiple times. In laboratory tests, the pH value of the slurry has varied from 2 for the oldest material to 8.5 in the youngest.

These are the main reasons that the material needs a separate flotation line with necessary pretreatment units as it probably would interfere with the fresh ore feed pyrite circuit (Environmental permit 2004).

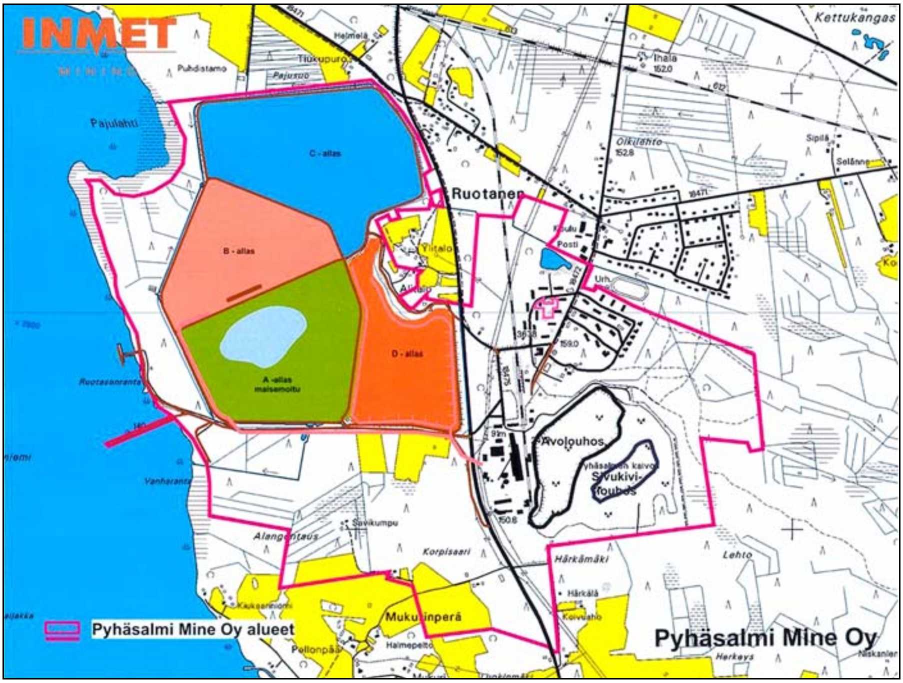

Figure 6.6. Map of mine area, Pyhäsalmi Mine Oy
Source: Pyhäsalmi Mine Oy

The mine has all the necessary equipment for the purpose, including a satellite ore treatment plant with mill and spare flotation cells. Particle size and pH challenges can be reduced by mixing stacks, gentle regrinding and conditioning. Mill scale tests have indicated that it is possible to produce good quality pyrite with high recovery also from the material that was once directed to the tailings pond. Future work is still needed to optimize chemical dosages and other operational controls (Environmental permit 2004).

Wastewater is cleaned by neutralization. At the first stage, waste water, together with the process tailings, is pumped into the clarification pond D, where lime is added to keep the pH level above 10. In the pond, suspended metals are precipitated and settled on the bottom. The clarified water is fed to the pond C before being released via an open ditch into the Pyhäjärvi Lake. Seepage water is pumped back into the ponds (Environmental permit 2004).

Pond A is rehabilitated by covering the tailings with a 1 m layer of till and sowing with grass. Pond B is a clarification pond for pyrite containing tailings. Based on environmental legislation the pyrite tailings is not classified as waste. The use of the pond strongly depends on the market situation of pyrite.

Figure 6.7. Stacking of pyrite in Pond B in summer 2012, Pyhäsalmi Mine Oy
Photo: H. Karjalainen

Tailings management at the Pyhäsalmi Mine includes several means of utilizing the waste rock and post-production waste. Apart from using the waste rock as backfilling material and the tailings in fill production, the mine authorities have investigated possible ways of recovering pyrite from pyrite-rich tailings deposited in one of the tailings ponds over the last decade. The conclusion drawn is that the variability of mechanical and chemical properties of the material in the different layers deposited in the pond requires a separate flotation line. This is a promising development, but at the same time one which makes any future large-scale recovery operations dependent on the market price of pyrite.

6.2.3. Case study from Poland – engineering solutions for safer development and operation of the Żelazny Most tailings storage facility

The Żelazny Most Tailings Storage Facility (TSF) is currently the sole site for the deposition of tailings generated during the flotation process of copper ore, extracted by

KGHM Polska Miedź. Tailings from three ore enrichment plants (OEP) are stored within the site. Tailings, which are a mixture of water and crushed rocks, are delivered to the Żelazny Most TSF by a pipelines network. About 94% of the tailings comprise rock material, 6% liquid material. After the mixture is deposited at the TSF, the solid particles sediment on the bottom, while the clarified water is returned to the ore enrichment plants so it can be reused. This case study focuses on the engineering solutions in place, which are meant to ensure that the waste facility can be developed and then safely used. The present study was developed on the basis of engineering works done by made by KGHM Polska Miedź JSC and Hydroprojekt Ltd, Poland[14].

Żelazny Most TSF covers an area shared by three municipalities: Rudna (9.18 km^2), Polkowice (5.23 km^2) and Grębocice (1.26 km^2). Construction works at the site started in 1974. Three years later, in 1977, Żelazny Most was launched. Since then, the site has been gradually raised and development works have continued. Today, the site occupies an area of 1394 ha. Approx. 498 Mm^3 of tailings have already been deposited (Figure 6.8).

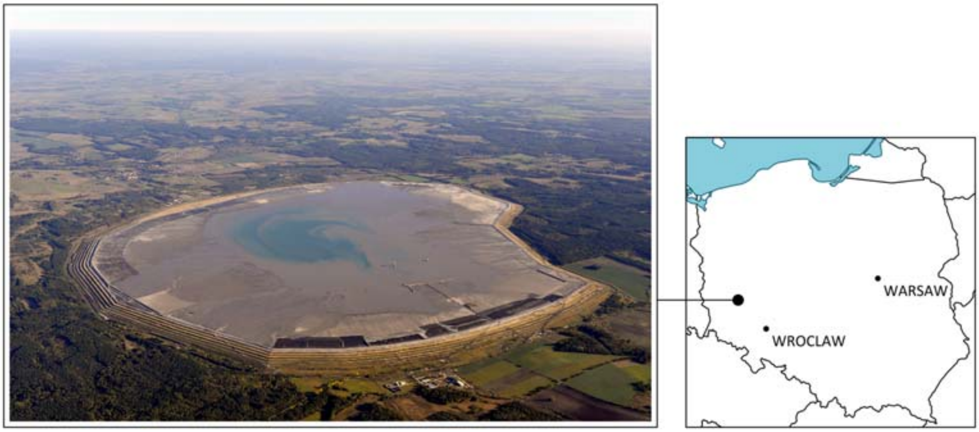

Figure 6.8. The location of the Żelazny Most Tailings Storage Facility

Due to the new law (The Act of 10th July 2008 on Waste from Extractive Industry), Żelazny Most cannot be treated as a regular landfill. This is due to the fact that the tailings stored in it are not a threat to people, animals or plants because of continuous actions taken to ensure low impact on the environment. All observations and laboratory tests show that the influence of the reservoir (ground contamination with salty water, dust emission) is restricted to within a few hundred meters from the slopes. Taking into

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[14] Co-operation: Paweł Zieliński, KGHM Polska Miedź JSC, Poland; Paweł Wac, KGHM Polska Miedź JSC, Poland; Maciej Dmytrow, DHV Hydroprojekt Ltd, Poland.

account the design, development, operation and technical maintenance, the Building Code Act (2010) along with the accompanying implementing regulations remain fundamental. The engineering solutions, together with the requirements included in the act ensure the site's safety.

In order to better understand the validity of the engineering solutions aimed at improving the safety and operation of the Żelazny Most, one needs to be informed about its basic functions, which are listed below:

- deposition of tailings generated during the copper ore flotation,
- production and storage of process water (reservoir function).

The Żelazny Most has been in constant operation and development since its launch. The design process drew on the experience gained during the construction and operation of the Gilów TSF, which in turn benefited from the conclusions drawn from the Iwiny TSF disaster, which was caused by a dam failure in 1967.

Because the reservoir is located in the central part of the site, Żelazny Most is considered to be a 1st class hydraulic structure. The highest safety requirements are set for structures of this kind. The Żelazny Most has been designed as a 1400 ha pile, surrounded by dams with a joint length of 14 km. At the time it began to operate, it was surrounded from only two sides (east and west) and it was naturally delimited by higher grounds from the north and south. As of now, the site is elevated entirely above the surrounding land. The height of the dams above the ground level ranges from 35 to 65 m.

Engineering solutions

Tailings deposition technology is the fundamental engineering solution ensuring safe exploitation. Tailings of thicker granulation from Lubin and Rudna are spigotted from the dam crests, creating beaches of gentle slopes (about 1%) towards the site's central part. From the ∅ 800 mm pipelines located at crests, tailings are transmitted through sections of about 500 m. The much finer Polkowice tailings are transmitted to the site's central part through pipelines laid on piers comprised of low earthen structures, perpendicular to the dams. The piers are also used for the spigotting of the Lubin and Rudna tailings during the winter, when low temperatures prevail.

Such a deposition system results in reduction in the amount of additional building materials utilized during the development of Żelazny Most. The soil, conventionally used during the construction of dams, is here replaced by separated tailings.

Figure 6.9 represents a scheme of tailing zoning in the site's embankment, while Table 6.3 shows selected geotechnical parameters of the soil. An apostrophe next to the zone number indicates that the parameters refer to a fully saturated material.

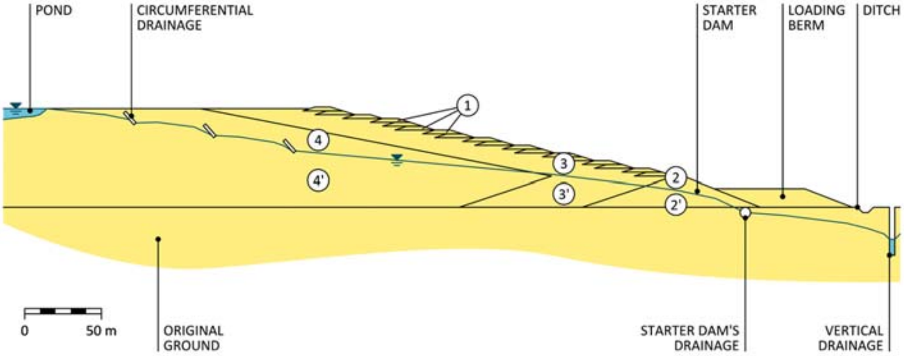

Figure 6.9. Tailing zoning in the site's embankment

Table 6.3. Soil geotechnical parameters

Zone	**Material type**	**γ, [kN/m^3]**	**ϕ', [°]**	**c', [kPa]**	**S_u, [kPa]**
1	Embankment (sandy tailings, mechanically condensed)	19.0	34	0	–
2	Starter dam (natural sands, mechanically condensed)	19.0	34	0	–
2′		20.5	34	0	–
3	Zone I (sandy tailings, not mechanically condensed)	18.0	34	0	–
3′		19.5	34	0	–
4	Zone II (uncondensed dusty tailings)	17.0	34	0	–
4′		18.5	–	–	0.25 σ'_v

where:

γ – unit weight,
ϕ' – effective internal friction angle,
c' – effective cohesion,
σ'_v – vertical effective stress,
S_u – undrained shear strength.

The location, range and parameters of soils in the Żelazny Most TSF were obtained from a very comprehensive and detailed program of in situ and laboratory research. It was carried out between 1992 and 1997 under the scientific supervision of the International Board of Experts (IBE), appointed by the KGHM Polska Miedź management. The research has continued and its results have been verified by the observational design method used in the site's development.

The observational design method is a standard method adopted worldwide. It was recommended by the IBE. Its goal is to use the data obtained from the monitoring during the course of the superstructure design process. Stability is analysed repetitively, based on the most up to date observations and data.

The TSF is raised in stages of 2.5 m. The pace of the site raising is approx. 1.3 m/a. Therefore, the raising stages follow each other in two-year intervals. The joint amount of tailings produced annually by the three ore enrichment plants (OEP Lubin, OEP Rudna and OEP Polkowice-Sieroszowice) is 17 Mm^3 (approx. 28 Mt).

The adopted deposition system causes the coarse tailings to remain on the beach, near the crest. At the same time, fine-grained (dusty) tailings flow into the pond, where they form a virtually impermeable bowl underneath the water table. The bowl restricts the water infiltration into the original ground. Observations proved that only 6% of technological water flows into the ground beneath the bowl, while the remaining 94% infiltrates through the beaches and is captured by the drainage system. The site is equipped with an aforementioned extensive drainage system, consisting of:

- A ditch at the dam's toe.
- Starter dam drainage and additional (auxiliary) drainage.
- Circumferential drainage.
- Vertical drainage (barrier of dewatering wells).

Starter dam drainage and additional drainage

The drainage was provided for the entire circumference of the site at starter dams' toe. In some regions, local seeps were spotted on the slope of the ditch adjoining the dam and on the lower ground at the foot of the dam. Additional drains were placed in these areas, which redirect water to the ditch adjoining the dam.

Circumferential drainage

Circumferential drainage has the form of three rings of tilted filtration walls. These 10 m high (when measured vertically) walls run parallel to the site's slope and have been constructed in stages in the pits on the beach. The lower part of the wall has the shape of a trapezoid. A perforated pipe has been placed in it to collect the water from the filtration wall and redirect it to the pipelines, buried in the spans of 100 m.

The drainage pipelines outlets have been inserted in wells located inside the slope. Wells are connected by the collective pipe running parallel to the slope. Every few hundred meters, a cascade discharge pipeline has been placed in a well. It redirects the water to a ditch at the foot of the slope or the pipeline running underneath a loading berm.

Vertical drainage – a barrier of dewatering wells

On the downstream side of the dams, a barrier of wells has been built. The barrier was located in places where the highest infiltration of salty water into the dam's forefield underneath the primary drainage was identified. In total, 48 wells have been built that capture 6 m^3 of water per minute.

The fundamental assumption of lowering the ground water level (e.g. prior to the site's construction) was to restore the natural directions of water runoff towards the site or parallel to its dams in places, where the majority of wells are now located. In regions where the rest of operating wells are to be found, a partial lowering of the water table has been achieved.

Risk factors

A sudden release of a large amount of water gathered in the site's pond (approx. 8 Mm^3) is a primary risk factor. The reservoir's capacity results from its primary function. A minimum water volume is indispensable for the rock particles to sediment on the bottom of it, and for the clarified water to be used again. Thus, it has been necessary to assess the effects of such a phenomenon, identify all factors potentially leading to it and take proper technical action to eliminate or minimize the risk of their occurrence. Those factors are: slope and ground stability, piping through a dam body, weather events and intentional and unintentional human actions.

Slope and ground stability

Loss of slope or ground stability remains one of the main causes of earthen dam failures. In the case of the Żelazny Most TSF, stability analyses are carried out systematically. The analyses are based on continuous geotechnical monitoring.

Stability calculations are made for every construction stage. Considering the raising rate, a detailed stability analysis is carried out for the entire site every 2 years. Stability is also analysed, when the monitoring data (displacement observations and water table changes) indicate certain trends, which diverge from the forecasts or show that threshold values have been exceeded. Stability analyses also include dynamic loads caused by mining activity. Any forecasts prepared by specialists are verified and used during calculations.

It should be stressed that so far, no signal indicating that a parameter(s) had crossed a threshold value has turned out to result in an actual threat. Also paraseismic tremors have reached no more than 30% of the forecasted acceleration values used in calculations Furthermore, restrictions were imposed on the mining works, so the influence of paraseismic activity is reduced below accepted boundaries.

Piping through a dam body

One needs to bear in mind that the Żelazny Most TSF differs a lot from a classic dam, as it lacks the upstream slope, which means that the slope is nearly flat. A hydraulic gradient (pressure to distance ratio) is a substantial parameter here. Privileged filtration routes, including poorly compressed soil zones also are a threat.

At the Żelazny Most TSF, continuous geotechnical monitoring is conducted. It includes static probing that makes it possible to identify loosened soil zones, both in the body of the dam and in its ground. Additionally, the KGHM is obliged to carry out daily inspections of slopes and the forefield. Also, ditches are inspected in order to identify any seeps.

It should also be stressed that identifying concentrated water leaks on slopes or in ditches doesn't necessarily translate into a threat. Usually, these are local phenomena, which require catching and discharging additional water.

Weather events

The site operates in winter. During the periods of sub-zero temperature, no construction works take place. That prevents frozen ground from being used as a construction material. It is also forbidden to deposit tailings on the frozen surface.

The site is resistant to heavy rains. For 1st class hydraulic structures, the dam's crest must be 2 m higher than the water surface in the pond. In practice, the elevation difference is larger than 3 m. Heavy rains do not cause any substantial (e.g. 2–3 cm) water level increase.

However, rainfall water on slopes and ledges may become a problem. At the Żelazny Most TSF, water is captured by specially shaped ledges. Such a solution was chosen because:

- Rainfall water irrigates plants on slopes, which prevent dust emission.
- Capturing water from such an extensive area would require the construction of an expensive system of ditches, reservoirs and pumping stations.
- Water distributed on ledges poses a smaller threat than the water collected at the foot of the dam.
- Infiltration does not pose a slope stability threat.

One of the drawbacks of such a solution is the local soil erosion. After a thaw or long-lasting, intense rainfalls, uncontrolled runoffs have been observed. Some local repairs performed by the KGHM are necessary then.

The dam's crest elevation, 2 m higher than the water surface in the pond, eliminates the influence of wave motion and backwater caused by wind action. Moreover, keeping the pond's shoreline min. 200 m away from the dam's crest prevents the water from overflowing.

Intentional and unintentional human actions

Construction disasters may be caused by people who trigger catastrophes by their unintentional actions. Hydraulic structures erected nationwide have been and will be designed taking a terrorism threat into consideration.

It is obviously possible for people to take actions at the Żelazny Most TSF that will lead to a disaster and pose a threat to the lives of others. Operational negligence and intentional human actions have been taken into consideration when controlling procedures were created.

The possibility of unintentional actions occurrence is minimized to an acceptable level by the system of inspections carried out by various external entities, such as the IBE (twice a year), Polish Geotechnical Expert (at least once a month) and the construction site inspector (at least once a week). Daily inspections are conducted by dam engineers.

Measures to protect groundwater and surface water against salty water infiltration

Surface drainage of areas adjacent to the TSF

Some local submersions of areas adjacent to the TSF have been recorded. In order to protect those areas, a surface drainage system has been put in place. It is based on certain assumptions:

- the intake and discharge of the water to the perimeter drain by a drainage system,
- renovation or conversion of the existing ditches (including sections of the ditch adjacent to the dam),
- providing conditions for proper tree growth (particularly in the newly reforested zones and marshy areas).

Regardless of the aforementioned actions, drainage works have been conducted on the forefield of the west dam, on the area of about 82 ha (drainage) and about 21 ha (ditches). Existing ditches are also intended for restoration.

What is more, action has been taken to protect the nearby Żdżerowita and Kalinówka streams from being contaminated by salty water infiltrating from the TSF.

Retków-Stara Rzeka intake and GWZP 314 protection

A large reservoir of groundwater is located in the north of the TSF (see figure 6.10). It has been declared one of the major groundwater reservoirs in the region (Polish name GWZP 314). The reservoir is mostly utilized by the Retków-Stara Rzeka intake, which has an exploitation reserve of 370 m^3/h. The intake was launched in 1988.

According to calculations made, which include the optimization of the existing vertical drainage wells as well as field observations, the Żelazny Most TSF will not contaminate the groundwater flowing into the Retków-Stara Rzeka intake. The assessment is based on the assumption that the water pumping will not exceed the value of 370 m^3/h.

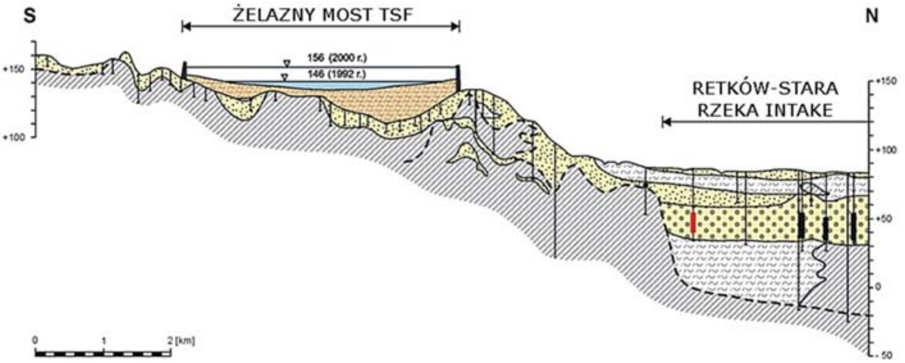

Figure 6.10. Simplified cross-section of the Żelazny Most TSF
Source: Duda and Witczak 1993

Techniques for limiting dust emission from beaches and dams

Żelazny Most TSF utilizes three methods of reducing dust emission: sprinkling with water, stabilisation with chemical agents and biological reclamation of dam slopes.

Sprinkling with water – water curtain

Sprinkling with water is performed using a "water curtain" situated on the TSF crest, as well as on the beach. It consists of a pipeline (∅ 200–500 mm) with sprinklers. The water is sprinkled under pressure up to a height of 3–4 m. Particles of water precipitate dust grains lifted from the beach and increase the beach tailings humidity within a 60 m wide zone and on the dam's crest. If required, the range of the sprinkling zone can be increased by additional devices installed on the beaches. The system is supplemented by sprinklers located on the beach, about 150 m away from the dam's crest. The main component of this installation is a pipe laid parallel to the dam's crest, out of which the water is ejected through the connections tilted upwards, towards the downstream slope, which are fitted with proper sprinkling endings. The installation's goal is to sprinkle the beach area during unfavourable weather conditions like strong wind, particularly when earthworks are performed on the beach.

Stabilisation with a water solution of emulsified asphalt

Since 1989, beaches and dams have been stabilized using medium-breaking cationic emulsified asphalt, manufactured originally for road construction. Thanks to this, the number of days with dust emission has been reduced by 50–60%. The solution of emulsified asphalt is applied by a helicopter equipped with typical spraying equipment. Farming tractors can also be used for this purpose.

In 1995, a formula for a new type of emulsified asphalt, called Beta 21B was invented. It is a nonionic, 65% medium-breaking emulsion with extended breaking time. The emulsion is characterized by high stability and breaking time adjusted to the physical and chemical properties of the tailings. Hydrochloric acid and oil liquefiers were eliminated from the formula.

Biological shield preventing the dams from water erosion and deflation

Slopes of dams at the Żelazny Most TSF are exposed to water erosion. Simultaneously, aeolian processes occur on slope surfaces, leading to air contamination by the dust. To mitigate this problem, slopes of the TSF are systematically covered with organic soil, and are sown with grass. New methods of biological regeneration are also being tested. The diagram below (Figure 6.11) presents actions undertaken to reduce the environmental impact of the Żelazny Most TSF.

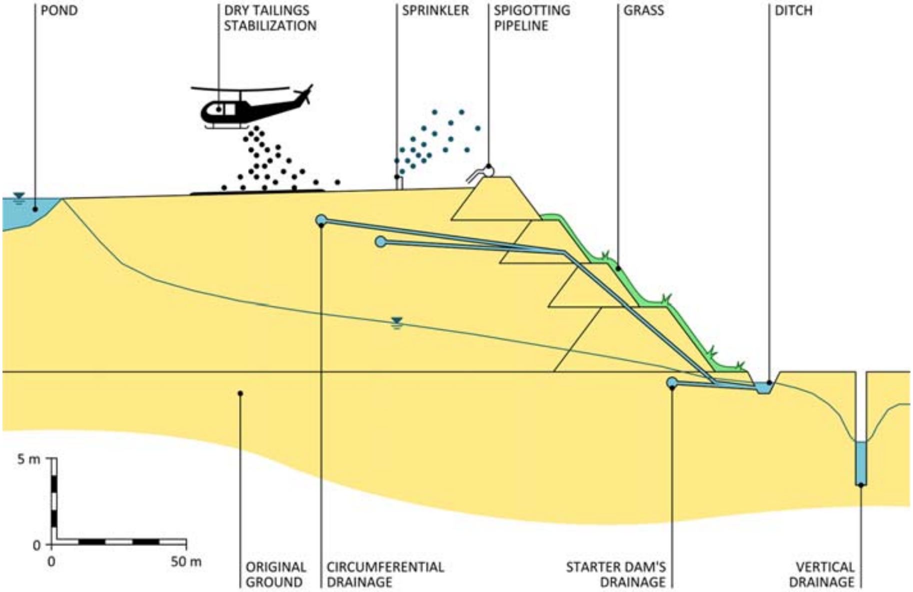

Figure 6.11. Actions reducing the Żelazny Most TSF environmental impact
Source: According to KGHM Cuprum CBR's study

In conclusion, it may be said that a construction disaster involving the release of the water collected in the pond is unlikely. The applied engineering solutions are more rigorous than the requirements set in appropriate regulations.

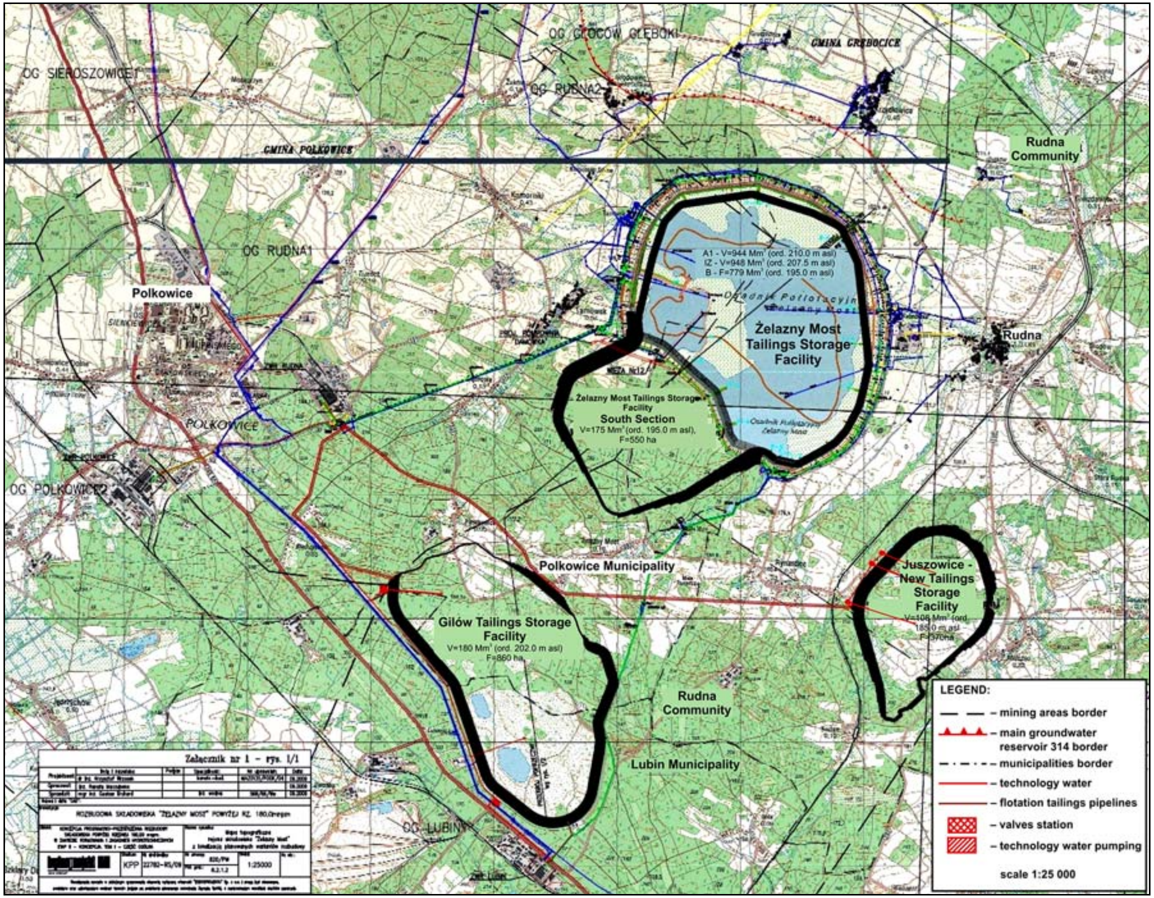

Figure 6.12. Conceptions of tailings deposition after 2016 – site plan

Source: Hydroprojekt Sp. z o. o. 2009

The crucial engineering solutions meant to ensure the safe development of the Żelazny Most TSF include:

- Method of tailings deposition, making it possible to properly segregate them.
- Relocation of the pond's shoreline to a distance of at least 200 m from the dam's crest.
- Maintenance of the low water table in the slope's interior by using the circumferential drainage and its gradual expansion.
- Aadaptation of observational method during the design, expansion and use of the site, as recommended by the IBE.
- Maintenance and continuous modifications of the site monitoring system.

Despite the unlikelihood of a failure, a complex operational and emergency plan has been prepared and is in place, along with a warning system in the flood-risk areas adjacent to the Żelazny Most TSF.

Future expansion of the Żelazny Most

Currently, the Żelazny Most TSF is being raised up to the elevation of 180 m asl. As a result, it will be capable of storing totally 620 Mm^3 of tailings by 2016. Since 2008, KGHM Polska Miedź had been preparing conceptual studies of solutions, which would secure tailings deposition until 2042 (969 Mm^3). Different scenarios of development were proposed, like further dam raising up to 205 m asl or launching an additional TSF.

Eventually, bearing in mind the crucial aspects, chiefly occupational and environmental safety, it was decided that the development of the Żelazny Most TSF will be carried out by building the Southern Extension (609 ha). This will be an additional site adjoining the main TSF from the south side. As a result, the height of dams of the entire site will be limited to 195 m asl, thus ensuring a high safety level. The Southern Extension will be located in lands belonging to the State Forests (540 ha), KGHM Polska Miedź (67 ha) and the Polkowice municipality (1.3 ha).

6.3. Waste from oil shale mining

Oil shale is extracted in surface mines or underground mines. The primary stages at which waste material is created are: the mechanical processing stage (incl. separation or heavy media separation) and the retorting stage.

During the mechanical processing stage, oil shale is separated from the limestone by crushing. Limestone is a stronger material than shale and allows for the oil shale to be more crushed in the process, while the limestone remains intact. Small pieces of limestone remain in the oil shale, so further separation occurs in a Heavy Medium Separation Process (HMS). HMS uses the density difference between shale and limestone and other mass in a wet process. Oil shale floats, while the other masses sink to the bottom (Valgma et al. 2012).

The resulting limestone aggregate is of relatively low quality, and can be used only for road construction in areas with little traffic, as well as for cement production for use in frost-free areas. Due to the low demand for such aggregates, they are usually deposited in heaps without being used (Väli et al. 2008).

However, such wastes can be used also in underground mines to backfill mined pillars. This makes it possible to extract oil shale from the original pillars, and then replace it with waste materials. This means that they can achieve greater production from the mine. To do this, waste rock is first mixed with cement and fly ash or gypsum, and then pumped into the mine (Valgma et al. 2012). A specific backfilling technology is highlighted in the case study below.

While the mechanical processing stage is responsible for the generation of the majority of waste rock, it is not the most serious concern in terms of environmental impact.

The waste from the retort is of two types: ash and semi-coke. The type of technique, which is used for retorting defines the impact. In Estonia, there are two types of retorts in use: Kiviter and Galot (Väli et al. 2008). Obtained oil shale grains greater than 25 mm are retorted in Kiviter, while smaller particles are filtered out for further recovery in Galot or as fuel in a power plant (Väli et al. 2008).

The waste from Kiviter is essentially a solid mass called semi-coke (SC) with TOC content of around 14% (Soone et al. 2007). Francu et al. (2007) showed that for a barrel of shale oil produced over a tonne of SC was produced. It was also shown that the volume of the heat treated masses increased by 15–25%. It is possible to carry out further processing of such waste to make it less environmentally harmful. Trikkel et al. (2008) have done tests on the burning of semi-coke, either alone or mixed with oil shale. The experiments showed that the circulating fluidized bed combustion (CFBC) can solve the problems of SC utilization.

In the Galot process semi-coke is also produced, but the process utilizes the remaining energy of waste combustible material. The waste from the Galot process is therefore ash containing less than 1% TOC (Golubev 2003). It forms as much as 600 kg ash per tonne of oil shale. The ash remaining is then separated by gravity, the water is recycled and sent back to the retort. The majority of ashes are still subject to the landfill, though this is a smaller environmental problem than semi-coke. There are different methods for utilizing the ashes. Although several treatment and reuse methods are available, the amount of ash deposited each year is large. This is because products created for reuse have a limited market. Research on further treatment and alternative uses will in the future be important to reduce the need for landfilling.

A final form of waste generated during the retort process is sludge or fine soil. This is most often a mud-like slurry consisting of shale oil, water and slate dust, which accumulates in the condensation process in the retort. Oil sludge and washing oil are collected and separated in a tank. The amount of sludge is approx. 2% of the shale oil produced.

6.3.1. Case study from Estonia – utilization of oil shale waste rock

Overall characteristics of oil shale waste rock

Oil shale waste rock (limestone, marlstone or dolostone) is produced during extraction, from waste material from separation plant and material from crushing and sizing operations in aggregate production. A major part of waste rock from opencast mines is deposited and the mining site is restored. Waste rock from underground mines is piled up in waste rock dumps near the mines and the deposited amount is approx. 3–4 Mt/a. Total amount of already deposited waste rock is over 100 Mt. Crushed waste rock from the separation plant is produced in classes 25/100 and 100/300 mm and is partly utilized as a fill soil, in road building and in civil engineering.

Waste rock, which is produced during extraction or separation in a plant can be used for different purposes. The main problem of the properties of the resulting aggregate is its low resistance to fragmentation and resistance to freezing, which is caused by the presence of fine and weak oil shale particles. It is thus essential to find ways to effectively extract oil shale and limestone separately and to prevent oil shale residuals in mining waste rock.

The main study on the utilization of waste rock from oil shale mining was prepared by Tohver (2011). The author's suggestions and recommendations were that aggregates' resistance to freezing and thawing determines the utilization areas of waste rock. Tests confirm that a selective crushing method is the best solution to remove oil shale from waste rock aggregate. Material from some interlayers (A'/B and C/D) can be used for civil engineering and road building, while from other interlayers for backfilling of the already mined areas.

Future studies of oil shale waste rock should focus on selective crushing with crushing buckets, on utilization of waste rock as a backfilling material and on implementation of new technologies into the technological scheme. This study can also play an important role in regards to the Min-Novation pilot unit "Oil Shale Waste-to-Product Mobile Unit", which is described in subchapter 3.4.

Systems of oil shale underground mining in Estonia

Underground mining is performed for half of the Estonian oil shale mining capacity. Underground production is about 7 Mt of oil shale, not including separated limestone, which amounts to an additional 40% of the produced mass per year.

Currently, oil shale is mined in three underground mines in addition to seven surface mining fields (Valgma 2000). Oil shale bedding depth reaches 80 m. The room and pillar mining system with drilling and blasting is the most prevalent method in use with square-shaped pillars left to support the roof (Figure 6.13).

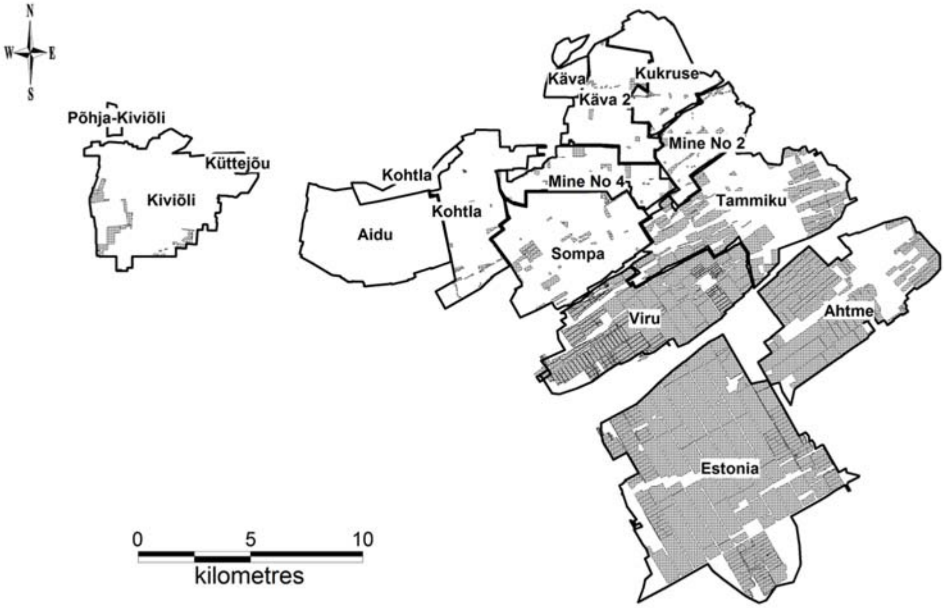

Figure 6.13. Room and pillar mining areas, marked with hatching
Source: Tallinn University of Technology, Department of Mining

The oil shale mine fields are divided into panels by panel drifts. The panels, 600 to 800 m wide and several kilometers long, are then divided into 350 m wide mining blocks. Bottom cutting, drilling of blast holes, blasting, loading of blasted rock on the chain conveyer and supporting the roof by bolts are some of the main types of operations carried out in the rooms. Their height corresponds to the thickness of the commercial oil shale bed, which was mostly 2.8 m. Today, the height in Estonian oil shale mines is up to 3.8 m with a new room and pillar method, while the width of the workings varies from 6 to 10 m (Figure 6.14).

Studied backfill mix components and their origin

Large amounts of neutral (limestone) and hazardous waste (ash) is generated by the oil shale industry (Valgma 2003). The use of ash and limestone as backfilling materials could reduce the volume and area required for surface disposal and consequently the environmental taxes (Adamson et al. 1988).

Figure 6.14. Room and pillar mining in Estonian oil shale mine
Source: Tallinn University of Technology, Department of Mining

The typical components of the backfill mix include water, waste limestone rock from oil shale mining, ash from the power plant (after oil shale burning), and in addition sand, fibers or cement (Figure 6.15). For dry underground separation of limestone rock, tests with Bradford drums have been carried out. In addition, crushing buckets have been tested in several sites. The currently used impact crusher also partially works like a selective crusher, but additional Heavy Media Separation is needed on the surface.

Sizers or other types of crushers are needed for generating the 0–15 mm oil shale fraction, and 0–45 mm limestone fraction. Since fines are difficult to handle both in the power plant and in the oil generation process, the smallest, 0–5 mm fraction should be avoided. The main problem in mines is the high percentage of the 0–25 mm fine fraction, which amounts to 30% of the total production. However, once the fines have undergone appropriate treatment, they can be used in power plants. If the separation process produces suitable material, the residue (ash) could also be used as backfilling material (Valgma 2009).

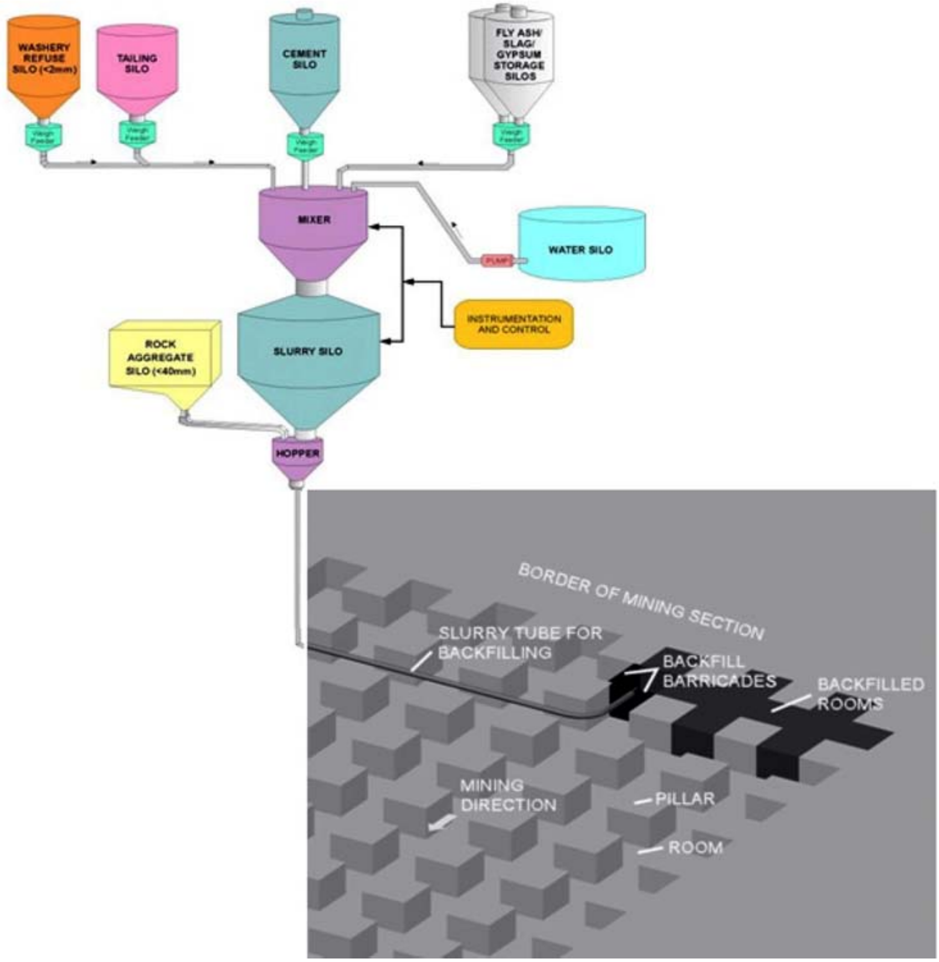

Figure 6.15. System of limestone wastes used in room backfilling in underground oil shale mines

Source: Bäckstrom et al. 2013

Backfill materials tests

Industrial tests were performed with ash, aggregate and water mixture. Valgma et al., 2012 started a preliminary investigation into the optimal backfilling technology in Estonian oil shale mines.

Other experiments in mines have also been performed (Väizene 2009). The main methods that have been tested are:

- dry casting of waste rock to the mined out rooms and adding ash and water mixture,
- pumping wet mixture with piston pump to the rooms.

Additional experiments have looked at new ashes (new burning and heating technologies) and waste rock aggregates. Road stabilization tests were performed in a mined out area using a hydraulic backfilling technology (piston pump, slurry, frill hole, pumping tube; Figure 6.16). The drift was stabilised and the mixture reached stability within 2 days.

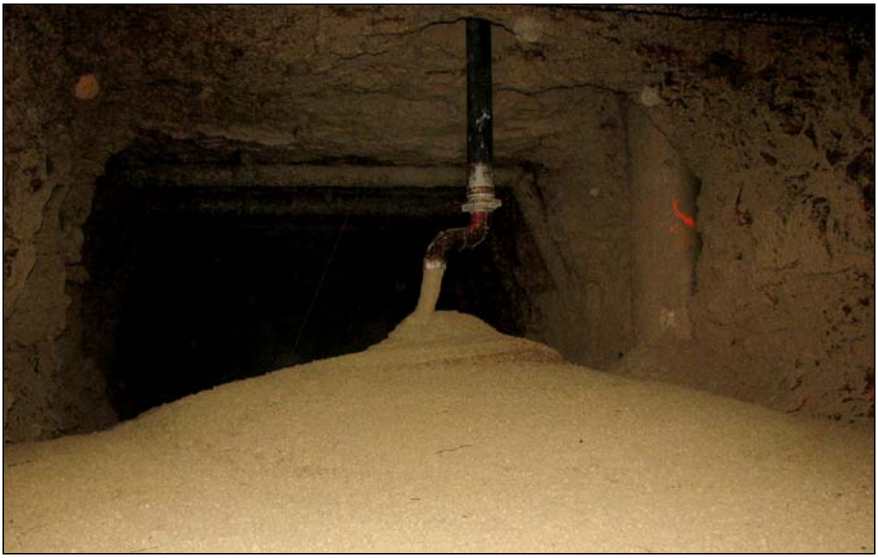

Figure 6.16. Hydraulic backfilling in an oil shale mine
Source: Valgma et al. 2013

Laboratory tests were performed using different ash mixtures (Figure 6.17). Ash mixtures were formed in the standard concrete moulds and kept in different conditions. For simulating the mining environment, a refrigerator was built with temperature and humidity monitoring. For holding low temperature (8 °C) an air conditioner and an air humidifier were used. In addition, water circulation with wet textile was applied. The air conditioner together with the wet textile and the air humidifier guaranteed 8 °C temperature and 90% humidity. The refrigerators stored samples for different periods of time. After each period, the sample was tested for uniaxial compressive strength. In addition, the sample was kept in water and leached water was analysed (Valgma et al. 2013).

In case of testing backfill material, the temperature, humidity and size of the sample play an important role. Several samples that have been kept in standard conditions show good compressive strength. Meanwhile, samples kept in the mine environment showed less compressive strength. Tests conducted in the mine actually showed better compressive strength results: 10 MPa. This could be related to the warming effect of the large scale mixture, which can have a positive influence on the hardening process (Valgma et al. 2013).

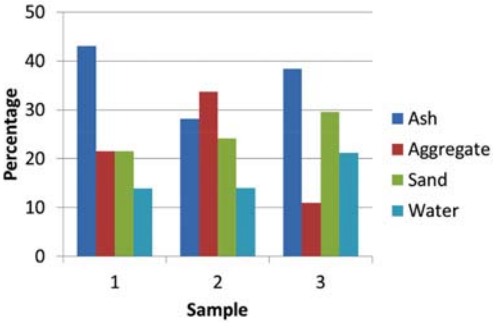

Figure 6.17. Composition of tested mixtures
Source: Valgma et al. 2013

6.4. Waste from oil drilling and production

The drilling for oil creates a series of waste streams, which need to be carefully managed to avoid short- and long-term damage to the environment. The main types of waste generated on a drilling rig are oily drill cuttings and slop water. Produced water is not generated from drilling operations, but from production of oil and gas. By volume, produced water is by far the largest by-product during oil and gas operations (Knutsen and Farsdal 2013).

The produced water is separated from the oil and gas on the oil platform by different technologies and when reaching 30 ppm oil in water concentrations, or some other agreed on concentration, then disposed of at sea. Produced water was formerly re-injected into formations, and this practice is still used. However, leaks of produced water and reappearing produced water into the sea bed have negated this practice from being a chosen technology. Produced water typically contains dispersed oil, monocyclic and polycyclic aromatic hydrocarbons, alkylphenols, metals, naturally occurring radioactive material, organic substances, organic acids, inorganic salts, mineral particles, sulphur and sulphides. Synthetic additives are also used to e.g. prevent the growth of bacteria, corrosion or the formation of emulsion. One of the major concerns about produced water are its presumed effects on the reproductive ability of fish, particularly the influence of alkylphenols (Research Council of Norway 2012).

The focus of this section are drill cuttings, which as mentioned in chapter 4 represent next to produced water, the largest portion of hazardous waste generated in Norway's petroleum sector. Cuttings are small fragments of rock from the bedrock that are contaminated with drilling fluid used during drilling. In other cases, cuttings are also contaminated by oil from the geological formation itself. Discharges of oil based drill cuttings on the Norwegian Continental Shelf directly into the sea were common before this practice was banned in 1993 (from then on, cuttings with more than 1% oil content were to be injected into a fracture or taken to shore for treatment). Drilling fluids used prior to that were largely based on diesel (up to 1980), which is highly toxic (Kvalheim and Ugland 1997). A study indicated that between 1985 and 1993 there were substantial reductions of key organisms such as food for fish in areas with discharge of oily drill cuttings. These findings were made up to a radius of 2–3 km from the discharge point. It was concluded that these reductions of organisms were associated with discharge of oil based cuttings. It was also shown that the impact remained several years after the disposal ban had taken effect, but later investigations and experience show a clear reduction in contamination and biological effects in the Norwegian sector.

Cuttings containing drilling fluid or oil must therefore be treated before they can be deposited. How the cuttings must be treated is determined by the type of fluid that has been used during drilling. Treatment of oily cuttings constitutes a relevant issue related to oil production. For instance, Statoil paid around NOK 21 million only for the transportation of cuttings to shore from the Uranus oil field.

Cuttings consistency depends on the drilling fluids that have been used. A distinction is made between oil based and water based drilling fluids. Discharge of cuttings directly into the sea, which contain more than 1% of oil-based drilling fluid is prohibited. Discharge criteria for oil content in the cuttings are at a level that it is technically difficult to reduce the content to an acceptable level. Oil based fluids are nevertheless used when water based drilling fluids do not work. Current waste practices are injections of oil contaminated drill cuttings into designated wells or transport the cuttings to shore for treatment and disposal.

Discharge emissions of cuttings are regulated and cuttings should not be discharged when the oil content exceeds 10 g/kg dry weight. In the Barents Sea area it is not allowed to use oil based drilling fluids at all nor is it allowed to discharge water based drilling fluids contaminated cuttings, but it is possible to apply for a permit for discharge of cuttings from the top well section (start of drilling). If it is not possible to inject the cuttings back into the geological formation, the oily cuttings have to be pre-treated offshore and shipped to shore. Pre-treatment is performed in order to reduce the amount for transportation and further treatment on land. The most frequently used method to separate the oily cuttings from the mud offshore is by using a shaker. To treat minor particles it has also been common to use gravity-based methods such as hydrocyclones and centrifuges. Hydrocyclones have become smaller and less used as shaker units have been more effective in removing smaller particles.

In Norway, a number of companies are authorized to receive and process this waste on shore. The most common treatment method separates the oily cuttings in three categories of waste: oil, water and solids. The water must be purified before it can be reused or disposed of to sea. Oil and solids are disposed of or reused. The most common treatment method for oily cuttings is the Thermo Mechanical Cuttings Cleaner (TCC) that treats 80 000 of the 110 000 t treated in Norway (Svendsen and Taugbøl 2011).

6.4.1. Case study from Norway – Thermomechanical Cuttings Cleaner

Thermal desorption of drill cuttings was introduced to the oil industry in the early to mid-1990s, following the successful treatment using this method of contaminated soils from industrial activities. Since then, thermal desorption has evolved into an acceptable technology for treatment of drilling wastes from both onshore and offshore operations (Zupan and Kapila 2000, Antle et al. 2003, Pierce et al. 2006, Murray et al. 2008).

Incineration is sometimes erroneously regarded as thermal treatment, but the thermal destruction of the waste cannot be compared to the thermal recovery methods. Since the base oil in oil based mud (OBM) is highly valuable, the ability to reuse the oil recovered from the treatment process makes a substantial impact on the business case (Kleppe 2009). In thermal desorption heat is added to a material resulting in a temperature rise above the boiling point of the volatile compounds in the material. By subsidiary cooling of the vapors, the volatile compounds can be recovered and fractionated (Murray et al. 2008).

The main volatile compounds are the base oils and the water from the drilling fluid. The thermal desorption treatment can improve the quality of the recovered oil in comparison with the oil in the feed, by removing those oil fractions not specific for the virgin base oil. The technology based on the heat generated by friction with the consequent evaporation in the Thermomechanical Cuttings Cleaner (TCC) has been successfully applied in the treatment of the drilling waste since the year 2000. Influent cuttings to a TCC unit convert kinetic energy to thermal energy by creating friction in the cuttings. A drive unit rotates a series of shaft mounted hammer arms inside a barrel shaped process chamber (Figure 6.18). The solid particles are forced towards the wall of the process chamber where the kinetic energy from the rotating arms is transformed into heat by friction. The liquids oil and water evaporate and leave the chamber, while the solids are discharged continuously through a cell valve. The hottest spot in the process is in the cuttings. The fluid flash evaporates and is under influence of the process temperature for only a few seconds[15].

A benefit of the TCC process is the intense agitation that efficiently breaks up the solid particles. This provides minimal diffusion distances for oils, which must overcome the capillary forces, which bind the oil internally in the solid particles. From an environmental

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[15] Valentinetti R., Kleppe S.: Re-using Recovered Base Oil from OBM Drilling Waste. Personal communication, 2013.

standpoint, the advantage of the TCC thermo mechanical desorption process is the high degree of recovery of the hydrocarbons for reuse. Operators of the process are able to recover base oil for reuse in new drilling fluid, while the quality of the solid particles makes them potentially valuable as a filler material in different industrial products.

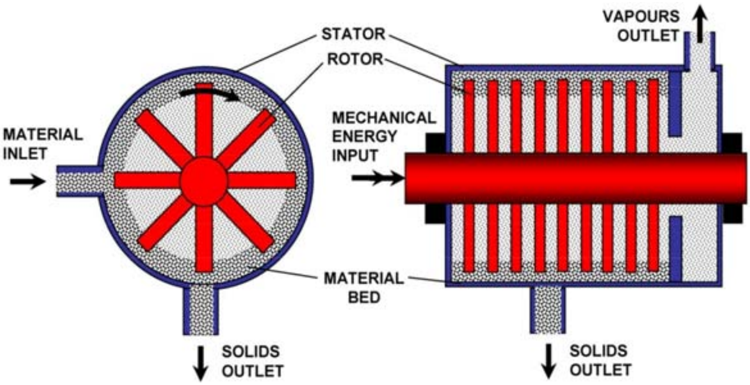

Figure 6.18. Principle Sketch for TCC
Source: Thermtech 2013

Heat Generation Mechanics

The rotor and stator unit is a central element in the TCC process mill in figure 6.19. Heat is produced through dissipation of the mechanical energy supplied to the material bed from the rotor in figure 6.18. A combination of volatilization of fluids and the centrifugal force field generated by the highly turbulent-causing rotor, keep the material bed fluidized in a well-mixed bed near the walls of the stator. The overall dimension of a normal cylindrical reactor is 1 m × 1 m, through which a shaft with a series of hammer arms is mounted. This chamber is referred to as the process mill. An electrical motor or diesel engine drives this shaft (Figure 6.19). The total bed mass is limited to 200–400 kg of feed material. This corresponds to an average retention time for solids in the reactor of 6–12 min and 15–30 s for the oil.

The TCC is the only friction-based thermal separation technology, which recovers the different components of the oily waste for reuse. TCC operates both onshore and offshore.

Flow through the process

The main feature of the TCC technology consists in the heating of the waste stream up to a temperature higher than the evaporation temperature of the oil in the waste, normally 250 to 300 °C. The oil and water will then evaporate and condense in separate condensers for oil and water. There is no evidence that the base oil decomposes during the TCC treatment.

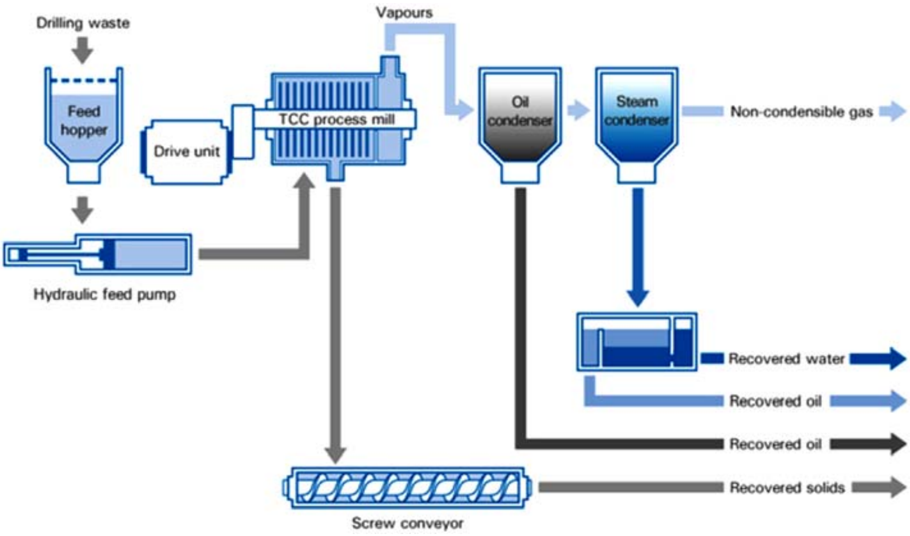

Figure 6.19. TCC Schematic
Source: Thermtech 2013

Table 6.4. Properties of drill cuttings from OBM drilling

Cuttings	Typical density: 1.750 kg/m^3
Solids	70% solids by weight Typical density: 3.000 kg/m^3 Maximum particle size 20 mm Minimum particle size 50 µm
Oil	15% oil by weight Density: 800 kg/m^3 Initial boiling point IBP > 230 °C Final boiling point FBP < 330 °C Auto ignition temperature T_{auto} < 230 °C Flash point FP > 65 °C
Water	15% by weight

Source: Thermtech 2013

TCC separates the drilling waste into three streams: a solid phase, a phase containing the recovered hydrocarbons and a processed water stream. The process does not generate any additional waste streams.

A synthetic base oil is a very pure mixture of n-paraffin in the range C10 to C16. Flash point changes of <2 °C of the recovered base oil compared to the virgin oil indicates that little or no cracking of the synthetic oil occurs in the process (Thermtech 2013). Table 6.4 contains typical qualities in drill cuttings from drilling with OBM.

Quality of cuttings

The solids in the drilling waste vary with the lithology of the borehole. It is not possible to guarantee the composition, but expectations can be defined based on historical data from similar feedstock and similar operations. The solid phase from the TCC process is a light and dusty mineral powder with particle size in the range from 0.1 to 2000 μm (Figure 6.20). The solids leaving the unit are hot and dry, appearing very lightweight and dusty. In most cases the powder is damped with the recovered water to avoid dusting. Their bulk weight is typically 2 kg/dm^3. The solids carry a minor amount of organic matters and hydrocarbons, less than 4000 ppm (Thermtech 2013).

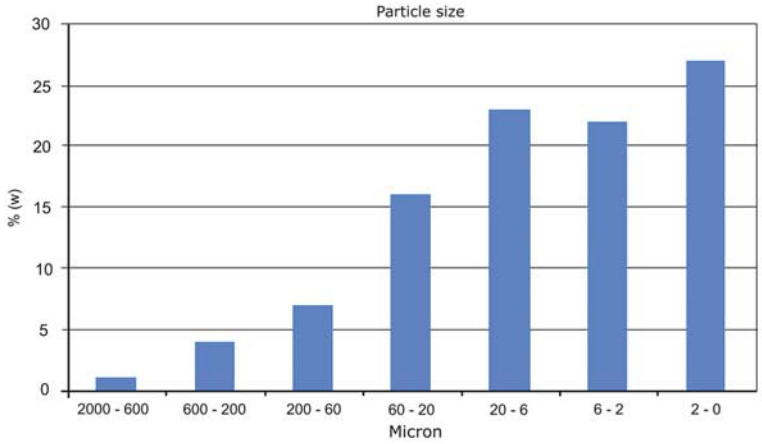

Figure 6.20. The median size of cuttings after TCC is less than 50 micron
Source: Thermtech 2013

Quality of recovered base oil

Base oils used for drilling fluids are well defined, low sulphur, low aromatics oils within the diesel range of distillation. Among the quality specifications for the base oil are density and flash point. In addition HSE requirements are low in aromatics, BTEX and sulphur.

Fingerprint

An example with oil from a TCC operation shows a GC-MS profile of used base oil before it is treated (Figure 6.21) and base oil recovered in the hammer mill. The recovered oil has the same fingerprint as virgin oil, and is directly reusable as base oil in new mud.

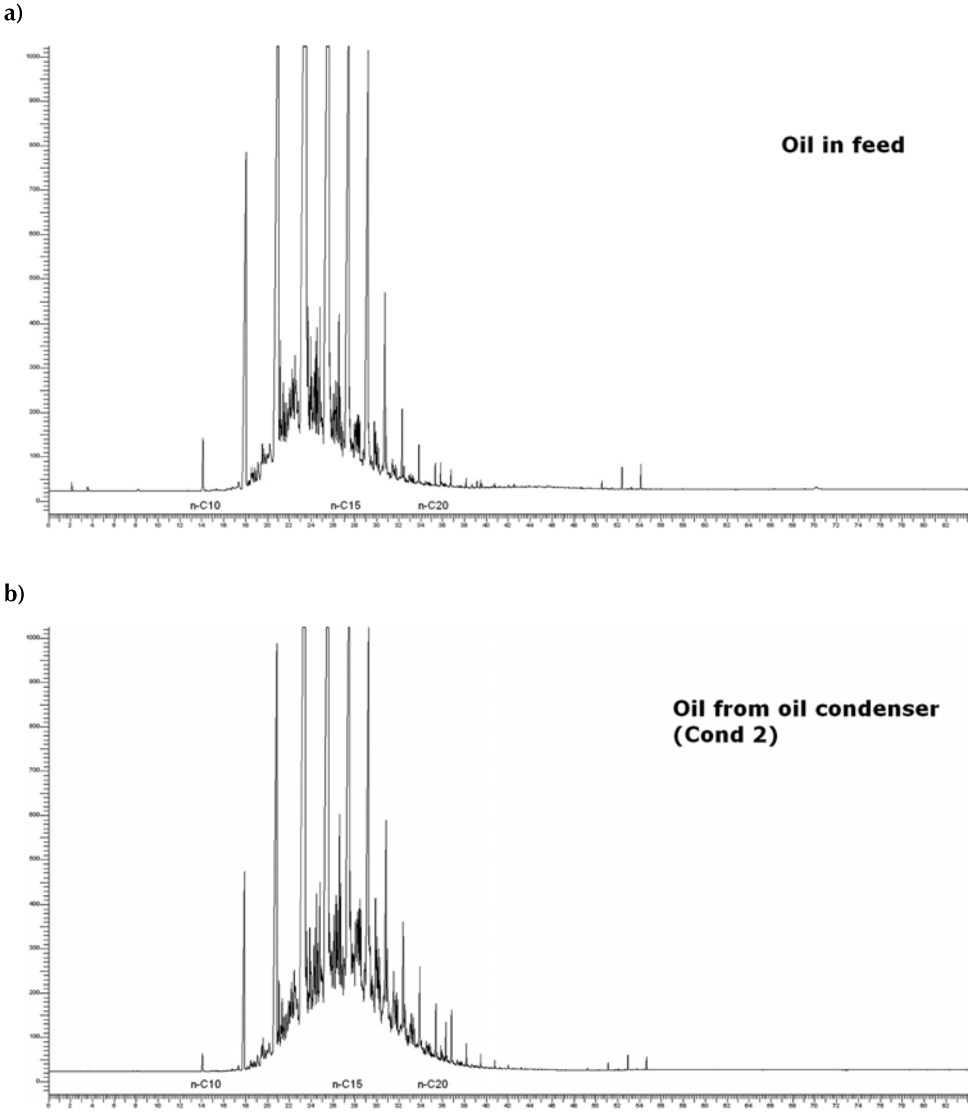

Figure 6.21. GC-MS profiles of base oil and TCC effluent:
a) oil in feed, b) oil from oil condenser
Source: Kleppe 2009

Conclusions

The TCC hammer mill is used for cleaning cuttings containing hydrocarbons. The solid phase from the TCC process is a light and dusty mineral powder with a particle size in the range of 300 to 2000 µm. Recoveries of high quality oil from OBM drill cuttings take place without degrading oil quality. In fact, by removing oil fractions outside of the virgin base oil specification the thermal separation process can actually be used to raise the quality of the oil fed into the unit. Compared to other drying methodologies, TCC friction driers offer a gentle evaporation, low cuttings residence time of 6–12 min. in the reactor and low required process temperature. These, in addition to the homogenous mixing, are all factors that ensure the best possible oil recovery and oil free cuttings.

6.5. Waste from hard coal mining

Hard coal mining and processing wastes are made up of sedimentary Carboniferous barren rocks, which are extracted as ripping material together with coal seams. Additional amounts of barren rocks are mined in course of preparatory works and during exploitation, when stone workings are built.

Hard coal mining and processing wastes are commonly divided into two groups:

- Mining wastes – constituting up to 20% of the total amount of hard coal wastes, coming directly from preparatory works and exploitation, with very variable quality parameters depending on rock types and geological conditions of the extracted deposits; granulation of such wastes is inhomogeneous, reaching up to 500 mm;
- Processing wastes – coming from hard coal processing, depending on the type of used processing equipment and applied technologies. They commonly are divided into three subgroups:
  - coarse-grained wastes from dense medium gravity separation – with homogeneous mineral composition, typical granulation 20–200 mm, coal content 5–15%, sulphur content <1%, humidity 4–6%,
  - fine-grained wastes from jiggers – with homogeneous mineral composition, typical granulation under 20 mm, higher coal content, sulphur content and humidity than in case of coarse-grained wastes,
  - very fine-grained flotation wastes – with high content of coal, sulphur and high humidity, with presence of residues of flotation reagents and flocculants (Lutyński and Blaschke 2009, Galos and Szlugaj 2009).

Regarding petrographic types, the main components of coal wastes are in variable amounts claystone, clay shales, mudstone, sandstone and rarely conglomerate, with leading share of claystone. Sandstone is rare in processing wastes, appearing more often in mining wastes. Conglomerate can occur only in mining wastes.

Coal wastes in individual mines exhibit a variable petrographic composition and content of combustible particles. This results from the geological setting and type of rocks accompanying the coal seams, as well as from the processing technology. Sometimes, claystone and clay shale dominate in barren rocks, while in other cases, the sandstone content can reach up to 70%. The content of combustible particles can reach 10% (Potempa and Szlugaj 2007, Koperski and Lech 2007).

Some technologies allowing coal wastes utilization have been used for years, but new technologies or modifications of existing ones are still under development. Taking into account available processing technologies, it is possible to:

- manage processing in such a way as to obtain directly not only coal, but also a secondary product, e.g. aggregates, and/or
- recover coal mining and processing wastes to obtain aggregates and other raw materials for building materials production.

Coarse-grained wastes are the most promising due to large possibilities of industrial use. Currently, their main applications are (Galos and Szlugaj 2009):

- Engineering, hydrotechnical and road construction, including production of aggregates for such purposes.
- Production of raw materials for building materials production (cement, building ceramics).
- Recovery of coal and production of low calorific materials for power plants.
- Use of such wastes as filling material for backfilling of underground workings.

For such purposes, several technological schemes of hard coal wastes processing are applied. Most commonly, they consist of various processes of mechanical processing:

- crushing (jaw crushers, cone, crushers, impact crushers),
- classification (vibrating screens, hydrocyclones),
- gravity separation in dense media;

but sometimes also additional processes:

- mixing with binding materials (cement, fly ash, blast-furnace slag) to stabilize aggregate properties,
- granulation with use of lime.

The most important examples of such uses of hard coal mining and processing wastes in case of Poland are given below.

6.5.1. Case study from Poland – applications of hard coal mining and processing wastes

Production of aggregates for engineering, hydrotechnical and road construction

Two main areas of application of coal wastes in aggregate production are:

1) Production of aggregates exhibiting variable graining and mechanical parameters on the basis of raw (unburnt) coal wastes.
2) Production of lightweight aggregate (shale gravellite) with use of self-burnt coal shale.

<u>Production of aggregates from raw coal wastes</u>

Haldex JSC is the main company dealing with the comprehensive utilization of coal wastes in the Upper Silesia region (Figure 6.22). The company was established in 1959, and in 2008 it started to be a part of the Kompania Węglowa JSC capital group (the largest hard coal producer in Poland). Now, Haldex JSC is the sole operator of coal wastes coming from mines belonging to Kompania Węglowa JSC. During over 50 years of activity, plants of Haldex JSC processed over 150 Mt of coal wastes. From these wastes approx. 10% of coal was recovered, approx. 6% constituted coal shale for building ceramics, approx. 7% coal shale for cement production, approx. 7% materials for engineering and land reclamation works and approx. 3% materials for lightweight aggregates production (shale gravellite). The remaining 67% of wastes was used as material for backfilling in underground coal mines (Koperski et al. 2008).

Recently, Haldex JSC started to be an important producer of good quality, certified aggregates on the basis of coal wastes from the mines of Kompania Węglowa JSC. Such aggregates exhibit various graining, being composed of variable shares of claystone, mudstone and sandstone. Currently, processing of coal wastes with recovery of coal and aggregates is carried out in four plants operated by Haldex JSC: Z-1 Michał in Siemianowice Śląskie (since 1961), Z-2 Szombierki in Bytom (since 1963) and Z-6 Brzezinka in Mysłowice-Brzezinka (since 1980), each with a processing capacity approx. 2800 t/d, and since 2011 the new Z-12 Panewniki plant in Mikołów (processing capacity 5000 t/d). The new Z-3 Makoszowy plant in Zabrze will be commenced in the near future.

Each Haldex plant operates according to the following process (Kucharzyk 2004):

- Preparation of input (0–200 mm coal wastes).
- Initial classification on pin grate into grain classes <80 mm and >80 mm; grain class >80 mm is directed to jaw crusher and merged with grain class <80 mm after crushing.

- Second stage of classification on vibrating screens into grain classes <45 mm and >45 mm; the grain class >45 mm is directed to a crusher and then merged with the grain class <45 mm.
- Classification in hydrocyclones with the use of dense media, then washing, dewatering and classification, with separation of: thermal hard coal 0–20 mm and 20–45 mm.
- Thickening and classification of wastes from hydrocyclones, with obtainment of ceramic shale 0–3 mm for cement and building ceramics, and 3–45 mm aggregate.

The aggregate 3–45 mm obtained in the above mentioned Haldex JSC plants is commonly a mixture of Carbonaceous claystone, clay shales, mudstone and sandstone, with predominance of clay shales and claystones and a small share of sandstone (<10%). It exhibits variable water absorption and commonly weak freeze resistance. It can find use in engineering works (road construction, hydrotechnical construction), for land reclamation, for construction of landfills and for backfilling of underground workings. Due to weak freeze resistance, such an aggregate can be used in road construction only after stabilization with use of cement, active fly ash or granulated blast-furnace slag. Some modifications in Haldex plants in recent years allowed changing the assortment of produced aggregates, with separation of coarse-grained aggregates (Table 6.5). Total production of aggregates in the plants of Haldex JSC reached 1.8 Mt in 2008 (including approx. 30% of aggregates >31.5 mm), and after the commencement of operations of Z-12 Panewniki and Z-3 Makoszowy plants it will probably exceed 3.0 Mt/a in 2013 (Koperski et al. 2008).

Table 6.5. Aggregates from coal wastes produced in the plants of Haldex JSC

Granulation, (mm)	**Z-1 Michał**	**Z-2 Szombierki**	**Z-3 Makoszowy**	**Z-6 Brzezinka**	**WKS Rydułtowy**
0–31.5	x	x	x	x	x
31.5–63	x				x
31.5–90	x				
40–90				x	
10–31.5	x			x	
0–63			x		x
0–200		x	x		x
63(100)–150(200)	x	x	x	x	

Source: Haldex JSC

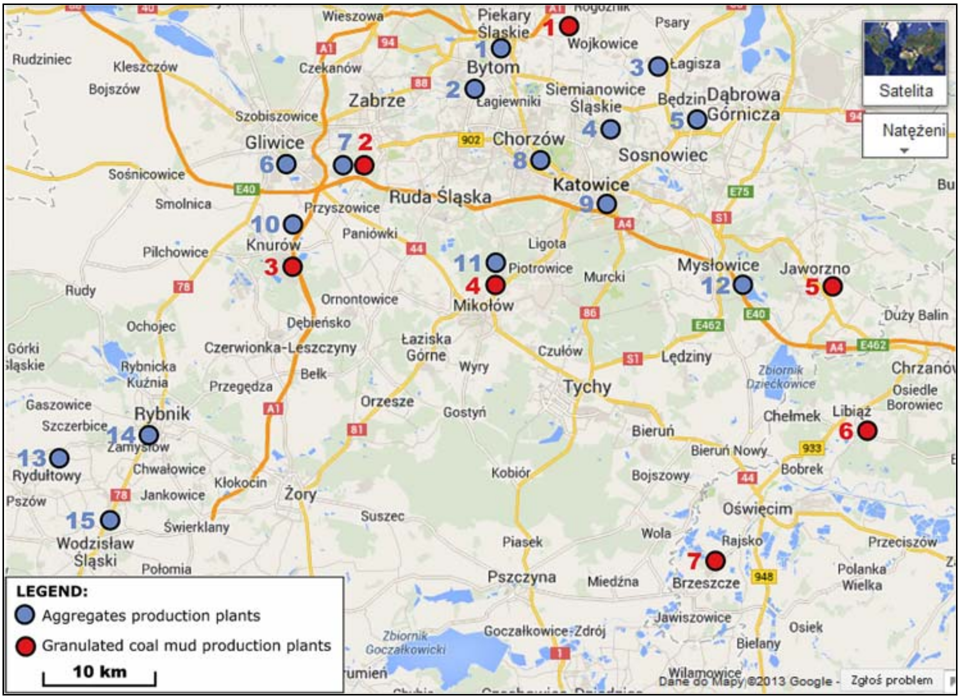

Figure 6.22. The location of main aggregate production plants and granulated coal mud production plants in Upper Silesia Region
The main plants delivering aggregates from raw coal wastes or from shale gravellite:
1 – Foreko Śląsk Bytom, 2 – Haldex Z-2 Szombierki, 3 – Azas Będzin, 4 – Haldex Z-1 Michał,
5 – Wirex Będzin 6 – Trakt Gliwice, 7 – Haldex Z-3 Makoszowy,
8 – Tercharpol Siemianowice Śląskie, 9 – IBC Katowice, 10 – Haldex WKS Knurów,
11 – Haldex Z-12 Panewniki, 12 – Haldex Z-6 Brzezinka, 13 – Haldex WKS Rydułtowy,
14 – Stef-Pol Rybnik, 15 – Barosz-Gwimet Marklowice
Granulated coal mud production plants:
1 – Haldex ZG Piekary, 2 – Haldex Makoszowy, 3 – Haldex Szczygłowice,
4 – Haldex Panewniki, 5 – PKW Sobieski, 6 – PKW Janina, 7 – Haldex Brzeszcze

Several years ago, Haldex JSC started to also process wastes not contaminated by coal (e.g. mining wastes from preparatory and providing mining works, not mixed with coal processing wastes). Such wastes are directed to mobile crushing-sieving units, where aggregates with granulation consistent with customers' expectations can be provided. To date, Haldex JSC has opened two such crushing-sieving units, each of 2000 t/d capacity:

1) Knurów crushing-sieving unit (WKS Knurów) – near Aniołki shaft of the Knurów Hard Coal Mine, since 2007.
2) Rydułtowy crushing-sieving unit (WKS Rydułtowy) – in the Rydułtowy Ruch II Anna Hard Coal Mine, since 2008.

The total aggregates production in these units can reach 0.7–0.9 Mt/a (Kugiel and Piekło 2012).

Production of shale gravellite aggregates

Shale gravellite is an artificial lightweight aggregate, obtained in the course of thermal processing (sintering) of raw coal shale or due to mechanical processing of self-burnt coal shale from old dumps. Shale gravellite, for dozens of years, was manufactured by sintering raw coal shale, mainly in the Lightweight Aggregates Production Plant in Siemianowice Śląskie, belonging to Haldex JSC. Its production sometimes exceeded 200 000 t/a. Such production was abandoned in the early 1990s due to high production costs (energy costs) and environmental problems (gas and dust emission).

Table 6.6. Main producers of shale gravellite aggregates in Poland

Company	Assortment of aggregates produced, (mm)
Barosz-Gwimet Marklowice	0–10, 10–16, 16–31.5, 0–31.5, 0–63, 31.5–63, 63–100, 100–350
Foreko Śląsk Bytom	0–10, 0–63, 31.5–63, 63–200
Wirex Będzin	0–10, 0–31.5, 31.5–63, 63–90
IBC Katowice	0–31.5, 31.5–63, 0–63, 60–200
Stef-Pol Rybnik	0–3, 0–16, 0–31.5, 0–63, 4–16, 16–31.5, 31.5–63
Azas Będzin	30–60, 80–120
Trakt Gliwice	0–10, 0–63
Slag Recycling Kraków (dump in Nowa Ruda)	0–63, 31.5–63, 63–250, >250
Tercharpol Siemianowice Śląskie	0–10, 0–31.5, 0–63

Source: Galos and Szlugaj 2012

Shale gravellite can also be obtained from self-ignited coal shale from old dumps (red shale). Self-ignition of coal shales can last over a period of years or even decades. To obtain lightweight aggregates from such material, simple processes of crushing and classification are employed, being analogous to processes of natural crushed aggregates production. Since the 1990s, production of such shale gravellite aggregates intensified. Self-burnt shale is extracted from old dumps in Upper Silesia, e.g. in Pszów, Radlin, Rybnik, Gliwice, Zabrze, Ruda Śląska, Chorzów, Katowice, Bytom, Czeladź, Będzin, Dąbrowa

Górnicza, as well as in Nowa Ruda in Lower Silesia. On such basis, lightweight aggregates of various granulation are obtained, from 0–3 mm to 16–63 mm, sometimes even 125–350 mm fractions. They find use primarily in construction of internal road and storage yards of industrial factories or parkings. Their use in road construction is very limited due to increased water absorption values. There is a lack of exact data on the level of production of shale gravellite aggregates, as such production is commonly carried out by small and very small companies. It is estimated that their total production amounts to min. 500 000 t/a, but it is possible that sometimes it exceeds even 1 million t/a (Galos and Szlugaj 2009). Their main producers are shown in table 6.6.

Production of coal shale for cement and building ceramics

The chemical composition of coal shale 0–3 mm obtained in the Haldex JSC plants is similar to brick clay, but unfortunately a higher content of combustible particles has been recorded, which restricts its use in the classical technology of building ceramics production. Such coal shale, depending on the place of origin, the way of receiving and granulation, can have an average calorific value ranging between 1200–4500 kJ/kg. In case of the upper limit of calorific value, thermal energy contained in such shale exceeds several times the amount of energy to be utilized during the process of building ceramics production. This parameter restricts the usage of high calorific coal shale in the production of wall building ceramics (Galos and Szlugaj 2009).

At present, coal shale, mainly Haldex coal shale, is utilized in small amounts as a supplementary component (20–30% of the batch), decreasing plasticity and drying sensitivity of body in technology of plastic forming of building ceramics in a few plants in Upper Silesia. The advantage of their usage is the lower energy consumption in production of building ceramics, due to a substantial combustible particles content. It is estimated that the total utilization of such material in building ceramics production does not exceed the level of 50 000 t/a.

The Ekoklinkier plant near the Bogdanka Hard Coal Mine in the Lublin Coal Basin (eastern Poland) is an example of a successful implementation of building ceramic production exclusively on the basis of clayey coal processing waste. A highly automated factory of yellow-brownish facade bricks (annual capacity 20 million units), built on the basis of a licence granted by the the French company Occidental Industries, commenced operations there in 1996. Coal shale (grain size 20–80 mm) from the coal processing plant in the Bogdanka Hard Coal Mine is applied in this plant. The production process is energy-efficient, mainly due to utilization of residual coal contained in the applied coal shale. This plant is the only European plant and the second in the world, which applies such technology and raw materials.

The cement industry is the most important user of Haldex coal shale. It consumes 150 000–200 000 t/a of such raw material. Coal shale is applied as an important aluminium-rich and silica-rich material. Transportation cost to cement plants is the key barrier, which limits wide utilization of this coal shale in the cement industry. This is why it is used only in the cement plants of the Opole region (Galos and Szlugaj 2009).

Recovery of coal and production of low calorific materials for power plants

Coal mining wastes are a substantial source for coal recovery, because, depending on their type, they may contain 10–15% or even more of coal substance. Coal recovery from coal mining wastes was conducted for decades by Haldex JSC Coal with Haldex JSC processing plants recovering fine coal (0–20 mm) and pea coal (20–45 mm). It is steam coal (type 31.1 and 31.2), with an average calorific value of 22–23 MJ/kg, ash content 18–20%, sulphur content 0.7–0.8% and moisture 8–12%. The annual coal production in Haldex JSC plants varies between 120 000–170 000 t/a. During the last 50 years, Haldex JSC recovered approx. 17.5 Mt of such coal (Kugiel and Piekło 2012).

Besides Haldex JSC, coal recovery is also conducted by a few other smaller companies in Upper Silesia region, e.g. Gwarex Polska in Świętochłowice (approx. 2 Mt of coal recovered since 1991) and Polho in Czerwionka, which since 1993 has recovered coal from the Dębieńsko coal mine dump site.

Coal mud also started to be utilized for the production of granulated coal mud, which has found use as low calorific material for power plants. The production process involves proper mixing and granulating. The installations are located directly on the coal mud dump sites, which in effect eliminates transportation costs of wastes and allows the company to produce cheaper products. The applied granulation technology makes it possible improve basic parameters of produced fuel, e.g. to reduce moisture and to increase calorific value.

The production of granulated coal mud has been carried out by Haldex JSC since 2003 in the Makoszowy plant in Zabrze. The production capacity amounts to approx. 20 000 t/month. Subsequently, similar plants were built by Haldex JSC: in Piekary coal mine in Piekary Śląskie (production capacity approx. 20 000 t/month), in Brzeszcze coal mine in Brzeszcze (12 000 t/month), in Knurów-Szczygłowice mine in Szczygłowice (20 000 t/month), and Z-3 Makoszowy plant (12 000 t/month). The granulated coal mud from the Haldex plants has calorific values from 10–12 MJ/kg up to even over 18 MJ/kg (Kugiel and Piekło 2012).

Recently, Południowy Koncern Węglowy (PKW, the Southern Coal Concern) also started to utilize coal mud. The developed technology of coal mud agglomeration (with participation of binder) and then the granulation of such material allows one to produce low calorific agglomerated coal mud granulate. Its calorific value is relatively low: approx.

9.3 MJ/kg in the coal mud granulate from the Sobieski Hard Coal Mine and only approx. 5.5 MJ/kg in the coal mud granulate from the Janina Hard Coal Mine (Szymkiewicz et al. 2009).

Use of coal wastes for backfilling underground workings

Utilization of coal wastes as a component of hydraulic backfilling of underground workings makes up for a large proportion of the use of these wastes. Up to 3 Mt/a of coal wastes is utilized for that purpose. Although such a way of coal wastes utilization should be preferred, due to technical and mainly economic reasons there are no growth tendencies of such use in recent years.

The potential technical possibilities of coal mining waste usage as a component of dry-pneumatic or hydraulic backfilling material exist in approx. 30 coal mines in the Upper Silesia Coal Basin, which are equipped with backfilling installations. In hydraulic backfilling, coal wastes are used as a supplement to basic backfilling material, e.g. quartz sand (lately – also some wastes from power plants). Their share of up to 50% of the total amount of backfilling material does not cause the decrease in backfilling effectiveness (Galos and Szlugaj 2009).

6.6. Waste from chemical mineral extraction

6.6.1. Rock salt mining

Rock salt mining in Poland has almost a thousand year history. During the last few years, the average yearly rock salt production amounted to 3.8–4.1 Mt. Currently, the salt is mined from Permian limestone deposits by means of an underground method in the Salt Mine Kłodawa JSC in Kłodawa and in the KGHM Polska Miedź (Polish Copper) JSC, Mining Plant Unit Polkowice-Sieroszowice in Kaźmierzów. Salt is extracted by means of the borehole method in the Salt Mine Góra in Góra near Inowrocław and in the Salt Mine Mogilno in Mogilno.

Apart from the rock salt mines mentioned above, there are two historic salt mines located in Miocene deposits: in Wieliczka and in Bochnia. These mines do not mine salt any more, nevertheless because of their historic value, part of the headings are under conservation protection, whilst the remaining ones with no heritage valors are gradually liquidated.

In this context, the Kosakowo Underground Gas Cavern Storage under construction in Mechelinki (Kosakowo commune, Pomorskie voivodeship) is also worth mentioning. It is located in Permian limestone rock salt deposit. During the first stage, until the end of 2014, the storage capacity will be as high as 100 $\mathrm{Mm^3}$, but in the future, by the year 2020, the capacity will have increased to as much as 250 $\mathrm{Mm^3}$.

Issues related to mining and processing wastes generation and utilization occur only in mines, which use the dry mining method (Kłodawa, Polkowice-Sieroszowice). These include the generation of salt dust during mechanical extraction of rock salt and the generation of waste processing anhydrite during rock salt processing. When rock salt is mined with the wet method (leaching in boreholes), insoluble particles released from the rock during leaching fall to the bottom of the leaching cavity and are not classified as mining waste.

Salt Mine Kłodawa JSC in Kłodawa

At present, the Kłodawa Salt Mine is the only mine in Poland, which extracts rock salt by means of the "dry" method in underground headings. The salt is mined in a salt diaper using the blasting technique (mining with explosives). After hauling to the surface, the raw material is directed to the processing plant where the processing is continued. The initial stage of processing is to separate the waste rock from the salt. The waste rocks consist mainly of sulphates in the form of anhydrite, which are stored at an outdoor storage site on the mine premises (Figure 6.23). Anhydrite contains trace quantities of salt, which is washed out by the water coming from the rain that affects the storage place. The storage place itself is constructed such that it enables collecting the salty water (of relatively low salinity), which is directed to sediment ponds before being discharged to surface streams.

Figure 6.23. View of the Salt Mine Kłodawa with waste storage in the foreground; Kłodawa, Poland
Photo: Albin Marciniak

The waste quantity in 2010 reached approx. 1940 t given a yearly output of over 800 000 t of salt. From the ecological point of view, this waste does not pose any great danger for the environment, whilst the storage site itself is planned to be liquidated during the stage of the mine decommissioning. At that time, the remaining waste rock will be used up to backfill mine shafts. The waste rock discussed above is the only waste in Polish salt mining, which falls within the scope of the Act on Waste (2013) and Act on Waste from Extractive Industry (2008).

KGHM Polska Miedź JSC,
Mining Plant Unit Polkowice-Sieroszowice in Kaźmierzów

The Polkowice-Sieroszowice mining plant is a copper ore mine. In the roof-rock layers above the deposit of copper ores (at the depth of approx. 950 m), there is a salt deposit reaching a seam thickness of approx. 200 m. Mining operations in the salt deposits are conducted on the basis of a licence for research and prospecting. The drilling of the headings in the salt deposit is done by means of combined cutter loaders. On the one hand, they provide the high level of mechanization of the work conducted, but undoubtedly the drawback is that as a result of mining the body of salt, approx. 16–18% of the output is dust fraction. In absolute numbers, this translates to approx. 65 000–70 000 t of salt in relation to yearly output of approx. 400 000 t. From a technological point of view, this material does not meet the definition of waste included in the Act on Waste (2013) and Act on Waste from Extractive Industry (2008), since it is not transported onto the surface. It should also be noted that salt dust due to its fraction cannot be sold on the market. Salt dust does however have market value (e.g. salt blocks for domestic animals), but this requires a special type of installation for pressing the salt dust. The salt dust is stored in completely exploited chambers, and only a small quantity of it is sold to the Desalination Plant Dębieńsko, where it is used for extra saturation of salty underground water, which is directed to the salt-works.

Within the mine, in the copper deposit, approx. 2 Mm^3 of water of high salinity (≈140–160 g $NaCl/dcm^3L$) is flowing into the mine workings. This water is directed to the Ore Concentration Plant, from where it is sent to the Żelazny Most storage site by means of pipelines after being used in technological processes.

There are plans for the mine to get a licence for mining the salt deposit with a yearly output of approx. 1 Mt. It should be expected that the quantity of the salt dust produced will reach 170 000–180 000 t/a. To increase the effectiveness of the venture, both in economic and environmental terms, plans are underway to manage approx. 50% of the mine water, which will be extra saturated with the salt dust (100% management of salt dust produced), and then to use it as the raw material in the designed salt-works. In this way, the mine will “reclaim” approx. 300 000 t of salt, receive approx. 800 000 m^3 of de-mineralized water and reduce the quantity of dumped salty water by 50%.

Salt Mine Mogilno in Mogilno and Salt Mine Góra in Góra

The Mogilno and Góra Mines are located in the region of Inowrocław. They are borehole mines that mine salt domes by means of the "wet" method. The main aim of the two mines is to build underground storage cavities in salt deposits, which will in the future serve as storage sites for rock oil materials and gas, whereas salt mining is a secondary issue (Jasiński et al. 2012).

Both mines, according to the Waste Act, do not generate waste. The technology used for underground dissolution (leaching) of salt causes possible waste in the form of waste rock to remain at the bottom of the leaching cavity, whereas the obtained brine is fully-saturated (min. 310 g NaCl/L of brine). The consumer of the whole brine is Soda Polska CIECH JSC (Production Plants in Janików and Mątwy near Inowrocław).

As already mentioned, obtaining fully-saturated brine produces no waste *per se*. The initial waste is produced on the salt-work premises during the evaporation process, which is part of the brine preparation stage (purification). These are mainly calcium and magnesium compounds, which may be used in the production of fertilizers for agriculture. The next stages of brine processing in the salt-works cause the occurrence of more waste (e.g. fallout salt), which, however, cannot be classified as mining waste (group 01 according to the Waste Act), but rather as waste deriving from chemical processes.

Figure 6.24. View of the salt borehole mine Mogilno;
Mogilno, Poland
Photo: Robert Rydwelski / www.polskaniezwykla.pl

Salt Mine Wieliczka in Wieliczka

Mining activity is limited to preservation work in the historic part of the mine and liquidation of the headings outside the historic part. The operation of the mine does not involve generation of waste. The rocks removed during preservation work (rebuilding of headings) are relocated to other headings as an element of the flooring. The output is also used to provide extra saturation of the brine, which is pumped from the mine up to the surface where it is then transported to the modernized salt-works (Salty Water Utilization Plant; Figure 6.25).

Figure 6.25. Salty Water Utilization at the Wieliczka Salt Mine Plant; Wieliczka, Poland
Photo: Piotr Frydrych / www.fotopolska.eu

Salt Mine Bochnia in Bochnia

Similarly to the Salt Mine in Wieliczka, the Bochnia Salt Mine does not extract salt on a commercial basis. The salt obtained during reconstruction work is used completely within the mine, mostly for “dry” backfilling of abandoned workings (Figure 6.26).

The lowest part of the mine was liquidated by flooding with brine. The mine is supplied with extra-deposit water to a small degree and the “excess” of brine is, during the winter period, sold for use in road maintenance operations (2000–4000 m^3/a) and during other periods in the decommissioning of the nearby Mine Siedlec-Moszczenica. Consequently, the mine does not produce any waste which could be regarded as mining waste.

Figure 6.26. One of the old headings planned for liquidation using dry flooring at the Bochnia Salt Mine; Bochnia, Poland

Source: Langer 2011

<u>Kosakowo Underground Gas Cavern Storage</u>

At present, the storage area at the Mechelinki site is being built (Figure 6.27). Storage headings are made by means of the "wet" borehole method (Mroziński et al. 2012).

Figure 6.27. Building site of the Kosakowo Underground Gas Cavern Storage; Poland

Source: www.rgkosakowo.pl

The construction of the Storage Area does not generate any waste, which has to be transported to the surface. However, pollution does occur and is the result of the leaching of salt, which releases fragments of waste rock, which then settle at the bottom of the cavity (Czapowski et al. 2013). The problem with the obtained brine has been solved by releasing it into the waters of the neighboring Puck Bay. From the cavity being built, the brine is forced through a pipeline that has been laid at the bottom of the Bay to a specially constructed launching column, from which the brine is radially launched to the waters of the Bay by means of special nozzles. Research has shown this solution to be fully ecologically safe, given that the pumped brine is quickly diluted and scattered in the sea water. The dumped load of NaCl does not endanger the ecosystem of the Puck Bay (Ceklarz et al. 2012).

6.6.2. Sulphur Mining – current state

At the beginning of the 1990s, Poland was among the top 5 sulphur producing countries in the world. The yearly output exceeded 5 Mt (Ney 2000). The technological progress and negative environmental conditions accompanying extraction caused the demand for Polish sulphur to rapidly drop. The condition of this sector became exacerbated with the possibility of recovery of substantial quantities from purifying processes of other mined minerals (e.g. coal, crude oil, natural gas), and also with the introduction of pro-ecological installations (e.g. sulphur removal from gas in coal power plants). The end result was that the mining of this raw material dropped substantially, and during recent years the volume extracted has remained at the level of approx. 800 000 t/a.

In Poland, sulphur was extracted by means of two methods: the open cast (the Mines Machów and Piaseczno in the area of Tarnobrzeg) and the borehole method, which involved smelting sulphur underground by means of the Frasch method (the Mine Osiek in the area Połaniec, the Mine Grzybów in the area of Staszów, the Mines Jeziórko and Machów II in the area of Tarnobrzeg and the Mine Basznia in the area of Lubaczów).

Only the first method generated noteworthy amounts of processing wastes during the flotation and refining stages. At present, the only mine still in production is the Osiek mine, which uses the Frasch method, while the Jeziórko mine is being decommissioned. The remaining mines have all been closed down.

According to the data given by the National Geological Institute, the remaining active sulphur mining does not generate any mining waste (PGI 2013). However, there is a waste issue when it comes to areas where sulphur was mined in the past. It is also the case that when the last sulphur mine closes down, the surrounding soil will be polluted enough that it will require removal and treatment as waste.

In previous years, sulphur mining was centered in the area of Tarnobrzeg, where more than 63 Mt of post-flotation waste and approx. 1.5 Mt of post-refining waste was gathered, mainly around the Machów plant. Approx. 7.5 Mt out of the whole post-flotation waste was used, mainly for land reclamation work (Rosik-Dulewska 2011). Some examples related to this problem are presented in further sections.

Sulphur Mine Machów

The Machów mine was the largest open-pit sulphur mine in Poland, in operation from 1969 to 1992. The most typical waste problem encountered was the issue of managing overburden rock, which, in this case, consisted mainly of krakowiecki[16] silt. During the expansion of the extraction area, the overburden rock layers were partially stored in the dump area located outside the pit, which was successively subject to reclamation processes, and also within the strip mine in the internal dumping ground. The decision to liquidate the mine by flooding it made it necessary to make a barrier to isolate the sulphur deposit from the water filling the heading. The krakowiecki silt gathered in the dumping grounds, which was perfectly suitable for building such a barrier was this put to good use. The dismantling of the external dump made it possible to restore the original morphological situation of the terrain in the mine area as it had been before exploitation (Burchard et al. 2007).

Figure 6.28. Part of the water basin in the former pit after sulphur mining; Machów, Polska
Photo: Jerzy Żmihorski / www.polskaniezwykla.pl

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[16] Generic name.

At present, the heading is filled with water, and its surroundings are reclaimed for recreational and natural functions (Figure 6.28). The flooding of the heading also influenced the restoration of water eco-balance in the areas adjacent to the former mine and encompassed by the depression funnel.

The last event is the liquidation of Clarifier no. 2, where the sludge coming from the strip pit dehydration was stored. The first clarifier was liquidated a few years ago, and the area was reclaimed for natural purposes. For Clarifier no. 2, a design was made, which anticipated the thickening of the stored sludge with the dust coming from the power plants supplied with brown coal. Such a solution was thus intended to solve two problems at the same time: the liquidation of the Clarifier by means of power plant dust management. Due to the high cost of such liquidation, this idea was not carried out. It is predicted that, in the near future, the Clarifier will be liquidated in a different way, and its surface reclaimed for natural or agricultural purposes.

Sulphur borehole Mine Jeziórko in liquidation

The Jeziórko mine finished sulphur mining in 2001. At present, the mine is in the last phase of liquidation, which mainly involves land reclamation of the area degraded by mining. The land on the area of approx. 1500 ha over the years has undergone substantial degradation.

Figure 6.29. Part of inoperative installations of the Sulphur Mine Jeziórko in the background of the reclaimed part of the mine surface; Jeziórko, Poland
Photo: Jerzy Żmihorski / www.polskaniezwykla.pl

The soil contamination primarily caused by numerous failures in transmission pipelines, emission of sulphur during technological activities and also numerous eruptions caused uncontrolled relocation of sulphur to surface layers (Hajdo et al. 2007, Ossowska 2011). The dispersion of sulphur dust from dumping places was also substantial. The factors listed above caused severe soil acidity. Chemically active sulphur in the soil environment underwent different kinds of changes, the consequence of which was the creation of sulphuric acid. That, in turn, caused a drastic change of pH values, which even dropped below 2 (Michno et al. 2009). Starting in 1986, the degraded terrains have been undergoing successive land reclamation, which is based, among other causes on neutralization of sulphur compounds by means of post-flotation lime with a total amount of approx. 4.5 Mt having been used to date. The land reclamation is planned for forest-water-meadow purposes (Figure 6.29).

Sulphur borehole Mine Osiek

The Osiek mine is currently the largest sulphur mine of this type in the world, which has a production capacity of approx. 800 000 t of sulphur a year. The mine, under the current legislation, mines without any waste generation. Modernizing of the mining processes, introduction of new solutions within the scope of process water circulation, elimination of sulphur refining process (elimination of sulphur cake occurrence – the waste from sulphur refining), substantial reduction of eruption phenomena, discontinuity of sulphur storage and its dispatch in the form of pieces towards the dispatch of fluid sulphur, and, finally, usage of the installation for hydrogen sulphide chemisorptions – all these actions mean that during exploitation there is no waste and the negative influence of the mine on the environment has in effect been substantially limited (Hajdo et al. 2007).

6.7. Relations between different stakeholders in the mining and processing waste management field

Mining and processing waste management, especially waste recovery, creates research fields and markets for activity of different stakeholders. Dozens years ago, technologies for recovering waste materials were not known. This resulted in the construction of a number of landfill facilities visible in mining regions. As technology has advanced, materials stored in landfills, which were once regarded simply as waste, now represent potential added value for the market and in the field of environmental engineering.

Waste recovery processes, conducted in mining regions show, that many different stakeholders can be involved in the waste management, predominantly small and medium enterprises (SMEs) but also large enterprises (LEs), as well as R&D institutions, including laboratories for waste sample or product analysis. In the Baltic Sea Region, where mining activity has a long tradition, one can identify the following forms of cooperation scenarios between different stakeholders in mining waste recovery:

1) Mining company enters into an agreement with an SME(s) or LE(s) concerning the terms of recovery and then reclamation activities at a given waste site.
2) Mining company sets up a daughter company for waste recovery.
3) The SME designs an installation for waste recovery and then installs it at the mine site.
4) An agreement between the commune/municipality and an SME(s) involved in waste recovery/reclamation, in the situation, where the local authorities own an old mining waste dump.
5) Ministry of the Environment enters into an agreement with an SME(s) concerning waste recovery.

The most common form of relation identified in the majority of mining regions is **co-operation between a mining company and SMEs or LEs** (Figure 6.30).

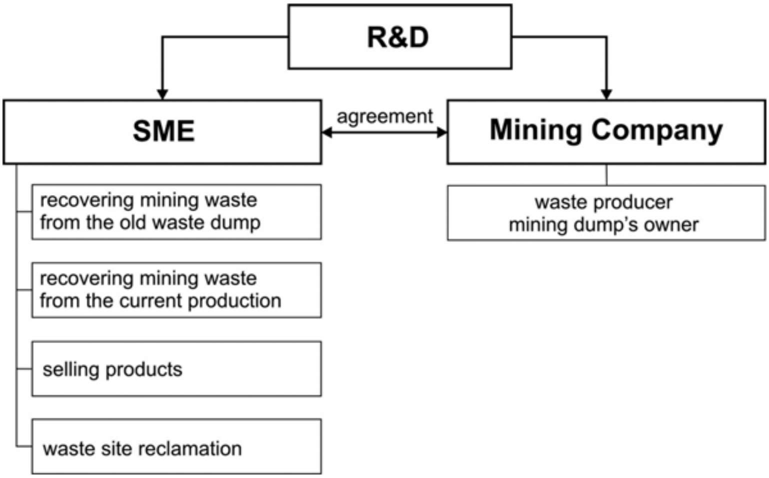

Figure 6.30. Cooperation between mining company and small, medium or large enterprise (supported by R&D)

It occurs in different versions and scopes. Usually, in line with the agreement, SMEs are responsible for waste recovery, sale of products and waste site reclamation. This model of co-operation is typical e.g. for Estonian, Polish and German mining regions. In Poland and Germany, co-operation between the mining company and SMEs or LEs is frequently supported by R&D institutions with respect to finding solutions for the reuse of waste by-products as well as soil and water cleaning. For example, waste from copper mining in the Mansfeld Region (Germany) has been the subject of many studies going back more than a decade. Scientists from different institutions have been developing a suitable process for an efficient extraction of non-ferrous metals from mine heaps (see subchapter 4.4 for more details).

A detailed description of co-operation between mining companies and SMEs in term of cost as well as economic, environmental and social benefit for all parties involved in the recovery process is presented in subchapter 8.2 of this monograph. It shows that both the mining company and SMEs achieve financial benefits. Also such benefits are gained by the commune, in which the landfill is located. The latter is gaining much more workplaces for local community and a cleaner environment.

In the Swedish case, an SMEs buys waste from the mining company and subsequently the process of recovery and the production of road materials is done at the site belonging to the SME. The road material is sold mostly to the mining company or some segment of the market. This model is also applied in the German Mansfeld-Südharz district (Figure 6.31). As described in chapter 7, Swedish legislation on cultural heritage (Heritage Conservation Act 1988) designated the areas with waste dumps as historic sites, what oftentimes make it hard or impossible to engage in both waste recovery and environmental remediation of the sites.

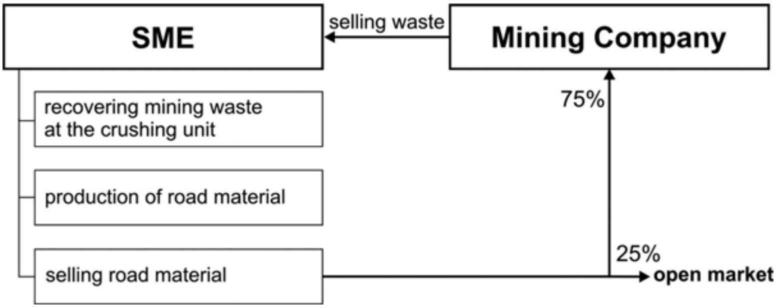

Figure 6.31. Mining company selling waste to SME, which recovers them and sells product

In order to avoid mining and processing waste storage, mining companies set up daughter companies devoted to waste recovery or with support of SMEs or LEs to provide an installation to enable waste recovery at the mining site.

In the first option, when the mining company sets up a daughter company, the latter is responsible for waste recovery both from the current production and old waste dumps, as well as searching for domestic or foreign markets for the products (Figure 6.32).

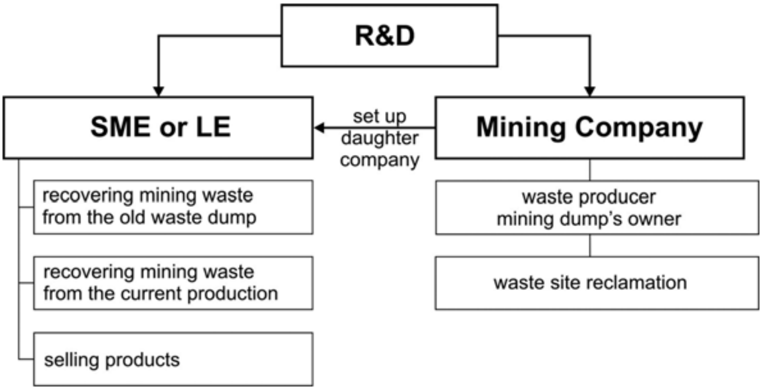

Figure 6.32. Agreement between mining company and SME, which is responsible for waste recovery

In another scenario of cooperation, the mining company together with an SME looks for a technological solution for its particular waste recovery objectives (Figure 6.33).

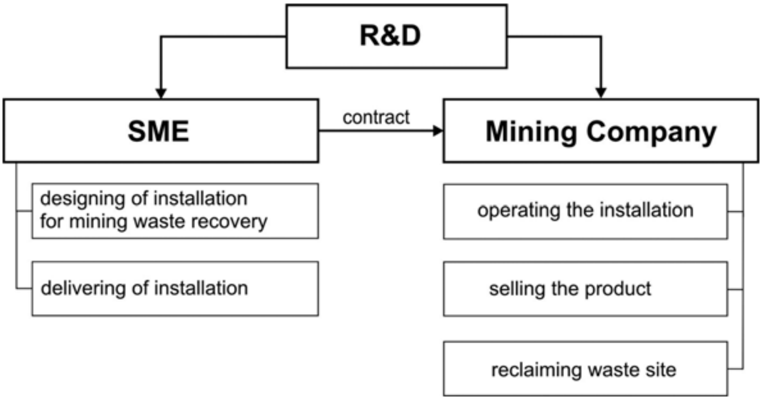

Figure 6.33. SME designs and installs installation for waste recovery at mine site

The SME then designs and delivers an installation to enable waste recovery to take place. The mining company is responsible for operating the installation, selling the product made from waste materials (e.g. aggregates) as well as reclaiming the part of the waste, which it is not profitable to exploit. This model can be found e.g. in Poland and the German Mansfeld-Südharz district. In Poland, for example at the two mining plants belonging to the Southern Coal Concern (Południowy Koncern Węglowy – PKW), the installations for aggregate production on the basis of mining waste were installed by an

SME. Produced aggregates are used in engineering works as well as in the construction of landscape structures, like those presented in subchapter 9.4. This investment made it possible to substantially limit the waste generated in the mining plants of the Southern Coal Concern.

In the situation, where the commune owns a historical waste dump, an agreement might be concluded between the commune and SME. In such a situation, SMEs are also responsible for land reclamation (Figure 6.34). This model is in place in Polish mining regions and also in Sweden, but without a reclamation stage. In Sweden the commune owns the historical mining waste and simply sells mining waste for paint pigment production. The SME simply buys the material without doing any reclamation. The obligation to do reclamation remains with the commune.

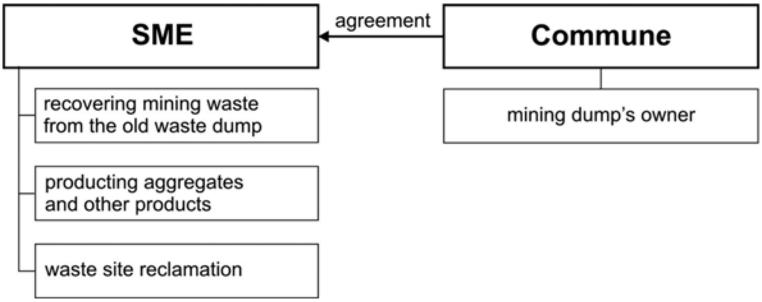

Figure 6.34. Agreement between commune and SME involved in waste recovery or reclamation, in situation where commune owns old mining waste dump

In circumstances, where an SME is looking for new innovative features to use mining waste, specific agreements are made. The agreement is coordinated by the Ministry of Environment. This model is in place in Estonian mining regions (Figure 6.35).

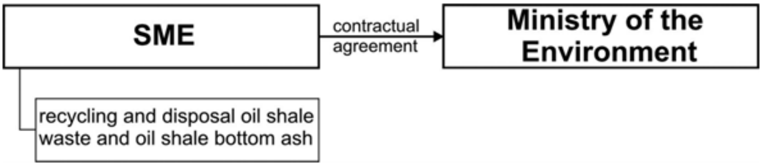

Figure 6.35. Ministry of the Environment enters into agreement with SME concerning waste recovery

In practice, there are many more models of co-operation in the field of mining and processing waste management. Barriers related to formal-legal issues especially natural and cultural protection, as well as fears of environmental contaminations sometimes effectively make recovering processes impossible, especially in the case of historical landfills. The interest in such landfills is very high due to the fact, that they contain valuable materials. It is much easier to initiate the recovery from the current production.

6.8. Conclusion

Mining and processing wastes from different kinds of mineral extraction processes create various challenges in how they are to be managed, but frequently also represent potential for further use, requiring an individual case-by-case approach. Searching for new solutions for waste prevention, recovery and reclamation opens up possibilities for closer co-operation between different stakeholders, especially: mining companies, small and medium as well as large enterprises dealing with waste recovery or installation delivery and of course research and development institutions.

Regardless of the kind of minerals in question, developing new technological solutions contributes to the protection of the environment by avoiding exploitation of natural deposits in favor of greater recovery and reuse of useful materials from the waste stream (both current production and old heaps) as well as limiting the amount of waste being stored in the heaps.

7. The natural, community and heritage dimension of mine waste disposal sites

7.1. Introduction

Issues related to mining waste management are connected not only to the very fact of the generation of such waste, its negative environmental impact and consequently to the financial burden placed on the entrepreneur (e.g. environmental fees, taxes, transport, documentation). They also overlap with cultural, environmental and social problems. The latter are related rather to historical waste dumps, created more than 100–150 years ago. Nowadays, the technological progress allows for the recovery of useful raw materials and thanks to appropriate processing capabilities, for their adaptation to a variety of economic and environmental engineering purposes. Ironically, however, in recent years there has also been a trend to preserve historical waste dumps, given that they are a key element of a historical mine site and frequently are a landmark in the surrounding landscape. The waste dumps are placed under various types of protection, whether this is related to their natural or cultural values. In some cases, mining waste dumps have even been qualified as UNESCO World Heritage sites (Cała and Ostręga 2012). This renders the recovery of useful raw materials substantially more difficult or outright impossible.

It would seem reasonable, that the areas already transformed by mining operations would be the easiest to re-exploit in contrast to areas holding unexploited natural mineral deposits. It would also seem logical, that the recovery of useful materials would have a positive impact on the environment, not only thanks to the elimination of risks (e.g. contamination of water and soil, self-ignition), but also to by minimizing the need to open natural mineral deposits for exploitation. However, that is often not the case. In practice, extraction from historical mining areas is often hindered or limited by law. In view of this, it is fair to conclude, that there is a disconnect between the way natural resources are consumed by the society and the way current policies regulate the extraction of such materials. This inconsistency is all the more relevant, when one considers the increasing number of areas with deposits, which are covered by natural protection designations (Nature 2000 in particular). Moreover, the lack of awareness of the importance of the minerals as well as the negative image of the mining industry translates into the lack of social acceptance for developing new deposits. It thus appears reasonable that in the face of the aforementioned problems, closed waste dumps, constructed many years ago from materials, which were useless then, should be an alternative to exploiting new deposits.

Nonetheless, unexpected conflicts arise around the topic of waste dumps and the recovery of useful materials. These complications often have their origin in differing views on, for example heritage protection and natural protection. What causes these potential conflicts? Is it a conviction about historical, natural and landscape values of the old waste dumps? Is it the incorrect interpretation of provisions of the law? Perhaps the fear of the recurrence of activities harmful to the environment following re-exploitation? These issues, supported with examples from several European countries, including those outside the Baltic Sea Region, constitute the content of the present chapter.

Subchapter 7.2 details how Swedish law approaches historic mining sites and what the possible area of compromise can be between heritage protection and waste recovery. Subchapter 7.3 describes some cases from Poland and illustrates the conflict between possible waste recovery, heritage protection and natural value of old mining waste heaps. Finally, subchapter 7.4 gives one example of a post-mining region – Nord-Pas de Calais, where on the basis of a ten year inventory of remaining mining heritage, part of the waste dumps have come under protection because of their cultural and natural value and from other ones useful materials can be exploited.

7.2. Waste from the extractive industry as an industrial heritage and environmental problem in Sweden

Bergslagen as a historic, economic and socially defined region (Figure 4.21) arose as a direct result of the rich supply of minerals and metals. These mineral raw materials have underpinned the region's social development since the Viking Age, although their importance has waned since the 1950s.

The industrial heritage values and the Swedish legislation on cultural heritage (Heritage Conservation Act 1988) are preserving the areas as historical sites, but are also hindering extraction and environmental remediation of the sites. In the following subchapter, some aspects of the current Swedish legislation and interpretation are discussed and some real or possible conflicts of interest are outlined.

The starting point for understanding the issue is the paragraph of the Heritage Conservation Act, which defines, when a site can be declared as "industrial heritage":

chapter 2 §1: Ancient monuments are protected under this Act.

Ancient monuments are the remains created by man during ancient times, which have been produced by ancient techniques and use and which are permanently abandoned.

The wording of this paragraph and the interpretation thereof may thus be hard to reconcile with the environmental need for reclamation (Figure 7.1–7.5) and the consequences of the progressing changes in world economy, that are creating an increasing demand for mineral based raw materials in the world.

Figure 7.1. Acid mine drainage;
Bondstollen, Ljusnarsberg Coppermine, Örebro County, Sweden
Photo: A. Ostręga

Figure 7.2. Iron–manganese ore mining waste, road and loading station; Svartviksfältet, Ställdalen, Kopparberg, Sweden

Photo: S. Sädbom

Figure 7.3. Remains of miner hut, itself built using mining waste; Rostbergsgruvan, Grangärde, Dalarna, Sweden

Photo: S. Sädbom

Within the EU, the manufacturing industry is the foundation for the economy. Because Europe produces far less raw materials than it consumes, this extremely important industry currently depends on a stable, reliable and increasing supply of raw materials from outside of EU. To get some sort of control over this, actions have recently been taken at the EU-level and nationally to map and possibly in the future also extract more raw materials from virgin and mining waste sources in the EU.

In this context and where extraction of a secondary raw material from mining waste is considered in areas, that as a whole or in part, are declared "industrial heritage", the interpretation of the legal phrase: "produced by ancient techniques and use and which are permanently abandoned" is of particular interest (Heritage Conservation Act 1988).

However, before delving further into the conflicting aspects of the Heritage Conservation Act and extraction of mining waste, it is worth looking at some other relevant legal issues. The Heritage Conservation Act is not the only legislation, that must be considered when mining waste is evaluated for possible extraction or environmental remediation.

The Swedish Land and Cadastrial legislation (1970) and the Minerals Act (1991) also stipulates certain rules and principles, that apply to the status of mining waste.

Firstly, mining waste at an abandoned mine without any active exploration or mining licenses belongs to the landowner. The landowner may, after permission, exploit the mining waste for his own use or for business.

However, if the land is or becomes claimed for mineral exploration according to the Minerals Act (1991) the exclusive right to explore the area for virgin minerals can be granted to an exploration license holder (and the license holder may, or may not, be the landowner).

An exploration license can be granted initially for a three year period and can be prolonged twice for three years and finally for four years (a maximum total of 3+3+4 or 10 years). If the area contains mining waste from previous mining that contains the same minerals as the exploration license is valid for, the exploration license holder may sample and use the mining waste in the process of exploration and development of the planned future mining process. Obviously, this is a point of possible conflict in itself as the exploration license may transfer the right for utilisation of mining waste from the landowner to the owner of the exploration license over a 3+3+4 year period. Additionally, if the exploration license holder is successful in the exploration, the exploration license holder may apply for a mining concession (with normally a 25 year duration), which then also includes the right to, after obtaining permission, extract the same minerals from the historical mining waste as for the *in situ* mining. In parallel with the now mentioned regulations in the Swedish Land and Cadastrial Legislation (1970) and the Minerals Act (1991), mining waste may also be a subject under the Heritage Conservation Act (1988).

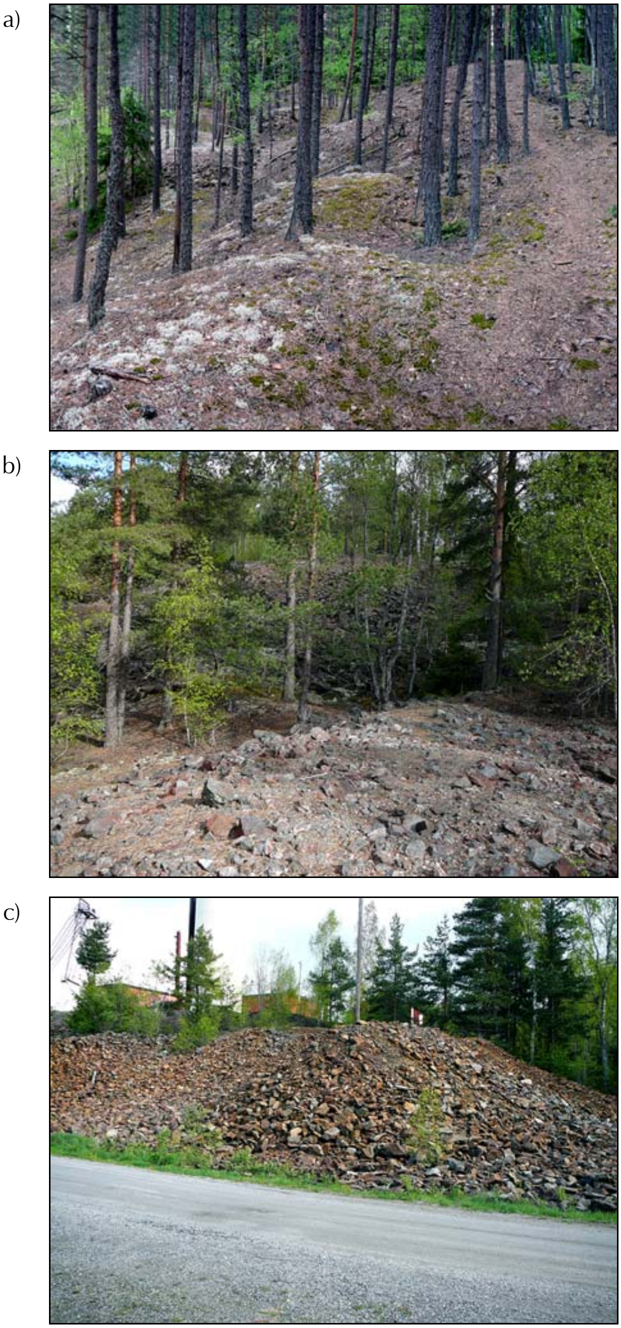

Figure 7.4. Ljusnarsberg Copper mine; Sweden: a) mining waste from about 1700; b) mining waste from about 1800; c) mining waste from 1975
Photo: S. Sädbom

The key paragraph in the Heritage Conservation Act has been quoted earlier in this section. The current usage of chapter 2, §1 can be generalised as follows:

- If an area has an active mining concession, it is considered to be in use and should not be declared as an area of heritage. That is, if the area is included in an active mining license or there is ongoing extraction of mining waste by the landowner or his representative.
- A site with mining waste that was or is believed to have been produced by an ancient technology and/or for ancient use, may be declared as a heritage site.

The Bergskraft organisations and the Swedish Min-Novation partners have started a dialogue with representatives of the National Heritage Board on this issue. The Board has acknowledged the potential conflict and has started (in 2012) an internal process aiming at a compilation of current praxis and interpretations of the legal heritage framework with the purpose to create a basis for future recommendations on how to tackle the present and future situation with regards to mining waste from a heritage perspective.

It is clear that different interests (heritage, raw material extraction, environmental needs for remediation) collide, when it comes to historic mining waste in Sweden.

One of the central points to be discussed is the definition of an "ancient monument".

Figure 7.5. Copper rich mining waste with traces of a horse-driven lift;
Stora Lobergsgruvan; Dalarna, Sweden
Photo: S. Sädbom

A starting point in the discussion are the terms of the Swedish Minerals Act (1991). A mining concession is valid for 25 years and may be extended if the mine is in production. When mining is finished or the mine is already closed, the mine and mining waste will either gradually or automatically fulfil the criteria qualifying for heritage protection.

Secondly, the heritage classification based on "ancient techniques and use" is quite diffuse and not very easy to practically determine from the evidence in the waste itself.

It also creates a peculiar situation, when a mine is in use for a long time (as is often the case in Sweden and other parts of Europe as well as the world). The implication could be that there is a "legal layering" in a pile of mining waste in the sense, that the lowest (now buried) part will be considered to have been produced by "ancient techniques and for ancient use", whereas the top layer is only 20 years old and was produced with modern technology and for modern use. The same discussion is also applicable to the mine itself, e.g. drift, tunnels, shafts, buildings or open pits.

Another experience is that there is no homogenous handling of historic mining waste cases, neither in the individual counties, nor on a national level. It is hoped that the ongoing review by the National Heritage Board will clarify and hopefully set up clear parameters and decisions points for the classification of mining waste. It is also hoped that guidelines for handling of mining-waste extraction applications will be established.

While the legal aspects are investigated, applied research and development work to make possible environmental remediation in areas of industrial heritage is ongoing, within the Bergskraft project and in cooperation with the University of Örebro. Currently, a toolbox for remediation in such areas is being developed. Of particular interest are technologies for remediation in situ (ISR).

Figure 7.6. The Stollen mine at the Stollberg medieval iron-manganese-silver-lead-zinc mine (left) and information board (right); Dalarna County, Ludvika, Sweden
Photo: A. Ostręga

Figure 7.7. Ljusnarsberg Copper mine (1622–1975) – the open cast and waste heap as well as information board; Örebro County, Sweden
Photo: A. Ostręga

Before any actions are taken, proper characterisation and remediation planning is essential. All physical, hydrological, geochemical or microbiological processes that occur in a waste rock pile must be taken into consideration. Complete knowledge of the properties controlling these processes is equally important. The heterogeneity of historical mine waste is large and this also applies to the sites. These are often of varying character (e.g. open landscape, forest, plateaus) and the waste is often widely spread with several sources of contamination. Individual field sites nearly always display some degree of uniqueness and might therefore need combinations of techniques specific for the particular site. Selected post-mining sites are adapted to function as tourist attractions (Figure 7.6 and 7.7).

7.3. Waste from the extractive industry as a cultural heritage and natural protection issue in Poland

Over the centuries, intensive exploitation of mineral deposits has altered the landscape of mining regions. Apart from elements of the mining infrastructure, the area under exploitation becomes dotted with waste dumps. Hard-coal mining waste dumps are to be found mainly in the area of Upper and Lower Silesia[17] and in the Podkarpackie region, while tailings ponds can be encountered in the Lower Silesia and Małopolska region.

With regard to the recovery of useful materials, the dumps with hard-coal extraction waste and processing operations are of particular interest. Old dumps are purchased by or leased to companies specialising in the recovery of waste and the production of aggregates. The levelling (deconstruction) of old dumps is of substantial importance in proximity to active mines since levelling and recovery operations create space for storage of waste from current exploitation. However, the attempts by companies to acquire dumps and to recover the waste, sometimes encounter the resistance of local authorities or communities, motivated by the desire to protect the cultural or landscape heritage or by the fear of temporary inconveniences (noise, dust, transport). Three examples of heaps (landscape or earth structures[18]) from Poland featuring a historical, cultural and natural value (Rydułtowy, Wałbrzych and Bolesław) are presented in this subchapter.

7.3.1. Heritage designation as a means of protecting historic mine waste heaps: the case of the Rydułtowy-Anna Hard Coal Mine in the Silesia Region

The waste dump (earth structure) at the Rydultowy-Anna Hard Coal Mine (Department of Kompania Węglowa JSC) in Rydultowy (Upper Silesia Region) is one such example of industrial heritage. The dump was created at the beginning of 20th century and has been continuously expanding since then (except Cone no. 1, which was completed in 1995). It occupies an area of approx. 70 ha (including Cone no. 1, which is approx. 7 ha)[19]. Its characteristic conical shape is a result of the storing technology in use at the time – the cone method[20]. Not only its shape, but also its height of 140 m (406 m asl) renders the dump a characteristic element of the urban landscape (Uchwała 2012 a). Due to the coal content in the stored material and due to endogenous fires, the material was subject to a partial burnout, hence the red colouring visible on the heap slopes. Vegetation from natural succession has also found its place there.

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[17] Whereas in the region of Lower Silesia hard-coal mining is now of purely historical significance, in Silesia and Małopolska region intensive hard coal extraction operations are continue – 29 operational mines, whilse in the Podkarpackie region 1 mine is operating.

[18] Most of the mines in Poland are building landscape or earth structures using waste rocks instead of landfills.

[19] Information from Rydułtowy-Anna Hard Coal Mine.

[20] Waste was transported in carriages equipped with a terrain-rope drive to the top of the cone, whereupon the waste was released. As it rolled down, the waste rock, in effect underwent self-segregation, in that the smallest part of the waste rocks stopped in the upper parts of the slope, whilst the coarser fractions rolled down to the bottom of the slope. This in turn gave rise to the steep slopes of the landfills with an inclination equal to the angle of internal friction (approx. 1:1.3 – 1:2.6). This method of waste storage was in use up until the 1995 (information from Rydułtowy-Anna Hard Coal Mine).

The interest in the recovery of useful materials from the dump, including burnt shale, caused protests of the local community, which considers the dump “its own pyramid“,“an element of the industrial heritage“, and “a symbol of the mining city“. For these reasons, residents objected to its demolition despite the prospect of employment opportunities for approx. 30 people, with the added benefit to the mine in the form of extra space for storage of waste from its current operations.

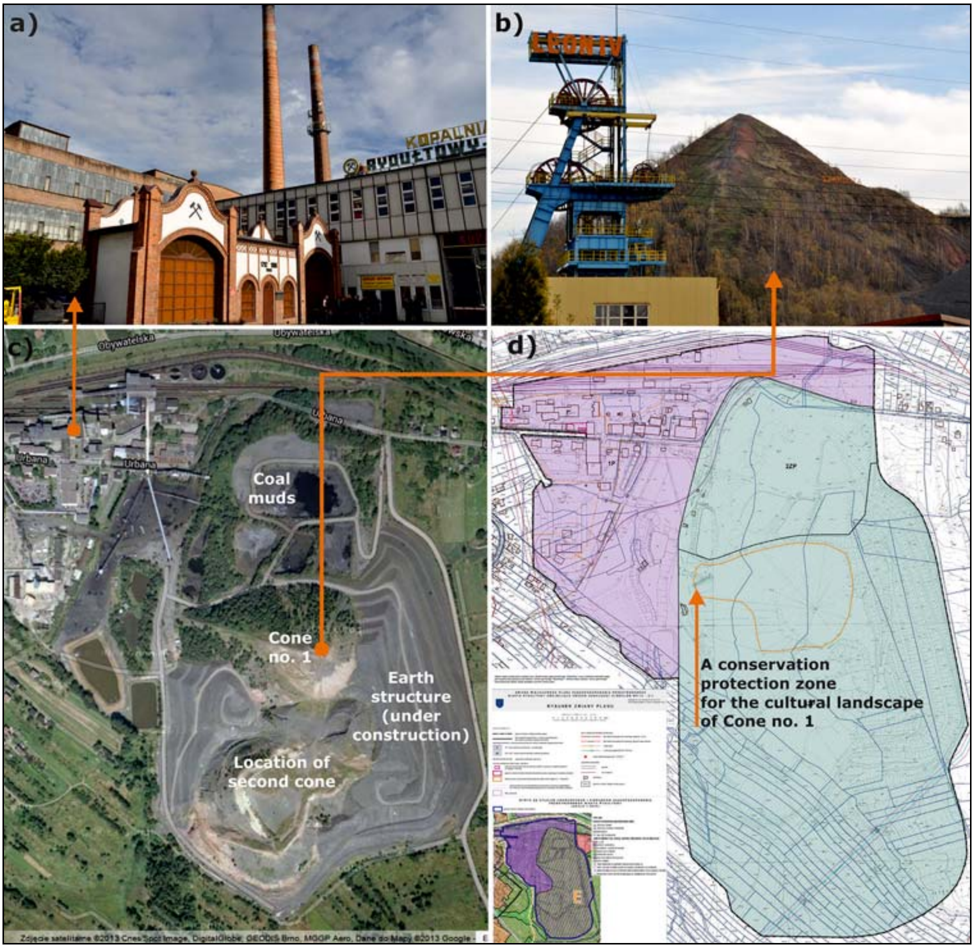

Figure 7.8. Rydułtowy-Anna Hard Coal Mine; Poland:
a) mining infrastructure protected as monument, b) earth structure – Cone no. 1,
c) aerial view of the Rydułtowy-Anna Hard Coal Mine,
d) local land use plan for the mining site
Sources: a, b) A. Ostręga, c) ©2013 Google, d) Uchwała 2012a

Eventually, it was the will of the residents that won. The dump was not designated to be demolished. What is more, the local land use plan established "A conservation protection zone for the cultural landscape of Cone no. 1" for a part of the dump and introduced a ban on altering its height and slope inclination (Figure 7.8 a, d) (Uchwała 2012 a). The justification for such a decision was that the shape and the height of the dump are the result of an already historical storage technology. Despite continuing hard coal extraction, waste dumps with the distinct conical shape will no longer be created. Presently, in the case of Rydułtowy-Anna Hard Coal Mine as well as other mines, the waste rock from extraction and processing operations is used to build landscape and earth structures or reclamation forms adapted to the surroundings and planted over with vegetation; sometimes additional functions, e.g. sports and leisure are also introduced (more about this in subchapter 9.4). The remaining part of the dump (the heap adjacent to the protected Cone no. 1) is in part subject to recovery operations concerning historical waste and in part provides a space for storing the waste from current extraction. By the time the Rydułtowy-Anna Hard Coal Mine closes, apart from the mentioned Cone no. 1 the same shape conic heap using modern technology will have been constructed (Figure 7.8 c, 9.23 d).

The earth structure still remains the property of the Rydultowy-Anna Hard Coal Mine, which developed a concept for its reclamation and target redevelopment for recreational functions.

In 2007, the Cone no. 1 was named Szarlota in honor of the name given to the first mine in Rydułtowy: Charlotte. The authorities have made use of this local landmark to promote the town as it is one of the tallest conical heaps in Europe. Mining infrastructure adjacent to the dump includes areas entered in the register, which in the future shall constitute a historical complex commemorating mining operations in the town of Rydułtowy (Figure 7.8 b).

7.3.2. Land use planning and historical mining waste heaps: the case of the Julia Hard Coal Mine in Wałbrzych

Located within the limits of the city of Wałbrzych, where hard coal mining is of historical importance[21], the waste dumps and settling ponds have become a bone of contention between a local company and the city authorities. Three post-flotation coal muds from the former Julia Hard Coal Mine are located in the town centre (Figure 7.9). The history of post-flotation coal mud storage dates back to the 1930s. They cover a total area of 14.8 ha and contain 4.127 Mt of coal muds. A lot of research has been done in order to examine the quality and reserves of coal muds stored in the settlers.

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[21] Hard coal extraction was conducted from the 16th century until the year 1996.

The results show potential application as raw material for building material and for energy production (Kominowski et al. 2010).

Figure 7.9. Location of the hard coal mine in Wałbrzych; Poland:
a) coal mud no. 3 and historical infrastructure of Julia Hard Coal Mine,
b) bird's eye view of the mine and adjacent coal muds
Sources: a) EcoCarbo Julia, b) ©2013 Google

The coal mud attracted the interest of a company, which planned to build an innovative facility for production of energy fuel based on the post-flotation coal mud. The company has obtained subsidies from the EU structural funds for this investment. Meanwhile, the local authorities expressed their opposition in the provisions of the local land use plans (Uchwała 2012 b, c, d). According to the land use plan, high greenery is the only solution planned for these areas with coal mud and dumps and it is also highlighted that the dumps have already been partially repopulated with plant life through spontaneous natural succession. The local land use plans also state, that the coal mud dumps are inseparable elements of a historical hard coal mine, now made into a museum and used as well for other cultural purposes[22]. The company does not agree with such arguments and has lodged an appeal challenging the local land use plan.

In the end, waste recovery from the coal mud dumps was made possible, because investors had obtained a permit to build the facility for waste recovery prior to the entering into force of the local land use plans.

As follows from this example, to avoid conflicts it pays to develop a prior vision of revitalisation of the post-mining infrastructure as well as waste dumps, one that considers both economic and cultural values.

7.3.3. Mine waste heaps as sites of outstanding natural value: the case of the Olkusz waste dump in the Małopolska Region

Unreclaimed waste dumps are dealt with by nature itself and although it takes more time, spontaneously colonising species are usually of higher value since they often constitute ‘wildlife’ enclaves attractive in environmental terms (Szarek-Łukaszewska 2009, Rostański 2009). The research conducted in the post-industrial areas allows one to establish the incidence of abundant plant and animal life impacting the preservation and enrichment of the local or even regional diversity (Rostański 2009).

A particularly interesting waste dump is located in the Bolesław Mining-Metallurgy Plant (Zakłady Górniczo-Hutnicze Bolesław), which is found in the Olkusz area (Małopolska voivodeship). The waste dump is more than 100 years old and has never been reclaimed (Figure 7.10). Zinc and lead ores were extracted in the region for more than 800 years. Despite the fact, that the dump is characterised by extremely difficult habitat conditions, it is overgrown with thermophilic plants, poor habitat species and heavy metal tolerant species accompanied by grassland vegetation and ruderal species. It is the only site in Poland outside of the Tatra Mountains with an abundant population of *Biscutella laevigata [Buckler Mustard]* (Grodzińska and Szarek-Łukaszewska 2002, Rostański 2009). In 1997, by virtue of the Resolution of the Commune Council, the dump was given protection status as ecological arable land and in 2009 was included in the Natura 2000 network (codes PLH120092, PHL120091, Katalog obszarów Natura 2000 2013).

Besides the example described above, other post-mining areas with waste dumps valuable for their avifauna are covered by one form or another of legal protection as nature protection sites.

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[22] In 2004, the complex of 14 mine sites was entered in the register of historical monuments of the Dolnośląskie province. The complex will in the future serve as a museum.

Figure 7.10. The more than 100 years old waste dump in the Olkusz region included in the Natura 2000 network (left) and *Biscutella laevigata [Buckler Mustard]* (right); Poland
Photos: G. Szarek-Łukaszewska (right), P. Kapusta (left)

7.4. Mining and processing waste in France – comprehensive natural and heritage protection efforts in the Nord-Pas de Calais post-mining region

Although the French region Nord-Pas de Calais was not represented in the MinNovation project, due to its similarity to other mining regions (especially Silesia in Poland), as well as the concentration of waste dumps and the manner of dealing with them, it deserves to be presented.

The history of Nord-Pas de Calais, a region in northern France, is connected to traditional sectors of industry such as mining, metallurgy and textile industry. Hard coal deposits were exploited in the years 1720–1990. During mining activities that span almost three centuries, 23 companies extracted in total 2 Gt of coal and the waste from the extraction operations was deposited in 326 dumps forming a chain of artificial elevations in the flat landscape (O'Miel 2009, Ostręga 2013). The economic crisis, which affected Europe in the years 1960–1990 resulted in the closure of many business operations, including those of the mining sector. Intensive work began to reclaim the post-industrial areas and to restore their commercial value. These activities were made possible with the support of public funds and were carried out by Etablissement Public Foncier Nord-Pas de Calais (EPF NPdC), established to manage post-industrial areas (Ostręga 2013).

Many dumps were demolished: today approx. 200 remain, of which some are subject to recovery operations, while others have been adapted for a variety of functions, e.g. leisure, with others left untouched.

In 2003, EPF NPdC purchased 130 waste dumps spanning a total area of 2200 ha from Charbonnages de France (a leading French mining enterprise). 30 of them were leased to Schistes du Nord-Pas de Calais (SNPC) for recovery of useful materials. After this process is completed, the remainder of the dump will be reclaimed by EPF NPdC. Of the remaining 100 waste dumps, 80 (1200 ha) have been reclaimed and sold to local authorities (Ostręga 2013).

Parallel to the reclamation of post-mining areas in the region of Nord-Pas de Calais, the mining heritage (mines, pit heads, workers' settlements as well as schools, churches, and hospitals built for miners and their families, railway facilities, but also waste dumps) was catalogued with the view of selecting those most valuable for landscape, historical, and environmental reasons and ensuring they are afforded protection. This ten year effort to secure the mining heritage of the region and the prospects for future growth resulted in 25% of the mining heritage of Nord-Pas de Calais being entered onto the UNESCO World Heritage List. Apart from technical infrastructure, 51 waste dump sites, recognised as symbols and elements of the region's mining identity, were also included in the list.

A good example of comprehensive heritage protection is where waste dumps adjacent to historical mines have been fully preserved and protected as historical memorials[23]. The waste dump at Mine 11/19 in Loos en Gohelle presented in figure 7.11 originally consisted of five cones. The twin cones along with the adjacent flat pile were entered on the UNESCO List and are the most characteristic and most frequently used to identify and promote the post-mining region. At 146 m above ground level and 186 m asl, they are the tallest in Europe, hence their name – *Géants* (English: Giants; Verfaillie 1996). The remaining two cones are exploited to recover useful materials (Figure 7.11).

The protected cones are subject to spontaneous natural succession and included within the Waste Heap Chain (French: *Chaîne des Terrils;* Figure 7.11 and 7.12). They are common destinations for nature trips organised by, among others, Centre Pernament d'Initiatives pour l'Environment (CPIE) Chaîne des Terrils.

Waste dumps have created a unique biological biotope. They are subject of studies by biologists and naturalists. The results of such studies prove, that the extraction of coal has created specific conditions for the occurrence of fauna and flora even in areas heavily transformed by extraction operations. Beside the repopulation by native species tolerant of difficult mine dump conditions, exotic plants can also be encountered. Among the most spectacular species, never seen before in the region, the Buckler's sorrel (*Rumex scutatus*) can be found on the waste heaps. It is likely to have found its way here from

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[23] Four mines in Nord-Pas de Calais have been preserved in full as memorial sites: Delloye Mine in Lewarde, presently the Mining History Centre (Centre Historique Minier), Mine 9-9bis in Oignies, Mine 11/19 in Loos en Gohelle and Arenberg Mine in Wallers.

the Alps mountains on trains transporting conifer trees for the mine galleries (Guillaume 2010). As sites with natural and scenic valors, historical waste dumps also constitute an attraction for the local community (Figure 7.12).

Figure 7.11. Waste dump at the 11/19 Hard Coal Mine in Loos en Gohelle – protected cones and the section recovered by the SNPC company; France
Photo: SNPC

Figure 7.12. Waste dump at the 11/19 Hard Coal Mine in Loos en Gohelle – cone cover by spontaneous natural succession (right), cone open to the public (left); France
Photo: A. Ostręga

In the case of the Nord-Pas de Calais, the inclusion of the waste heaps on the UNESCO list was well thought through. Only selected heaps were covered by this form of protection and today they enhance the tourist attraction of the region. Others may be subject to recovery.

7.5. Conclusion

In the presented regions, where intensive extraction operations were conducted in the past or are conducted presently, a variety of conflicts surrounding waste dumps are bound to occur, especially when they are seen to represent different values (economic, heritage, environmental) to different groups of people. The outcomes usually favour one set of values over the other although as the Nord-Pas de Calais case shows it is possible to reconcile and integrate these values with a comprehensive approach.

Several examples, where waste dumps are protected to ensure conservation of habitats and biodiversity show that to a certain degree, nature can successfully reclaim post-industrial areas. On the other hand, introducing legal means of protecting these sites can become an obstacle in their recovery if the accumulated waste happens to simultaneously be of economic value. The same can be said of conservation-oriented (heritage) protection. Swedish law affords protection to any currently abandoned man-made structures or sites created with the use of historical techniques; meanwhile, in northern France, 25% of the remaining industrial heritage, including 51 waste dumps enjoy the highest form of protection (UNESCO designation), while many others are not subject to such restrictions and can be recovered. In Poland, cases of friction surrounding historical waste dumps are rare, although when they do occur, they always involve economic arguments (driven by the demand for raw materials) opposed by protection efforts (guided by a sense of cultural heritage and desire to protect the local environment).

At the same time, there are no inventory or valorisation methods or guidelines that would make it possible to approach waste dumps based on their economic, historical and environmental value. Certainly, depending on the region and its conditions as well as the characteristics of a given waste dump, different values, whether economic, historical or environmental will have greater or lesser priority.

In conclusion, it can readily be said, that a common thread runs through most of the cited examples, namely a lack of logic and responsibility in the way natural resources are consumed by the society on the one hand and on the other the way current policies regulate the extraction of such materials. There is also a lack of coordination and tools for a holistic approach, when different societal values are prioritised.

The following conclusions can thus be made:

- Policymakers must be made more aware of the inconsistencies between waste management and heritage protection.
- Given that natural resource use is on the rise, existing legislation needs to encourage and facilitate resource extraction from waste heaps.
- Guidelines should be formulated for assessing the value of waste heaps for the community and the local economy, as well as their influence on the environment.

8. Economic aspects of recovery and reuse of mineral waste

8.1. Value estimation of the secondary raw materials located in waste storage sites

8.1.1. Waste management in the economy of mineral resources

The non-renewable nature and depletion of mineral resources necessitates economical as well as rational managing, which is also in line with the principles of sustainable development. Today's mineral resources management is marked by the following tendencies:

- Efforts to minimize the amount of mineral resource used in the final product unit.
- In a complex and rational way the resources of already developed deposits are to be used in a comprehensive and being used.
- The substitution of mineral resources by other, preferably renewable ones.
- Greater recovery as well as recycling of products made with mineral resources.
- Mining and processing waste accumulated in the past on landfills can now, thanks to new technologies, be turned into useful mineral resources.
- Only when the sources mentioned above do not close the mineral resource balance, new deposits are developed.

The specified tendencies in the mineral resources economy are also present in Poland, however with varying intensity. Mining and processing waste has been exploited relatively intensively in recent years, both from the current production and existing landfills. This is connected with infrastructure investments (road and railway). However, to a great extent, waste is used directly without undergoing any additional processing.

Despite the fact that low-waste technologies are becoming more common in the in the mining industry, part of the waste (and accompanying minerals) is still hard to manage. Therefore, there is the necessity to gather it in landfills; at the same time one needs to make sure that unused potential mineral resources be stored in a way that will preserve their useful properties. In Poland, these types of landfills are called anthropogenic deposits and constitute the future base of mineral resources.

Managing and using the mining and processing waste is not only a necessity from the formal and legal point of view but may also bring substantial economic benefits, not only at a corporate, but also at a national level.

8.1.2. Costs and macro- and microeconomical benefits from the use of mineral waste

Waste from mining and processing of minerals, if not used, increases the costs of producing the final product. It is connected with, first and foremost, the necessity to treat the waste, which in the mining industry, most often means accumulating it in special landfills. The environment protection regulations make the costs of building, maintaining and closing the landfills (along with the recultivation and monitoring) rather high. Alongside measurable costs, which directly affect the financial operations of a given enterprise, storing waste also causes indirect effects, often hard to quantify, but negatively affecting the environment (e.g. dusting, water environment pollution, landscape changes, deterioration of conditions and standard of life).

For a number of reasons it is worthwhile to minimise the amount of waste coming from current production, manage the waste already accumulated on the landfills as well as deposit, on special landfills, surplus mineral waste, the properties of which make it suitable for future use, but for which there is currently no demand. In the conditions of a market economy, the sale of waste coming from the current production is justified, since the income thereby earned effectively decreases the overall costs of the main product itself justified as the income and for that reason will decrease the costs of the main product itself.

The measurable benefits to a mining enterprise, which utilises the waste also cover savings derived from not having to build, maintain and close (liquidate and recultivate) the landfill. These types of outlays together with expenditures such as the purchase of the area and equipment require substantial operating costs (e.g. property taxes, environmental fees) not to mention complicated formal and legal procedures concerning permits for storing waste. Also of great importance are benefits coming from managing mineral waste, when scaled up to a nationwide level.

The most important are:

- Satisfying the needs of the economy for the resources without the necessity to making new deposits available.
- Maintaining existing functions of the terrain above the deposits.
- Not occupying the area needed for building new landfills.
- Limiting negative effects on the environment.
- Reclaiming areas occupied by the existing landfills.

The benefits mentioned above are realistic and most of them can be quantified. The transformation taking place in the Polish economy in recent years has changed, to a great extent, how waste mineral resources are perceived. Major infrastructural investments have caused a substantial demand for waste mineral resources for civil engineering. The development of processing technologies fosters the possibility of using these resources to add value to existing products. Every year, the proportion of waste from current production, which undergoes some form of utilisation rises. What is more, waste landfills accumulated in the past have received attention as sources of potentially useful mineral resources. The waste trade market develops along with the increase in demand for waste mineral resources. In line with these needs, procedures and methods for evaluating how enterprises use waste as well as assessment methods concerning value of mineral resources deposited in landfills have been developed and implemented (Kulczycka et al. 2012 c).

8.1.3. Methods for assessing the advisability of using mineral waste

When it comes to the advisability of using waste from the mining industry, the following scenarios have to be taken into consideration:

- Unprocessed waste coming from the current production which is sold.
- Some part of the waste from current production or recovered after processing is used and the surplus accumulated as stocks on special landfills.
- Previously accumulated waste in landfills is developed (extracted).

In the first case, the evaluation of profitability concerning waste use is simple. Even a minimum price at which waste is sold is beneficial as in such a case the costs of storing it are effectively avoided. This, in consequence, decreases the costs of obtaining the main product. The situation becomes more complex, when the selling of waste is conditional on taking additional action, for example utilization, obtaining certificates, temporary storage, record-keeping or sales. The mentioned operations are costly, and some are difficult to unequivocally assess, because due to e.g. the infrequency of their use, they do not require employing separate workers or measures.

The rest of the unused waste is accumulated in landfills and the expenses of constructing and maintaining the landfills add to the costs of manufacturing the final product. In recent years, landfills containing waste from the mining, preparation and processing stage that has accumulated over the years have become a source for a variety of mineral resources. The vast majority of waste is used directly in civil engineering works, but in some cases, as a result of advanced processing technologies, products of value are obtained.

The evaluation of whether it is advisable and feasible to manage waste, both from current production and from landfilled resources requires a convincing business case. The need to manage waste disposal sites has laid the foundation for an emerging market for processing these wastes, which in turn creates a need for tools to make a proper assessment of the market value of the waste-derived product.

The application of cost-benefit analysis (CBA) for the assessment of the feasibility of waste landfill exploitation

The cost-benefit analysis (CBA) approach is described in detail in a European Commission publication entitled Guide to Cost-Benefit Analysis of investment projects (2008), as well as Guidance on the methodology for carrying out Cost-Benefit analysis (2006). These documents consider financial, economic and in part ecological and social conditions as well. For big infrastructural projects, Article 26 of Council Regulation (EC) 1260/1999, which describes general regulations that apply in the case of structural funds, requires making a cost-benefit analysis, risk factor analysis, environmental impact assessment as well as evaluation of the investment impact on equal opportunities and employment.

The cost-benefit analysis has been defined in Poland on the basis of the above-mentioned EU documents in a Ministry of the Regional Development document entitled "The National Strategic Framework for 2007–2013" as an analytical tool aiming at determining if and to what extent certain projects deserve to be implemented from the public and social point of view.

Cost-benefit analysis differs from a typical financial evaluation by the fact that it takes into consideration all the profits and losses regardless of who bears them. CBA very often takes the form of an economic analysis, in which the results of the financial analysis are corrected by the fiscal effects, externalities as well as clearings prices. The CBA results may be expressed in many different ways, including economic internal rate of return, net present value and benefits/costs coefficients.

CBA belongs to the group of financial and economic analysis techniques often applied in the selection of projects subsidized from structural funds. In the CBA method, the estimated effects of the project are presented in financial categories. First, the internal rate of return (IRR) and net present value (NPV) are calculated and then the factors that cannot be included in the financial costs and benefits categories (e.g. the project's impact on the environment) are assigned a monetary value. For that reason, the economic rate of return (ERR) is the indicator used for evaluation. It takes into consideration the factors that cannot be presented directly in monetary form.

The CBA's main characteristics are, to name a few, the ability to describe potential effects of several alternative concepts of the project, determine the economic value of benefits and costs of a certain project as well as show the financial benefits and social costs from the project's realization. Among the CBA's limitations, it is worth noting that it does not consider redistribution effects and economic return of non-financial benefits and costs effects and uses discretionary criteria, for which the market value does not exist. Nevertheless, some clear advantages are comprehensive project analysis, creating rankings of investment projects by their ERR value and investigating the social effects of the project in monetary terms.

After carrying out the analysis in the financial terms, which is the basis for conducting CBA analysis, estimates of the value of externalities are added and this should be done in three steps, that is: identification of all the outer effects (positive and negative), their description, a quantitative description of the effects and their costs for society.

In the case of small investments, it is difficult to carry out a plausible analysis of the costs and social benefits for each separately as the environmental effects are limited and may not translate into measurable changes in environmental asset quality. For that reason complete analysis of costs and benefits should be carried out in the case of big projects (over 25 million Euro). In the case of small projects, a qualitative and quantitative assessment should be carried out in non-monetary terms of the economic, social and environment benefits, which have not been included in the financial analysis.

In the case of CBA application for the assessment of final cost-effectiveness as well as waste landfill exploitation (anthropogenic deposits) it is suggested to take into account the following effects:

- positive (benefits) that is, complete use of deposit resources, increasing the area's attractiveness, climate improvement, influence on the hydrologic cycle, social and society functions, which in the microeconomic calculation, may be defined as:
    - value of the waste managed (sold as products),
    - value of the mineral resources saved,
    - financial savings in the use of environment fees,
    - financial savings in the taxes paid (e.g. property tax),

  - ☐ financial savings in relation to paying compensations for other subjects (if such took place),
  - ☐ value of the area sold.
- negative, that is, noise, transport accidents, impacts on human health, environmental damage such as water and soil contamination, aesthetic impacts on the landscape, impact on the mobility, existing infrastructure, which in microeconomic terms translate into:
  - ☐ investment expenditures for additional undertakings related to mineral extraction as well as expenditures on current asset growth,
  - ☐ costs of obtaining additional minerals,
  - ☐ fees for the use of minerals (if such exist),
  - ☐ fees for the use of the environment,
  - ☐ costs of sale and marketing.

An example of applying CBA methods for the evaluation of profitability of mining waste management in the case of a hard coal mine landfill is the subject of the next subchapter of the monograph (8.2).

Other methods concerning valuation of the mineral waste landfills market value

Alongside the CBA method, which in a comprehensive way makes the assessment of the profitability of waste landfill exploitation possible, there are also other methods in relation to methods concerning the evaluation of the market value of natural mineral resources. The pricing of mineral waste landfill value shows similar features as the pricing of natural mineral deposits although it is easy to notice, that there are some discrepancies, which should be taken into account when it comes to methods and models of determining the value (Uberman et al. 2012).

For reasons mentioned above, the anthropogenic deposits are quite problematic to valuate.

The most important among these are:

- The fact that they were created as a result of material accumulated during the exploitation process, which makes them in many ways, like stocks.
- In many cases, the technology for extracting and processing them into a final product is quite different from the technology used to mine natural resources.
- The deposits are the subject of turnover concerning many forms of agreements, most of which are not subject to any registration requirement.

The problem of valuating anthropogenic deposits is important for several reasons:

- Companies, which identify the existence of such deposits (using the word "discover" may not be appropriate in such cases) face the necessity of referring to their values in their financial statements.
- For many company owners the identified anthropogenic deposits are not in the range of their basic activity. Often these are not even mining companies and because of that they do not have the competence needed for evaluation, not to mention general value estimation of such deposits.
- Some of the categories of the aforesaid deposits, e.g. mining waste landfills have become recently the subject of trade transactions; such tendency will be increasing (Kulczycka et al. 2012 a).

In considering what possible valuation methods for anthropogenic deposits to apply, it is essential to take into account the recommendations included in the Polish Code For the Valuation of Mineral Assets prepared by the Polish Association of Mineral Asset Valuators on the basis of equivalent codes from other countries as well as the experience of Polish experts (The POLVAL Code 2008). The POLVAL Code allows one to apply all three well-known approaches towards asset valuation, that is: income, comparative and cost. At the same time, by analyzing various types of geologic-mining assets (in practice corresponding to different stages of geological and mining activity), the POLVAL Code has made clear the necessity for a more precise definition of criteria for accepting individual approaches (Table 8.1 and 8.2)

Table 8.1. Methods of geologic-mining assets evaluation according to POLVAL

Approach to valuation	**The stage of examining and using the deposit**				
	Geologic and exploratory works	**Deposit recognition and documenting**	**Designing and managing of the deposit**	**Deposit exploitation**	**Operation liquidation**
	AGG Type I	AGG Type II	AGG Type III	AGG Type IV	AGG Type V
Income	no	in some cases	yes	yes	no
Comparative	yes	yes	yes	yes	yes
Cost	yes*	yes*	no	no	yes

* – only in the case of positive prospecting results,
AGG – geological and mining assets.

Source: The POLVAL Code 2008

Table 8.2. Hierarchy of geologic-mining assets evaluation methods according to POLVAL

Approach	Method	AGG Type I	AGG Type II			AGG Type III	AGG Type IV	AGG Type V
			II A	Temporarily closed				
				II B	II C			
Income	DCF	N	N	A* (N)	N	A* (N)	A* (N)	N
	ROV	C	C	C* (A)	A	C* (A)	C* (A)	N
Comparative	Comparative transactions	A	B	B	B	C	C	B
Cost	1) estimated value, 2) expenses for the geologic works	B	A	N	C	N	N	B
A	Method recommended by the POLVAL Code, commonly used							
B	Method recommended by the POLVAL Code, relatively widely used							
C	Method accepted by the POLVAL Code – it is recommended in certain situations, rarely used, not understood by everyone							
N	Method not accepted by the POLVAL Code							

* in the cases where NPV values, obtained from the DCF method, are negative, the ROV method is the most recommended one by the POLVAL Code.

Symbols in the table:

DCF – Discounted Cash Flow Analysis,
ROV – Real Options Valuation Method,
II A – AGG at the very early stage of evaluation or abandoned,
II B – AGG with the perspective for soon, economically justified management,
II C – AGG with no hope for soon, economically justified management.

Source: The POLVAL Code 2008

In the context of anthropogenic deposits, the method, among the presented ones, which has to be rejected, is the cost method. This results from the fact that anthropogenic deposits are the accumulation of the material, which at the stage when it was being produced, was treated as a by-product or even waste. In such a situation, the methods of costs keeping of their acquisition are not in any way useful for the purpose of valuation. They were based on indicative allocation costs between the volume of main and by-products and, in any case, do not constitute the basis for inferring their real market value.

Income and comparative approaches remain as options to be used. When it comes to the income approach, the two methods most often used should be considered: Discounted Cash Flow and Real Options.

Discounted Cash Flow method seems to be the most universal and most often used method of determining asset value (and even obligations). It has been described in the literature many times and in detailed ways. A review and discussion of the literature presenting the method of discounted cash flow in reference to deposit valuation is found in e.g. Uberman and Uberman 2007, Uberman and Uberman 2008, Nieć and Uberman 2001. Its use for determining the value of the deposit is based on two key assumptions (Uberman and Uberman 2007):

1) The deposit value is identical with the project value based on its management and sale of the mineral obtained.
2) The value of the investment project is the same as the updated net present value (NPV) resulting from the realization of the project.

The income stream coming from the mineral extraction and discounted to present value constitutes the deposit value along with the mineral treated as the joint investment project. A beneficial circumstance in the case of anthropogenic deposits is the fact that the process of making the deposit available is relatively easy and short lasting and in some cases, it is even hard to use the definition of mine in reference to the plant conducting the extraction. The appraiser does not very often face problems concerning investment expenditure valuation and investment works schedule, which commonly appear in mining investments.

A common problem in the case of value assessments of anthropogenic deposits is the correlation between the process of constructing disposal sites and exploiting anthropogenic deposits with the owner's range of activity, e.g. mining hard coal (brown coal) as the main mineral. Paradoxically, the greater synergy between the main business activity and constructing and utilizing the anthropogenic deposit, the more difficulties it may generate for the appraiser. The proper application of discounted cash flows requires adapting the assumptions about formulating the economic parameters in case their exploitation would be conducted in a totally independent way.

8.1.4. Method based on the mineral unit cost assessment

As far as the comparative approach is concerned, the method based on the mineral unit cost is the most adequate one in reference to the aim analysed. To apply the method, one should make sure the following preconditions have been fulfilled:

a) The mineral extracted will have certain parameters, which can be easily compared to the ones that are obligatory on the market and reflected in the predicted price.
b) The operational costs related to extraction are not only easy to determine, but also relatively low in comparison to the achieved price (fulfilling the second condition means that the prediction errors in this range will not have a substantial impact on the pricing value).
c) Hotelling's rule is applied here in a more or less obvious way (Uberman 2002).

The problem of the comparability of different kinds of properties of the mineral in the anthropogenic deposit (landfill) valued and the one, to which the indicator refers is easy to solve wherever standardization of physicochemical and economical parameters is possible. For this purpose, parameters substantial for its value should not be numerous. What is more, the possibility to process the mineral from one kind into another is beneficial for the application of the method described.

In the case of some common mineral resources found in anthropogenic deposits (for example ceramic stilts, building sands, post coal waste from the hard coal mine) their processing is technologically simple.

The problem of the amount of operational costs results from the fact that their designation is a multithreaded and complicated process and a possible prediction error may substantially change the valuation. If their level is low, the mineral in the deposit price obtained from calculations is not far from the market price of the already stored mineral. Owing to that, the changes of operational costs do not have any substantial impact on the profit made by the owner of the anthropogenic deposit.

The third problem that appears when using the method based on mineral unit cost is the need to consider the change of money value over time. Here, Hotelling's rule is helpful. It says that the updated value of annuity from extracting the mineral does not depend on the moment of its extraction. To understand this problematic issue, it can be assumed that the annuity corresponds to the profit made from the mineral extraction. The definition can be found in subchapter 6.2 of Uberman and Uberman (2008).

Put another way, it can be said that the future value of the annuity from extracting the mineral will always be equal to the value of the current annuity and the discount rate. Hotelling reasoned it as follows:

a) If the owners of the deposits predicted that the increase in mineral price would be higher than the expected discount rate they would wait with mining operations as it would be economically worthwhile to do so.

b) If the owners of the deposits predicted that the increase in mineral price would be lower than the assumed discount rate they would extract the entire mineral deposit in an attempt to avoid losses.

To simplify, it may be stated that the theory treats the deposit (including anthropogenic in origin) as a certain kind of product warehouse from where a resource (mineral) is 'taken out' rather than extracted. To conclude this short review of methods that can be used for the valuation of anthropogenic deposits the following generalizations can be made:

a) In the case of easy to extract deposits that do not require special preparatory and access works nor high investment expenditures over the short term, the method based on mineral unit cost (material) seems to be the most appropriate one.
b) For the deposits of substantial resources mined over a longer period of time and requiring more complex extraction technologies as well as, alternatively, processing with which the necessity of high investment expenditures is connected, the method of discounted cash flows should rather be chosen.

In Poland, minuend division calculation is the basis for determining the feasibility of using mineral waste resources from the current production cycle management of waste mineral resources. The chief aim of this calculation is to indicate the main product cost taking into account the income from selling the by-product (waste). The value of by-products (waste) determined at the level of the selling price is subtracted from the total costs borne in the production process. In this way it is used in open-pit mines selling mining and processing waste.

To determine the economic rationale for recovering mining waste from hard coal mines, the CBA method presented in subchapter 8.2 has been used. The estimation of waste landfill market value is most often made by using the comparison method (unit cost). In the case of mining landfills with large resources this estimation can be done by using the discounted cash flow method and including the profitable approach of minerals accompanying the lignite mines.

8.2. Cost-benefit analysis of recovery and reuse of mine waste – case study from Poland

Hard coal mining is classified as one of branches of the mining industry, where a substantial amount of waste is produced. The mining waste in question is generated as a direct result of mineral excavation as well as processing waste from coal enrichment processes. The waste is stored on the surface in landfills (solid waste) and in tanks (waste after enrichment).

The main modes of coal waste management are:

- Engineering, hydro-technical and road building.
- Raw material production for the construction materials.
- Coal recovery.
- Material for backfilling.

A profitability analysis has been carried out for one of the landfills of the mine, which is the subject of this case study. The landfill holds approximately 19 Mt of mining waste (mainly from coal shale production). As a result of the automatic burning of shale on the heap, the "red shale" was created which represents valuable material for road building, and which consequently was mined and mechanically processed.

The equipment in the system of load forming machines, mobile crushing and sorting plant is used in the process of waste recovery and aggregate production. After processing, an aggregate assortment of the following graining (mm) is obtained: 0–10, 10–16, 16–31.5, 0–31.5, 0–63, 31.5–63, 63–100 and 100–350. The production capacity of the plant can reach as much as several hundred thousand tonne/year and depends on the production sale.

The waste recovery was begun several years ago, after preparing the documentation and securing appropriate administrative decisions from regulatory bodies, which made it possible to go forward with the investment and begin production. Therefore, applying the CBA method refers to the ex-post assessment of waste recovery profitability, which has involved taking costs and benefits of three beneficiaries participating in this project into account:

- Mine – the owner of the landfill.
- Outside company – conducting the recovery.
- Local Authority – community on the area of which the activity is being done.

8.2.1. Cost-benefit analysis in practical terms

The analysis has been conducted from the perspective of the:

1) Lease holder (company A) – company leasing the dump area from the coal mine (company B).
2) Leaser (coal mine – company B).
3) Local community (municipality C).

The common assumptions for all stakeholders are:

- Preparation of the site for the landfilling of waste, specifically 5 Mt of waste coming from the coal mine.
- Taxes will be assessed only for a part of the landfill, which is leased. It was assumed that for this purpose it is operated on an area of 3 ha; the analysis has been

conducted for the period of 13 years, while the investment expenditures have been spent in equal amount in the period of two years. Furthermore, the landfill will be operated for the next 11 years, from which aggregates will be recovered in the amount of 0.5 Mt/a, except for the first year of operation where 0.23 Mt/a are expected (Kulczycka et al. 2012 b).

Lease holder (company A):

- about 3.73 of aggregate has been mined until 2011,
- 1.5 Mt is left to be recovered in 3 years' time (0.5 Mt/a),
- investment expenditure – obtaining permits (200 thousand Złoty)[24],
- revenue from aggregate sales – approximately 13 Złoty/t of aggregate,
- costs – approximately 12.2 Złoty/t of aggregate (including fees charged by the mine, which account for 15% of the income),

Some part of the landfill in company B is leased by company A. Until 2011 about 3.73 Mt of aggregate was recovered and to the plan is to recover a further 1.5 Mt.

It was assumed that the revenue of the company will only come from the sale of the recovered aggregate at a volume of 0.5 Mt/a at a price of about 12.95 Złoty/t, except for the first year of operation, where sales are expected to be at a lower level. Based on these assumptions, annual receipts from the sale of aggregates (0.5 Mt) were calculated to be 6.47 million Złoty. A more detailed breakdown of costs, which add up to a total amount of nearly 6.12 million Złoty, are presented in table 8.3. The costs include charges paid to the coal mine (B), which amount to 15% of that year's total income (e.g. about 970 thousand Złoty per year). The tax on land is paid for by the coal mine and therefore it is not included in this analysis.

The conducted analysis assumes that capital expenditures in the amount of 200 thousand Złoty will be incurred to obtain the appropriate permissions (expenditure divided proportionally over 2 years). Machine equipment is leased. Revenue allows one to achieve a profit and arrive at a positive NPV of 1.24 million Złoty over the 13 years of operation. The financial flows and the results of the analysis are presented in table 8.4.

Coal mine (company B)

Income

- from lease: approximately 1.94 Złoty/t of the aggregate regained,
- lack of need to expand landfill to make way for storage of 5 Mt: savings of 300 thousand Złoty.

Costs

- property tax: 0.83 Złoty/m^2,
- area reclamation: 70 thousand Złoty/ha.

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[24] Polish currency.

Table 8.3. Information and data costs of lease holder (company A) [in Polish Złoty]

I. Materials and energy	**1 633 773**
– *basic materials (fee for mine)*	970 923
– fuel consumption	589 150
– energy and water	15 200
– oil filters and grease	58 500
II. External services	**3 697 135**
– telecommunications	3 200
– supervision of geological and surveying services	5 535
– leasing	578 000
– transport services	5 000
– maintenance services	49 500
– hardware services, excavators, loaders, crushers	2 980 500
– other services, including laboratory analysis	75 400
– bank services	0
III. Taxes and fees	**3 060**
– PFRON fees	560
– tax on means of transport	2 500
IV. Salaries	**471 748**
– salaries; work	403 750
– retirement, pension, accident insurance	56 800
– labour fund	11 198
V. Other costs	**309 900**
– tools	2 500
– cleaning products	5 500
– spare parts for equipment	155 400
– tire wear	29 500
– travel expenses	0
– the costs of representation, advertising	12 000
– other costs and overheads	105 000
TOTAL	**6 115 616**

Source: Own calculations based on data provided by lease holder (company A)

Table 8.4. Financial flows of lease holder (company A) [Złoty]. Information and data costs of lease holder (company A) [Złoty]

Item / year	0	1	2	3	4	5	6	7	8	9	10	11	12	Total
Revenues from sales	**0**	**0**	**2 977 497**	**6 472 820**	**6 472 820**	**6 472 820**	**6 472 820**	**6 472 820**	**6 472 820**	**6 472 820**	**6 472 820**	**6 472 820**	**6 472 820**	**67 705 697**
Costs / overall expenses	**100 000**	**116 000**	**2 829 183**	**6 131 616**	**6 131 616**	**6 131 616**	**6 131 616**	**6 131 616**	**6 131 616**	**6 131 616**	**6 131 616**	**6 131 616**	**6 139 616**	**64 369 343**
– operational, including:	0	16 000	2 829 183	6 131 616	6 131 616	6 131 616	6 131 616	6 131 616	6 131 616	6 131 616	6 131 616	6 131 616	6 139 616	64 169 343
costs	0	0	2 813 183	6 115 616	6 115 616	6 115 616	6 115 616	6 115 616	6 115 616	6 115 616	6 115 616	6 115 616	6 115 616	63 969 343
depreciation	0	16 000	16 000	16 000	16 000	16 000	16 000	16 000	16 000	16 000	16 000	16 000	24 000	200 000
– investment	100 000	100 000	0	0	0	0	0	0	0	0	0	0	0	200 000
EBIT	–100 000	-116 000	148 314	341 204	341 204	341 204	341 204	341 204	341 204	341 204	341 204	341 204	333 204	3 336 354
The tax base	–100 000	-116 000	148 314	341 204	341 204	341 204	341 204	341 204	341 204	341 204	341 204	341 204	333 204	3 336 354
Tax	0	0	28 180	64 829	64 829	64 829	64 829	64 829	64 829	64 829	64 829	64 829	63 309	674 947
CFAT	–100 000	-100 000	136 134	292 375	292 375	292 375	292 375	292 375	292 375	292 375	292 375	292 375	293 895	2 861 407
NPV	**1 236 582**													

The landfill of company B is leased to company A, which according to the agreement gives the mine 15% of the revenue. It is estimated that in this respect the mine receives approximately 1.94 Złoty for every 1 tonne of recovered aggregate sold. This allows it to achieve annual revenue of about 970 thousand Złoty. An exception is the first year of operation of the landfill, when the mine sold less – compared to other years – in terms of aggregate volume (230 000 t) and income (446.7 thousand Złoty).

Another benefit of this scenario is the possibility of re-storage of waste in the area, from which about 5 Mt of aggregate was recovered. It was estimated that this solution saves around 300 thousand Złoty on landfill expansion. Meanwhile on the cost side a substantial item is the property tax in the amount of 0.83 Złoty/m^2.

Economic analysis of the described revenues and expenses showed that by leasing and preparing space for landfilling 5 Mt of waste, a positive result of NPV amounting to 3.87 million Złoty is achieved. It should be noted that savings coming from not having to invest in the expansion of the landfill site was treated as income. Table 8.5 presents the results of the NPV and cash flow of the coal mine.

Local community (municipality C)

Income:

- Property tax (0.77 Złoty/m^2).
- PIT and CIT tax (210 thousand Złoty/year).
- Motor vehicle tax– approximately 2500 Złoty/year.

In the conducted analysis, the annual revenue of the municipality consisted of:

- Participation in the revenue from income tax (PIT) of about 15 thousand Złoty and from legal persons tax (CIT) – about 4.4 thousand Złoty.
- Tax revenues from:
  - property (3 ha) – 23.1 thousand Złoty,
  - means of transport – 2.5 thousand Złoty.

In addition to financial benefits set out above, the analysis does not take into account social and environmental benefits and has not converted them into monetary terms, which are definitely an added advantage of this analysis, although not measurable. Such benefits include increasing the resource base, increasing employment / reducing unemployment, improving environmental performance or reducing the fire hazard in landfills.

The municipality in the assumed scenario was not an investor and therefore has not incurred any capital expenditure nor any other costs. Based on the above-mentioned assumptions, the positive NPV was achieved in the amount of 192.8 thousand Złoty. The results of the analysis and the financial flows are presented in table 8.6.

Table 8.5. The results of the NPV and cash flow of coal mine (company B) [Złoty]

Item / year	0	1	2	3	4	5	6	7	8	9	10	11	12	Total
Revenues from sales	**0**	**0**	**446 625**	**970 923**	**970 923**	**970 923**	**970 923**	**970 923**	**970 923**	**970 923**	**970 923**	**970 923**	**1 270 923**	**10 455 855**
Costs / overall expenses	**0**	**0**	**23 100**	**23 100**	**23 100**	**23 100**	**23 100**	**23 100**	**23 100**	**23 100**	**23 100**	**23 100**	**233 100**	**464 100**
– operational	0	0	23 100	23 100	23 100	23 100	23 100	23 100	23 100	23 100	23 100	23 100	233 100	464 100
EBIT	0	0	423 525	947 823	947 823	947 823	947 823	947 823	947 823	947 823	947 823	947 823	1 037 823	9 991 755
The tax base	0	0	423 525	947 823	947 823	947 823	947 823	947 823	947 823	947 823	947 823	947 823	1 037 823	9 991 755
Tax	0	0	80 470	180 086	180 086	180 086	180 086	180 086	180 086	180 086	180 086	180 086	197 186	1 898 433
CFAT	0	0	343 055	767 737	767 737	767 737	767 737	767 737	767 737	767 737	767 737	767 737	840 637	8 093 321
NPV	**3 750 327**													

Table 8.6. The results of the analysis and financial flows in the local community (municipality C) [Złoty]

Item / year	0	1	2	3	4	5	6	7	8	9	10	11	12	Total
Revenues from sales	**0**	**0**	**44 899**	**44 899**	**44 899**	**44 899**	**44 899**	**44 899**	**44 899**	**44 899**	**44 899**	**44 899**	**44 899**	**493 891**
Costs / overall expenses														
EBIT	0	0	44 899	44 899	44 899	44 899	44 899	44 899	44 899	44 899	44 899	44 899	44 899	493 891
The tax base	0	0	44 899	44 899	44 899	44 899	44 899	44 899	44 899	44 899	44 899	44 899	44 899	493 891
Tax	0	0	8 531	8 531	8 531	8 531	8 531	8 531	8 531	8 531	8 531	8 531	8 531	93 839
CFAT	0	0	36 368	36 368	36 368	36 368	36 368	36 368	36 368	36 368	36 368	36 368	36 368	400 052
NPV	**192 807**													

8.3. Conclusion

An analysis of the mining of the landfill and recovery of useful materials for economic use was conducted, which took into account three distinct perspectives: that of the lease holder (company A), coal mine (company B) and the local community (municipality C). For each of these parties, the economic activity of recovering and selling mining waste has delivered substantial financial benefits, of which the best result of NPV during the 13-year investment was achieved by company B with an NPV of 3.75 million Złoty. This is a result of a lease contract, where the only cost incurred by the mine is a property tax. Positive cash flows have also been demonstrated for company A, for which the NPV amounted to 1.24 million Złoty, which results from aggregate sale opportunities at favorable prices. NPV for municipality C is 192.8 thousand Złoty and derives from tax income. Additional advantages that are not represented in money terms are no less important and these are likewise social and environmental benefits, which cannot be measured.

9. Reclamation and revitalisation of waste dumps or land after waste recovery

9.1. Introduction

Despite the constant progress of technology, a waste-free method for exploiting and processing minerals has yet to be developed, although statistics register a marked drop in the amount of waste generated and at the same time an increase in the scale of reuse and recovery. Even *in situ* leaching (ISL) that does not produce any above ground waste often affects the ground water around the leached ore (Catchpole and Kirchner 1995). Waste rock, which amasses as a result of underground excavation is widely used in civil engineering e.g. ground levelling, construction of anti-flood embankments or raising of public use buildings (see examples in subchapter 9.4). There is also increasing interest in recovering useful materials deposited on old waste heaps. If, as a result of this process, new materials are produced which cannot find application in the marketplace, they are redeposited in waste heaps.

Therefore, the last phase in the waste life cycle is the reclamation and redevelopment (revitalisation) of waste disposal sites or areas, where disposal sites were once located. Waste may represent a threat to the environment through contamination of its constituent elements as well as through the loss of stability as a result of e.g. not following technical guidance or because of a flashover (see subchapter 9.3). At the same time, waste disposal sites provide a unique opportunity for adaptation of land that is by nature flat into areas with functions typical for mountainous regions (e.g. ski slopes).

Reclamation and redevelopment (revitalisation) are processes governed by general rules:

- Elimination or reduction of the environmental impact of the waste disposal site (soil, water, air and landscape).
- Ensuring the safety of the site in terms of the stability of the slopes of the waste heap, which would make it possible for people to safely develop the area.
- Use of the anthropogenic elevation in a wide variety of ways (as sports, recreational, cultural and other types of sites).

The present chapter describes the methods of reclamation, which aim to reduce the potential negative environmental impact of waste heaps, but also to adapt them for future revitalisation needs. Examples of successfully redeveloped waste heaps, as well as waste heaps, which have been put to good public use in a variety of European countries are also highlighted.

9.2. Methods of reclamation of waste dumps and contaminated sites

Public or private initiatives may require that a post-mining landscape become adapted to new or former uses, e.g. return of a natural ecosystem or farmland or creation of industrial or recreation land or other land uses. Especially surface mining represents an extreme landscape disturbance to the pre-existing ecosystem. The problem becomes more complicated, when waste dumps are located on the post-mining area. Mining waste dumps may represent great potential as sources of metals, but at the same time they can have a large impact on the near-field ecosystem, as well as on land and water in the far-field. Recovery might last for even decades and during this time intervention and active rehabilitation may well be necessary.

General principles

Some basic requirements for successful rehabilitation are listed below (Tibbet 2012):

- Land use needs have to be defined – *Final land use.*
- The properties and character of the site and its post-mining materials have to be defined – *Nature and properties of materials.*
- The desired cover principle such as vegetation or water has to be determined – *Plants and vegetation.*

- The proposed re-established ecosystem has to be considered and understood – *Ecosystem level consideration*.
- Qualitative and quantitative measurable criteria must be assessed, as well as defined goals, that can be evaluated and verified – what shall be accomplished and what can be tolerated considering future land use and the particular character of the site – *Criteria for rehabilitation success*.

Final land use

A clear goal for the landscape after rehabilitation is necessary for proper and relevant decisions concerning the choice of reclamation strategy. What contamination levels and what risks can be tolerated considering the future land use?

Taking into account that post-mining areas can be adapted for many different functions like e.g. forest or agriculture but also recreation, education, residential or cultural, several factors should be taken into account before a decision of future land use is made. They are as follows: economical, environmental, cultural, social, spatial, technical and formal-legal. An analysis of these factors is the basis for establishing the criteria, which determine the approaches to post-mining area reclamation and then revitalisation (Ostręga 2008).

Nature and properties of materials

The variability of post-mining materials and sites is generally very high with extremes in terms of chemical and physical factors. It is essential, that there is a sufficient understanding of the local processes, that govern the release of components (e.g. metals, acid) from the site or dump prior to reclamation, as well as the effects of the selected reclamation strategy on these processes. An evident source of information would be geological surveys of the site (e.g. bedrock, soil, stratigraphy, hydrogeology), as well as local composition and properties like erosivity, nutrient and essential trace element supply, acid generation potential or salinity, besides the detailed composition of the waste on site.

Plants and vegetation

The selection of plants suitable for rehabilitation of contaminated sites must be based on a detailed knowledge of the nature and properties of materials, as well as of plants that would grow under these particular conditions. Limiting factors would be the tolerance with respect to the soil conditions (e.g. metal levels, pH), as well as the available supply of essential trace elements and nutrients. Many plants would require microbial symbionts such as frankia, rhizobia and mycorrhizas in order to establish at a specific site. Plant-microbe symbiosis is often beneficial or even necessary for the host plant under challenging conditions and microbial inoculations may be effective or even necessary in post-mining landscapes.

Ecosystem level considerations

The post-mining landscape itself will evolve as a new ecosystem. Rehabilitation should not primarily aim at engineering an artificial post-mining landscape but rather engineering a biological system that will develop into a stable new landscape. Factors, that are essential for sustainability must be known and considered, including local and regional hydrology, climate and potential climate change, plant communities and their potential change with time in numbers or species.

Criteria for rehabilitation success

Success criteria for sustainable rehabilitation must address not only technical and environmental targets but also economic and social targets. Rehabilitation success based primarily on ecological factors, which relies on observation, such as presence or absence of particular flora and fauna, concentration levels of metals above or below certain guidelines in draining waters or sub-surface waters, is not sufficient. Success criteria must be based on definitive and implied measures of ecosystem function and of materials composition, as well as of processes and new steady-state conditions, below ground and above ground. Success criteria must take into account the proposed future land use and the economic and societal consequences, that can be foreseen.

A fundamental requirement of successful reclamation and redevelopment of waste dumps and contaminated sites is their integration with mining practice: mining operation and rehabilitation must be seen as two processes, that are inevitably interlinked. However, this insight will be of no help when it comes to old, historic mine sites and waste dumps, where thorough knowledge of the relevant processes before as well as after rehabilitation would be needed. Performance assessment is required (e.g. predictions and assessment of function, consequences or risks of various actions and procedures) to be considered in the selection of a proper reclamation strategy.

Reclamation methods

The following general methods or strategies for reclamation can be recognised (Höglund and Herbert 2004; Allard et al. 2008):

- Removal of waste or contaminated material from the site. Removal of the source, when feasible, would be an obvious and trivial method – *Mine waste relocation*.
- Treating the waste dump or the contaminated site in order to enhance weathering and the leaching of components (e.g. metals, acid) – *Accelerated leaching*.
- Putting a lid over the deposit, e.g. covering it with soil or water to reduce the in-flow of water (soil cover) and air (soil or water cover) – *Cover applications*.
- Installation of a physical barrier that serves as a filter, that accumulates dissolved species in effluents from the deposit or the site – *Barriers*.

- Barriers may be passive or active and designed to react specifically with certain waste categories – *Reactive systems*.

Accelerated leaching

Accelerated leaching can be a proper method for reprocessing or pre-treating mine waste prior to deposition, but also to treat existing deposits or heavily contaminated land. With this technique, the weathering or degradation process can be reduced or even stopped (e.g. sulphide oxidation in old sulphidic mine waste) by ensuring a constant supply of reactants (e.g. oxygen to sulphide-bearing mine waste).

Irrigation of deposits under oxidising conditions may be sufficient to mobilise various elements, including metals, such that the mine waste becomes depleted in these elements and becomes more stable for long term disposal. Drainage from the leached waste must be collected and treated. Under favourable conditions, electrowinning can be used to remove valuable metals from the collected leachate.

Accelerated leaching can in principle be achieved if a chemically reactive solvent is introduced into e.g. a metal-rich deposit, leading to an enhanced metal mobilisation and release. However, the reaction that has been applied on a technical scale is solely bioleaching, based on the oxidation of sulphide minerals by microorganisms (Fowler et al. 1999, Schippers and Sand 1999).

Bioleaching (denoted as heap leaching) has been applied for recovery of metals from low-grade sulphidic ore (see e.g. Doran 1995, Bartlett 1997, Hau et al. 1997, Rawlings 2002, Rawlings et al. 2003, Marchbank et al. 2003). The purpose is metal recovery, not reclamation, but heap leaching can in fact be a suitable technique for reclamation of e.g. historic sulphidic mine waste deposits, providing that the deposit is confined and that the released metals are collected (Schippers et al. 1996).

Cover applications

The most common method for reducing progressing releases from a waste dump, e.g. sulphide oxidation and the discharge of metals from mine waste deposits is through the installation of soil or water covers over the deposits. Both soil and water covers have been used with generally much success in many countries and under a variety of conditions over the past 25 years.

A soil cover would reduce the in-flow of water, which is the mobile phase transporting components from the waste (e.g. metals, acid). A soil cover, as well as a water cover, would reduce the exposure to air (oxygen), which would reduce the oxidation potential of the system and reduce the on-going weathering of e.g. sulphides. The most common methods are to apply dry covers consisting of several layers of different soil types, often combined with a sealing layer with low hydraulic conductivity. The sealing layer functions as a barrier against oxygen intrusion also in the case, when the groundwater surface is far below the cover.

Plants may be used to stabilise the cover material and to decrease erosion and dust formation. Addition of nutrients is often required in order to achieve a sufficient growth of the selected plants. Also mixing with e.g. sewage sludge has been tested with good results.

Dry covers can strongly reduce the oxygen in-flow and thereby the progressing oxidation of sulphides, when present, as well as reducing the in-flow of water. However, none of these two processes can be completely stopped. Water covers may in fact be a superior method for reducing the oxygen in-flow compared to dry cover. Dry covers are not adequate for the reclamation of historic sulphidic mine wastes, since the oxidation of the sulphides can progress in the absence of oxygen driven by precipitated trivalent iron on site. This is well-known text-book information (Langmuir 1997), that has been demonstrated in the field, e.g. at Bersbo (Karlsson and Bäckström 2003), but is still over--looked in many full-scale reclamation programs.

Various types of dry covers have been studied and evaluated within the Canadian MEND program (Feasby et al. 1997). One conclusion is that dry covers may be efficient under proper geochemical conditions (notably absence of trivalent iron), but they may be expensive to construct. Dry covers, especially two-layer covers, have been studied in the Swedish MISTRA program MiMi (Höglund and Herbert 2004), where also various amendments are discussed, such as fly-ash, cement or organic waste.

Barriers

Barriers may be constructed for the treatment of the surface and subsurface flow of low quality drainage water from mine waste deposits. There are numerous barrier designs that can be implemented, although all seek to improve the quality of drainage water before it is discharged to receiving water courses. Barriers can be divided into geological barriers such as natural wetlands and geological formations, that are utilised for treatment, and engineered barriers such as reactive barriers, that are constructed to fulfil a specific treatment goal. Most barriers are designed either to reduce acidity in discharge waters or to decrease concentrations of potentially harmful elements (e.g. lead, copper, mercury). In the context of mine waste remediation, barriers are constructed for short-term treatment.

Basic attenuation in principle in barriers covers (Allard et al. 2008):

1) Metal precipitation under oxic conditions. Precipitation/coprecipitation of Fe(III) and Al(III); formation of sparingly soluble oxyhydroxides that carry di- and trivalen metals.
2) Metal precipitation under anoxic conditions, precipitation of carbonates (Fe) and sulphides (under reducing conditions); formation of springly soluble sulphide phases, notably with iron.

3) Metal adsorption. Adsorption of trace metals on active surface sites of e.g. iron minerals, clay minerals, as well as certain other silicates and notably, organic surfaces (e.g. peat).
4) Particle removal. Physical filtration of suspended particulate carrier phases, e.g. of iron hydroxide, but also organic macro molecules (humics).

However, reactions can be reversed; precipitates may dissolve, when the hydrochemical conditions change and adsorbed species may desorb, e.g. due to changes of pH or intrusion of water with complexing agents (organics, but also chloride, sulphate).

There are several reported cases of successful use of barriers for metal recovery, active as well as passive ones, summarised by Younger et al. (2002): e.g. inorganic filter systems, acid neutralizing systems, alkalinity producing systems, aerobic wetlands, compost wetlands, reducing systems or permeable reactive barriers and there are numerous designs.

For reclamation of a deposit or a site, long-term treatment is required and a barrier system (geologic barrier) with high or in principle unlimited holding capacity, must be found. Such barriers may in fact be designed and nature itself provides natural analogues, such as wetlands and sediments, e.g. of precipitating iron (Fe(III)-oxides/hydroxides or Fe(II)-sulphides) may serve as irreversible co-precipitating agents for other elements (e.g. metals, arsenic) under proper geochemical conditions.

Reactive systems

Reactive systems may be designed and installed for the prevention and control of leachates from waste dumps and contaminated sites as well as from mines in operation. Reactive systems are defined as treatment techniques that utilise a chemically reactive component in order to decrease the mobilisation of specific elements, that are released from a solid phase. Metal stabilisation in soils and the treatment of soils to remove metals are examples of reactive systems. Mixing compounds with mine waste in a deposit or infiltration in e.g. a contaminated site, so as to minimise releases of components from the waste fraction, are examples of reactive system strategies. For example, the mixing of acid-neutralising agents (e.g. lime, fly ash) with mine waste prior to deposition is considered a reactive system, where acidity produced by sulphide oxidation is rapidly consumed by the neutralising agents.

Thus, the basic principles behind reactive systems are:

1) Stabilisation. Reduction of the mobility, particularly in contaminated soil. Various amendments have been tested, e.g. phosphorus materials, organic matter, clays, alkaline materials, oxides (Fe, Mn) and others.
2) Metal recovery. Ex. Removal of metals by chemical treatment such as soil washing, flushing, solvent extraction.

Leachate generation may also be controlled by reactive amendments added on site, e.g. alkaline waste products, fly ash, sewage sludge, residues from paper and pulp industry (Sartz 2010).

The use of reactive amendments on site is a promising technique under constant development. Of special interest is the prospect of using residues and waste products from other industrial activities or from society as amendments to control metal releases from waste dumps and deposit sites.

In recent years, an increasing number of studies have focused on using alternative products, for example cement kiln dust from the cement industry (Mackie et al. 2010), lime kiln dust from the lime industry (Bäckström et al. 2011), lime mud and green liquor dreg from the pulp and paper industry (Chtaini et al. 2001, Sartz 2010) or fly ash from combustion processes (Pérez-López et al. 2007). Utilization of industrial by-products would give great cost reductions and might solve potential waste disposal problems and ever growing deposits as well.

Injection of neutralizing material basically means, that the amendment is blended in stratified layers in the waste rock pile. This can be accomplished either by slurry injection or by moving masses. The slurry injection uses boreholes through, which the slurry is pumped down, filling out the voids in the pile. This method would be particularly efficient for coarse grained waste rock piles, as the slurry not only neutralizes the acid formed within the pile, but also prevents further oxidation by filling out the voids that otherwise are serving as channels for advective transport of oxygen into and within the pile (Bäckström et al. 2011).

Two alkaline by-products (green liquor dreg [GLD] and lime kiln dust [LKD]) have been tested for injection into weathered mining waste (Figure 9.1; Bäckström et al. 2011).

Figure 9.1. Pilot scale trials 1 m^3 during construction (left) and after completion (right)
Photo: M. Bäckström

Results indicated that the alkaline materials stabilized the waste both physically and chemically (Figure 9.2). The pH increased in the drainage and immobilized trace elements as a result.

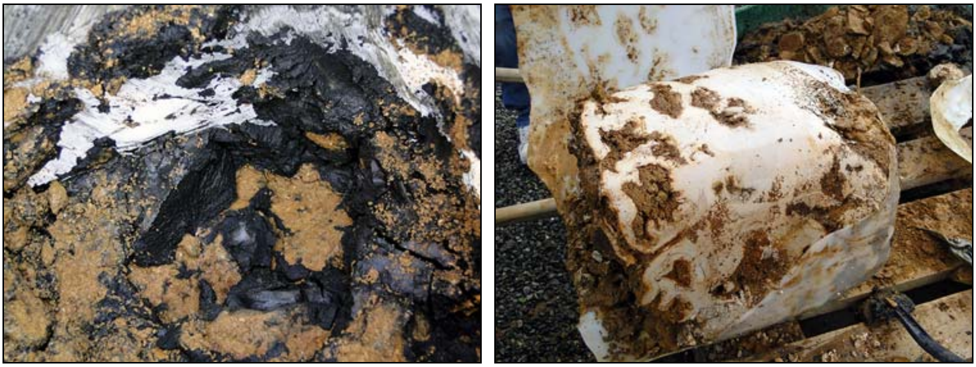

Figure 9.2. Injection with green liquor dregs (left) indicate, that all voids have been filled and that impermeable layers have been formed. Mine waste injected with lime kiln dust (right) has formed a solid unit with very low permeability

Photo: M. Bäckström

This study indicates that the alkaline by-products: green liquor dreg and lime kiln dust (LKD) can be injected into waste rock deposits as slurries. pH substantially increased (from pH 3 to above 7) and as a result trace element concentrations in the drainage leaving the deposit decreased by around 95% or more. LKD also formed hard pan layers within the deposit and thus minimized the formation of acid drainage.

9.2.1. Case study from Sweden, Sulphur Mine Ervalla – cover systems

Located about 190 km west of Stockholm, Sweden, the Ervalla sulphur mine was in operation from the 1840s until the 1920s. The ore consisted mainly of pyrite (FeS_2) and pyrrothite (FeS) with minor amounts of sphalerite (ZnS), chalcopyrite ($CuFeS_2$) and galena (PbS). Mine waste from the enrichment process was deposited in a 10 000 m^2 large area.

When mining ceased, the deposit consisted of a 0.2–0.4 m thick layer of yellow-red oxidized waste sand. 80 years after closure there was no vegetation at the site and reclamation was initiated. The thickness of the applied ash was 1–2 m and the sewage sludge layer for vegetation about 20 cm with 80% (v/v) sludge and 20% fly ash.

To make the site useful for the landowners, a flat non-vegetated surface useful for timber storage was prepared in the centre of the deposit (Figure 9.3). It is estimated that about 5800 and 1880 t of ash and sludge, respectively, were used to cover 2200–4400 m^3 of mine waste. The permeability of the covering layer is low ($2.6 \times 10^{-10} - 5.2 \times 10^{-10}$ m/s), allowing only 10–20% of the effective precipitation to infiltrate the deposit.

A ditch surrounds the deposit to collect rain and surface water and direct it from the deposit to the Lake Väringen some 4 km downstream.

Figure 9.3. Photograph towards the east after the completion of the cover
Photo: M. Bäckström

Already one year after completion of the cover there was vegetation covering the entire site (Figure 9.4).

The pH in the groundwater is naturally low in the catchment due to the presence of weathered sulphidic minerals. The impact of the alkaline cover material and water pathways is definitely envisaged in the groundwater. At this location, the pH occasionally exceeds 12 and the temporal variation is very high. Thus, in this catchment with naturally low pH the use of alkaline cover material might induce a pH increase, at least in the proximity of the deposit. One important aspect of increasing the pH is that a more efficient retention of cations can be expected through adsorption (Bäckström et al. 2003, Bäckström and Sartz 2011). If the waste contains an anionic contaminant, the conditions are reversed, e.g. increased mobility is possible.

The concentration gradients of calcium, sodium and potassium are very similar to that of chloride, which is consistent with the covering material being the primary source.

It is also evident, that the base cations and chloride are readily mobile under the conditions in the deposit. It is clear, that the covering material serves as a substantial source for the alkaline and alkaline earth metals.

Figure 9.4. Photograph towards the east from the western part of the deposit after establishment of vegetation in the first year, 2003
Photo: M. Bäckström

All trace metals analysed have elevated concentrations in relation to unpolluted groundwater. Arsenic has a concentration gradient that is similar to the alkali and alkaline earths as well as chloride. It is obviously not retained in the system, which is attributed to the redox conditions. It is likely, that the covering material releases arsenic as leaching tests indicated a release of arsenic from the cover materials and not from the mine waste present at the site.

The mobility of copper and zinc is highly related to the pH in the system, whereas the content in the different materials would be of secondary importance for their mobility and redistribution processes are mainly attributed to adsorption and coprecipitation.

The concentrations of molybdenum in the groundwater are almost entirely controlled by the pH value. Thus, the total content of this element in the different materials is inferior to pH control in order to minimise its mobility. This imposes a delicate problem since this oxyanion is immobilised at low pH, contrary to most other trace metals.

The surface water upstream from the deposit is acidic and has an average pH of 3.5, which is consistent with the composition of the groundwater. As the cover material produces an alkaline leachate an increase in pH would be seen at the locations, where this input exceeds the natural (background) acidity. This effect is most pronounced on the south side of the deposit (pH 6.3–8.4), where the lowest pH obviously is a result of alkaline dilution since it exceeds the background values.

Among the trace metals, arsenic follows the concentration changes of chloride and it is highly mobile. For zinc, the high concentrations are more related to low pH and the proximity to the mine waste and show some resemblance to manganese. The concentrations are highly variable in the system and it is believed to be a function of mixing in terms of source as well as immobilisation. Molybdenum concentrations are entirely determined by pH.

It was found that pH, sulphate, TOC, Cr, Mo, Cu, Ba and As had increased in the surface waters since the remediation, due to leaching from the cover material. Increased pH as a result of the added fly ash lowered the concentrations of Fe, Al, Cd, Co, Ni, Pb and Zn in the surface waters due to sorption and coprecipitation.

9.2.2. Case study from Sweden, Ranstad – barrier systems

Ranstad is an old open pit mine, where uranium was mined between 1965–1969 and since the late 1970s until today reclamation has been taking place. Mine waste leachate from the deposit, containing elevated concentrations of various metals and non-metals (e.g. iron, manganese, arsenic, uranium, zinc), is treated in a Natural Treatment System (NRS, Naturligt Renings System in Swedish). Developed by SWECO VIAK, this system was installed in the spring of 1999 and was actively monitored over the course of several years until the end of 2004. The performance of the barrier during its first few years of operation is evaluated in Börjesson (2001, 2002).

As shown in figure 9.5, the NRS consists of three main components: a sedimentation basin, a sludge separator and prefilter and a type of combined organic/inorganic filter system. Since the drainage water was net alkaline and hence relatively well buffered (pH 7.2–7.6 throughout system), there were no alkalinity-producing steps in the treatment scheme. Drainage water was first pumped into the system through aeration steps, which then led to the sedimentation basin (approx. 12 m × 8 m^2). During this first step, iron is oxidized, precipitated and allowed to sediment. It was intended that dissolved metals would adsorb to the precipitated iron oxyhydroxides and accumulate in the sediments.

After the sedimentation basin, the drainage water flowed by gravity into the sludge separator and prefilter, which were designed to remove suspended particulates (e.g. Fe oxyhydroxides) from the flow prior to discharge to the organic/inorganic filter. The presence of suspended particulates could otherwise lead to the clogging of the final filter.

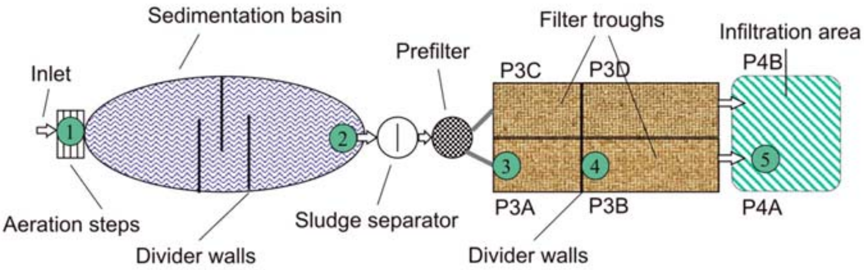

Figure 9.5. Pilot scale barrier ("natural treatment system") in Ranstad. Circled numbers and P-labels (e.g. P3A) indicate sampling locations

Source: Börjesson 2002

The final step in the treatment system consisted of a type of organic/inorganic filter system, which consisted of two parallel troughs (dimensions 10 m long × 1 m wide × 1 m deep, constructed in concrete) with two compartments in each trough, filled with various substrates. A cross-section through one of the filter troughs is presented in figure 9.6. Water flowed by gravity through the filter troughs and finally discharged to an infiltration area outside the barrier. During the five year period, when the NRS was developed and actively monitored, a number of reactive materials were tested in the two filter troughs. These materials include peat pellets, furnace slag, filter sand and mushroom compost. The purpose of this barrier component was to remove metals and non-metals from the water, that had not been previously removed in the sedimentation basin and sludge separator. In particular, the metals were to be removed by adsorption, organic materials (peat, compost) were used throughout the test period because of their well-documented adsorption capacities. In addition, it was possible that reducing conditions would evolve in the organic materials, so that sulphate reduction would occur, leading to the precipitation of metal sulphides.

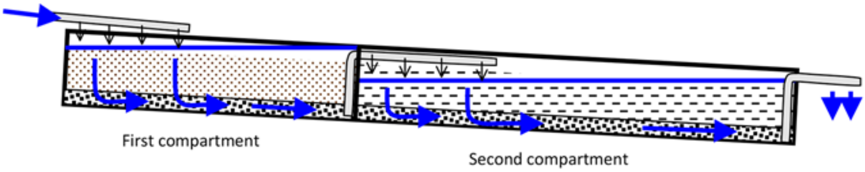

Figure 9.6. Cross-section of a filter trough containing two treatment compartments, in the final treatment step of the Ranstad barrier

Source: Börjesson 2002

The results of five years of leachate treatment and monitoring in Ranstad indicate that high levels of metal (and non-metal) removal were not maintained over extended periods. Since the leachate water was iron-rich (2–70 mg/L Fe), it was essential for iron to be almost completely removed in the first two treatment steps (e.g. sedimentation and sludge separation). Although a relatively high degree of iron removal (and also arsenic and chrome) was consistently achieved in the first two steps, sufficiently high iron concentrations remained in the water to be problematic for treatment in the filter troughs. Specifically, there were continual difficulties with iron precipitates clogging the filter troughs, where the precipitates formed both in the piping and also on the surface of the filter material, where water first entered the troughs. Although a certain metal mass adsorbed to these iron oxyhydroxides, which was a positive result, the overall treatment efficiency of the filter troughs was reduced since clogging often occurred, such that water ran over the surface of the material instead of infiltrating into the material, resulting in 'short-circuiting' within the barrier.

An important lesson can be learned from the dimensioning of the Ranstad barrier system. The conceptual model behind the barrier system was well-founded; however, the water residence time in the barrier was too short for the given barrier dimensions (the average water discharge was 0.5 L/s in the barrier). For sufficient iron removal, a longer aeration step and a larger sedimentation basin with a greater internal surface area are needed for a greater residence time in the system. According to the dimensioning criteria for aerobic wetlands, the sedimentation pond should have had a surface area of about 100 m^2 (Fe concentrations 25 mg/L, flow rate 0.5 L/s, oxidation rate 10 g Fe /day·m^2). Indeed, this is very close to the actual dimension of the sedimentation basin. However, the Ranstad sedimentation basin was relatively deep (1.8 m) and there was probably limited aeration of deeper waters and also limited surfaces for promoting the nucleation and sedimentation of iron precipitates. In addition, while much of the dissolved ferrous iron may have been oxidized during aeration, it may have precipitated as colloidal ferric oxyhydroxides (Langmuir 1997), that require surfaces (e.g. plants, basin walls) on which to aggregate and sediment. If iron removal had been more efficient in the sedimentation basin and sludge separator, a higher level of metal removal would probably have been attained in the filter troughs. In addition, metal removal efficiency in the filter troughs would have been greater if the contact time between the treated water and the filter substrate was longer. This could be implemented with larger and deeper filter troughs.

For additional cases see the Compendium & State-of-the-Art (Bäckström et al. 2013) or Allard et al. (2008).

9.3. Geotechnical aspects of waste dump reclamation

Apart from the methods for cleaning the soil and water as well as introducing vegetation described in the previous subchapter, a key aspect of the process of reclaiming waste dumps is ensuring the stability of the slopes. This aspect becomes more important, when the dumps are located close to populated areas or when they are adapted for use by the general public.

Dumped masses of soil and rock waste, which have variable mechanical parameters are especially prone to landslides. Their causes may be independent of human action: gravity, weathering or erosion of rocks and soils, a change in the level of groundwater or the humidity of the rocks and soils. Man-made causes include: lack of segregation of waste, incorrect formation of the slope profile or loading exterted onto the slope by e.g. a building.

The contents of a mining waste dump depend on a variety of factors such as the geological structure, the type of mineral exploited, the type of rocks associated with the seam of the given mineral or the enrichment technology. Bituminous coal mine waste dumps contain rock masses (shale, claystone, mudstone and sandstone) and combustible substances, which account for up to 20% of the total waste heap (Galos and Szlugaj 2009). In non-ferrous metal mining, the waste flow deposited is mostly made up of post-flotation waste (a mixture of water, finely ground waste rock and traceamounts of metals). Waste created during extraction represents a marginal share of the overall volume of waste (Lewicka et al. 2009). The main components of the waste stream in oil shale mining are: waste rock from oil shale separation and limestone mining fines from crushing and screening, both of which including some portion of oil shale. A separate group of waste heaps are those coming from different manufacturing processes, like for example energy or steel production and include ash, coke or slags.

Mine waste geotechnical properties

The geotechnical properties of the mine rocks change during treatment, transport, handling and compaction. They depend also on the methods and duration of storage. The properties, which have a large influence on strength parameter value are: petrographical characteristics, grain size composition, moisture content, density, compaction, permeability, consolidation settlement, mechanical crushing, swelling and spontaneous self-ignition (Skarżyńska 1995).

The latter mentioned property, spontaneous self-ignition, is characteristic for different types of landfills from hard coal, alum shale or oil shale mining and processing waste. Depending on the waste materials placed in landfills, local outbreaks can cause voids threatening the stability of the structurfe. These landfills, after appropriate rebuilding, sometimes combined with the recovery of useful materials are reclaimed and redeveloped for different functions e.g. recreational or cultural.

One example is Rheineble waste dump, which was part of the colliery of the same name, located in the central Ruhr Area, Germany. During the period 1871 to 1974 a total of 3.1 Mm^3 of waste material was deposited there on an area of 17.9 ha. Stored material contains 20% or more coal, which resulted from the available technology at that time. The level of temperature in the body of the heap at times reached as much as 750 °C, and 260 °C at the surface. Fire outbreaks combined with gas outburst resulted in local landslides and damage of vegetation. In 1996, reprofiling work was started by Deutsche Steinkohle. Much of the slope was stripped away and one side of the heap was flanked with a gabion wall (25 m in high) to act as a static and structural element (Figures 9.7). Once the landfill became safe, a sculpture, which is locally known as the "Stairway to Heaven" was erected at the top of the 106 m high heap (Brüggeman 2003). The area is open to the public and serves as a local adventure playground and recreational area with its network of pathways and cultural attractions.

Figure 9.7. Rheineble waste dump at a hard coal mine in the German Ruhr Area: (left) during reprofiling process, (right) after regeneration secured by gabion wall and equipped with artistic element "Stairways to Heaven"

Photo: RAG Montan Immobilien

The next example is Kvarntorp (Sweden) with a large waste deposit, where coke and ash from alum shale processing (pyrolization) is stored. It is estimated, that this deposit contains 3 Mt of finer fraction, 2 Mt coke and 23 Mt ash. This dump was built between the years 1942–1966 and its volume is 40 Mm^3 and the total height around 100 m. Even many years after closure of the waste pile, substantially elevated temperatures (>500 °C) could be measured in the body, resulting from a combination of hot ash, oxidation of pyrite and organic matter (kerogene). Temperature can be increased to 70–100 °C by oxidation of pyrite, followed by ignition of kerogene giving rise to temperatures close to 1000 °C (Bäckström 2010). This in turn is the cause of small landslides (Figure 9.8 a, b).

The waste dump is adapted for recreational use. There is a ski slope and a restaurant on the top as well as many artistic installations on the dump (Figure 9.8 a). Therefore, special attention has to be paid to the stability as well as the environmental impact.

Figure 9.8. Kvantorp mining and processing waste dumps in Sweden:
a) artistic installation and small landslide, b) burning part of waste dump
Photo: M. Cała

Several studies concerning the temperature evolution as well as leaching tests have been performed and the results indicate that today the environmental impact from the waste deposit is relatively small and local (Bäckström 2010).

Figure 9.9. Mining and processing waste dump in Estonia:
a) general view of the heap, b) burning part of the heap
Photo: M. Cała

In 100–150 years, the waste deposit will eventually cool off and start to leach substantially higher loads of trace elements (Bäckström 2010). What is good for the environment is not good for the physical stability and safety. This is why, further studies and monitoring of all aspects of this deposit have to be performed.

Similar phenomena occur in heaps, where waste from oil shale mining and processing is stored. One example is presented in figures 9.9 a and b, which show a waste heap located close to the Kukruse Oil Shale Mine (closed down in 1967) in Ida Viru County, Estonia.

Methods for waste dump slope stability analysis and monitoring

Ensuring slope stability is a subject of interest for many researchers, who have been searching for better solutions since the 17th century. The rapid development of slope stability analysis methods took place at the beginning of the 20th century, when fundamental methods, still applied today, were developed (Cała 2007). Resolving problems related to waste dump slope stability, including factors, which have an influence on their safety, is mainly conducted by using programs that enable construction of compound models and high performance computers. Empirical and analytical methods, both of which can be applied for waste dump slope stability analysis are presented in figure 9.10.

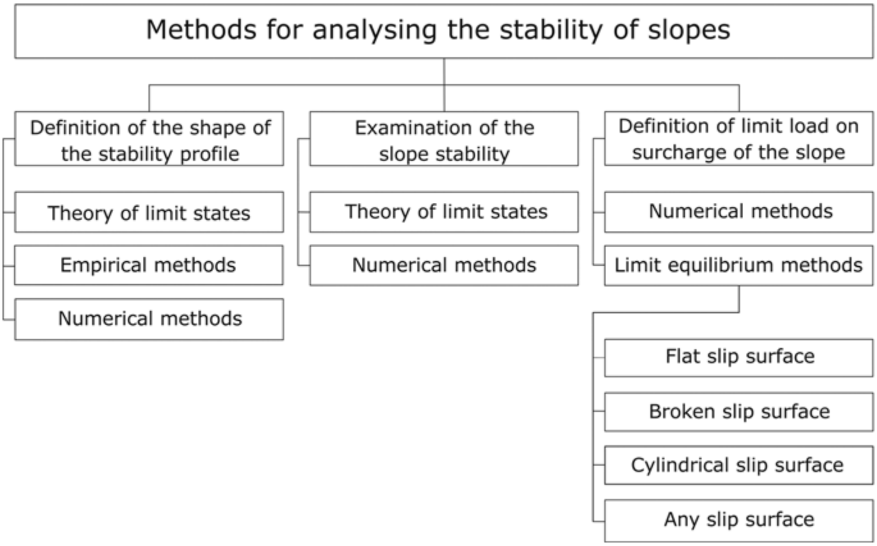

Figure 9.10. Methods for analysing the stability of slopes

Several methods are commonly applied for slope stability analysis: Limit Equilibrium Methods (LEM) and numerical methods: 2D and 3D slope analysis, Shear Strength

Reduction Method (SSR) and Modified Shear Strength Reduction Method (MSSR). The detailed description and examples of the above mentioned methods, especially MSSR which has been developed and verified on several examples can be found in Cała (2007).

To adapt waste heaps for particular uses it is necessary to:

- Monitor surface deformations by means of a system of survey coordinates.
- Monitor interior deformations using inclinometers.

Results of measurements of survey points should be the subject of analysis in order to assess their movements and the speed thereof.

In addition to this, water levels are monitored with piezometers.

As is described in other chapters of this monograph, despite developing prevention and minimization technologies, the mining sector continues to produce large amounts of waste. Since not all of them can be recovered and sold on the market or else applied in-house for engineering works, some portion has to be stored. Applying numerical methods for slope design can improve the safety of waste dumps, both during storage as well as over the period of reclamation and post-reclamation adaptation. Old waste dumps, the contents of which are not known well, need to undergo additional analysis and control.

9.3.1. Case study from Poland – Landslide on the inner overburden dump of the Machów Sulphur Mine

The extraction of sulphur and associated silica mineral sands in the Piaseczno Open Pit of the Machów Sulphur Mine ended in 1980. The post-exploitation area was designated for reclamation with an emphasis on water recreation (Frankowski et al. 2011). The Piaseczno Open Pit is located in Piaseczno in the Świętokrzyskie Voivodship. The nearby Machów Open Pit has already been adapted to serve recreational purposes (Figure 9.11).

The hydrogeological cross-section running through the sulphur seam in the Piaseczno region is shown in figure 9.12. In the vicinity of the open pit, two separate aquifers from the Quaternary and Neogene period exist. Currently, the open pit is filled with water with a maximum depth of 30 m and extends over an area of 62 ha.

The characteristic features of the landslide on the inner overburden dump of the Piaseczno Open Pit

Since 2005, decommissioning and reclamation activities have been carried out at the inner overburden dump, which involve loaming the outcrops of the Tertiary layers of the open pit and profiling the slopes to ensure their stability (Figure 9.13).

Figure 9.11. Location of the Piaseczno Open Pit
Source: own study on the basis of ©2013 Google

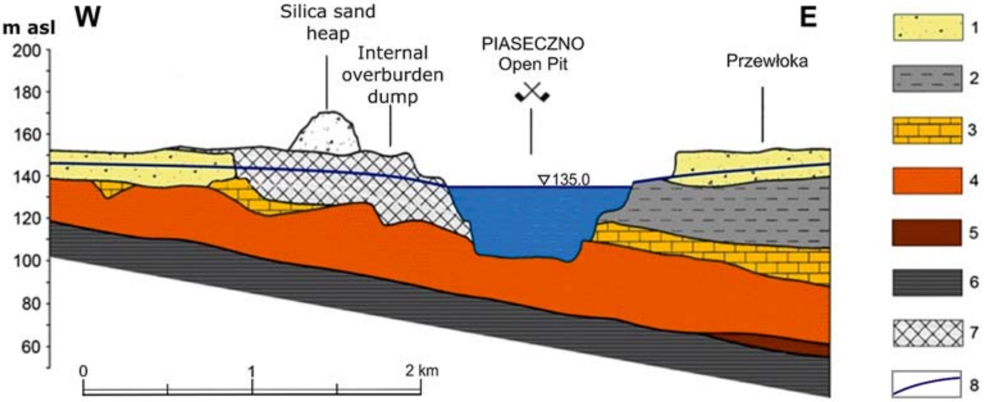

Figure 9.12. Schematic of hydrogeological cross-section through the sulphur deposit near Piaseczno:
1 – sands and gravels (Quaternary), 2 – Krakowiec clays (Neogene), 3 – sulphur-bearing limestones of the chemical deposits (Neogene), 4 – sands and sandstones of the Baranów beds (Neogene), 5 – loams of darkcoal formation (Neogene), 6 – shales and sandstones (Cambrian), 7 – made ground of the internal dump, 8 – groundwater table of the Quaternary horizon
Source: Kopalnia Siarki Machów w likwidacji

Figure 9.13. Formation of the target profile of the open-pit slopes
Source: Kopalnia Siarki Machów w likwidacji

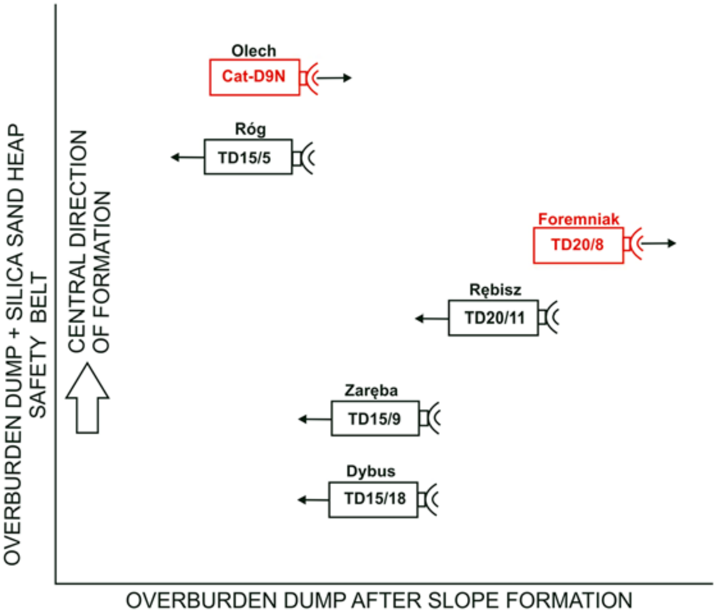

Figure 9.14. The location of the machines on the profiled slope
Source: Frankowski et al. 2011

In May 2011, during the formation of the target profile of the pit's waterside slope, a landslide occurred in the overburden dump. Earthworks had involved six bulldozers, the location of which during the occurrence is shown in figure 9.14. According to the testimony of eyewitnesses to the event, the landslide began as a result of a sudden collapse of the ground behind bulldozer TD20/8, which was working on moving earth in the direction of the water-filled pit. The rapidity with which this event transpired, led to the collapse of two bulldozers Cat-D9N and TD20/8 into a water-filled void together with the ground underneath (only the operator of the bulldozer TD20/8 managed to escape). To this day, the two bulldozers have not been found.

As a result of the landslide, the embankment of the reservoir moved by more than 200 m, which resulted in the formation of a bay with an area of approx. 5 ha. Approx. 600 000 m^3 of earth moved underwater (Figure 9.15 and 9.16).

Analysis of the causes of the landslide on the inner heap was performed on the basis of calculations using Limit Equilibrium Methods and numerical methods.

To properly identify the reasons for the landslide required carrying out the following documentational activities: core well drillings, CPT/CPTU probes, studies using geophysical methods, engineering geological mapping, laboratory research and laser scanning. As a result of this research, it was possible to define the engineering geological as well as hydrogeological conditions prevalent in the area surrounding the landslide.

Figure 9.15. Aerial view of the landslide (SW-NE perspective)
Source: Kopalnia Siarki Machów w likwidacji

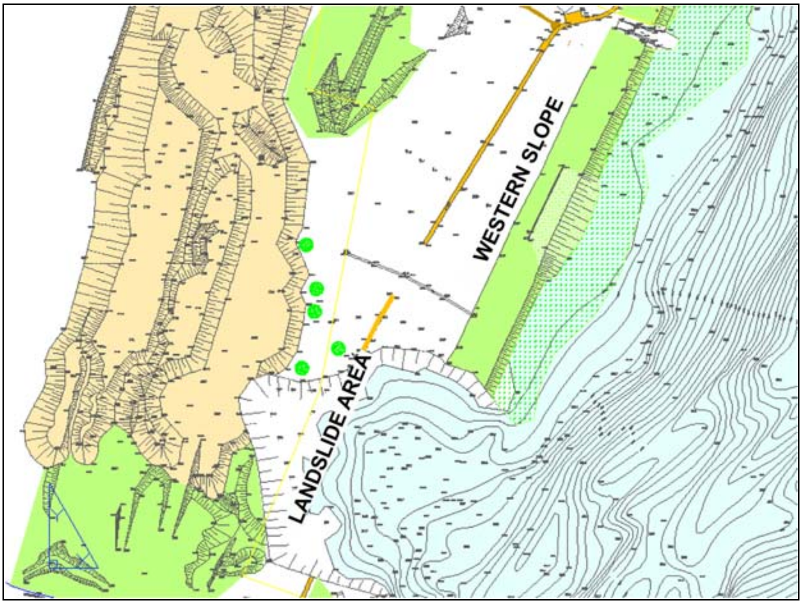

Figure 9.16. Aerial view of the landslide (SE-NW perspective)
Source: Frankowski et al. 2011

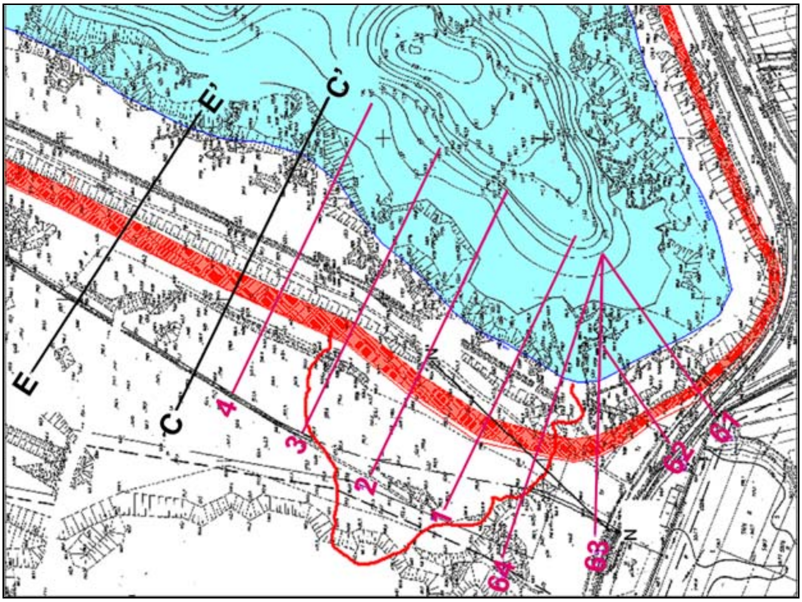

Figure 9.17. Indication of geological cross-sections subjected to probing, geophysical examinations and stability analysis
Source: Cała et al. 2013 a

This research provided the background for completing a series of stability analyses in 2D flat cross-sections (using the Limit Equilibrium Methods) and calculations in the 3D stress state. Numerical calculations in 2D and 3D were done using the Shear Strength Reduction (SSR) method and the Modified Shear Strength Reduction method (MSSR). Calculations were made for cross-sections within the landslide area: 1-1, 2-2, 3-3, 4-4, 61-61, 62-62, 63-63, 64-64 (Figure 9.17).

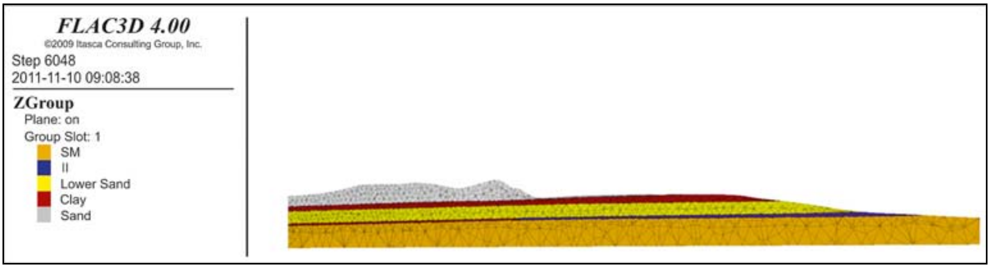

Figure 9.18. Geological structure in the 2-2 cross section
Source: Cała et al. 2013a

Sample results of numerical calculations in the stress state for the 2-2 cross-section running close to the central axis of the landslide are presented in figure 9.19 a–d. A simplified geological structure for this cross-section is presented in figure 9.18.

In the 3D numerical calculations, standard boundary conditions have been assumed, which are necessary to obtain the correct analysis results (Cała 2007).

Figure 9.20 a–d shows the 3D image of the numerical calculation results in a strain state for the view from above the model.

The calculations made it possible to deduce the most likely, two-stage development of the landslide processes, which occurred in the inner heap constituting the escarpment of the reservoir.

During the first stage, the lower portion of the soil moved to the reservoir, thereby creating a landslide colluvium, with very low strength properties. The loss of support for the lower part of the slope resulted in the further propagation of landslide processes, which reached the quartz sand heap, located approximately 300 m from the original edge of the slope. Eyewitness reports bear out the landslide progression described above.

Figure 9.21 shows the final shape of the landslide, obtained from 3D numerical calculations carried out in 4 phases. Meanwhile, figure 9.22 shows the result of a laser scan of the surface of the terrain, which was done after the landslide had occurred. The two images of the landslide demonstrate a high degree of correspondence.

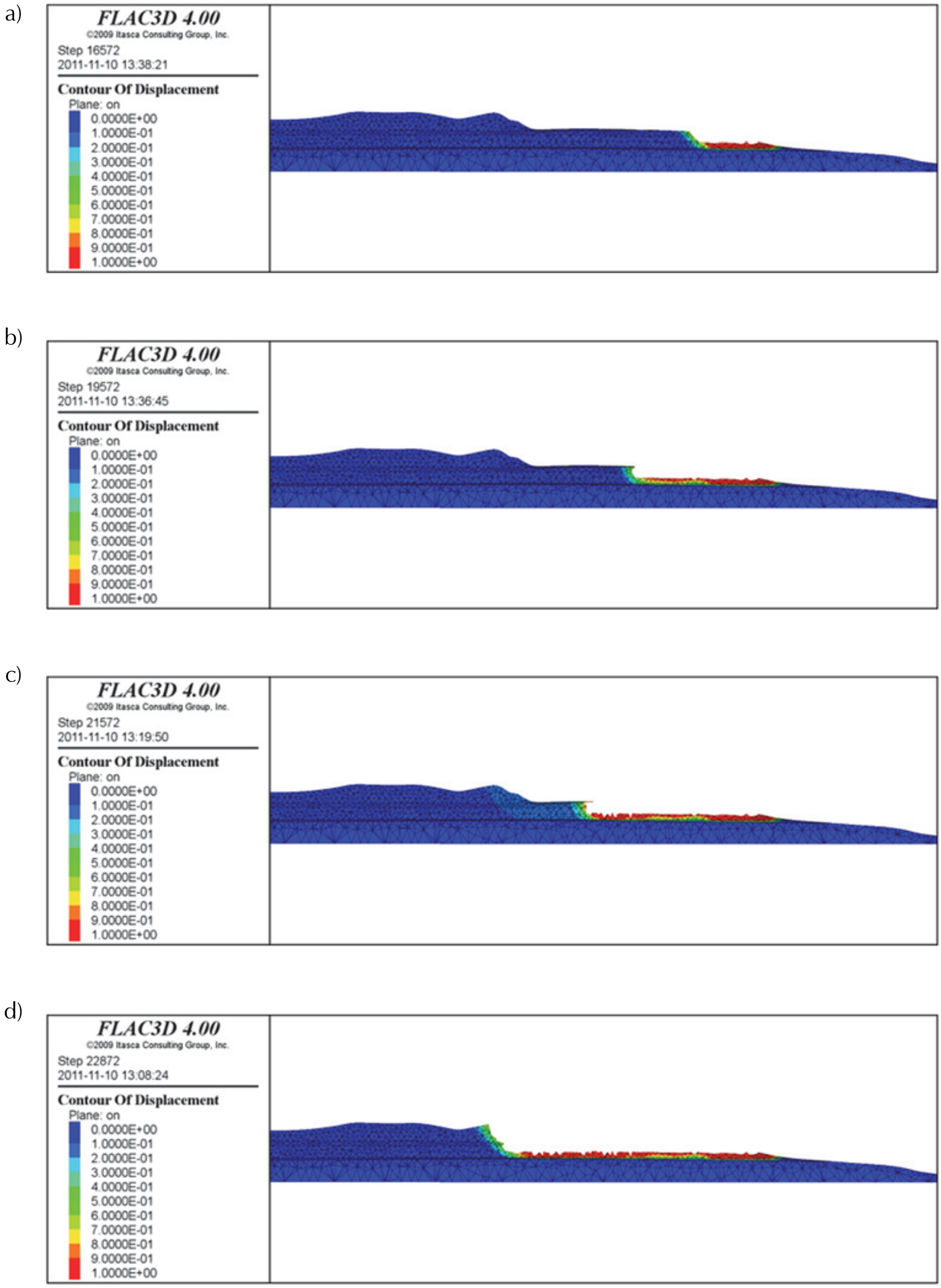

Figure 9.19. Results of stability analysis for each stage of the calculations in the 2-2 cross-section
Source: Cała et al. 2013a

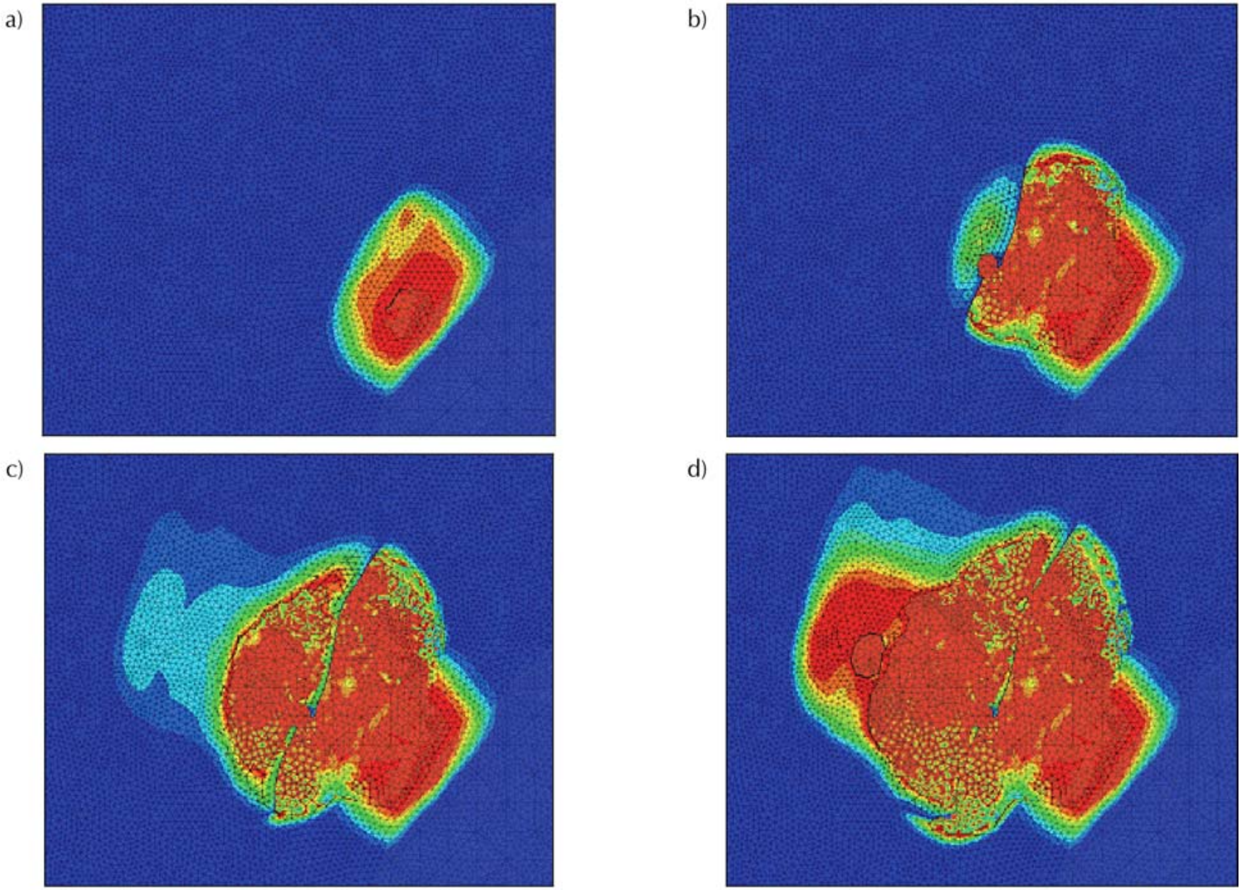

Figure 9.20. Results of stability analysis for each stage of 3D calculations – view from above

Source: Cała et al. 2013a

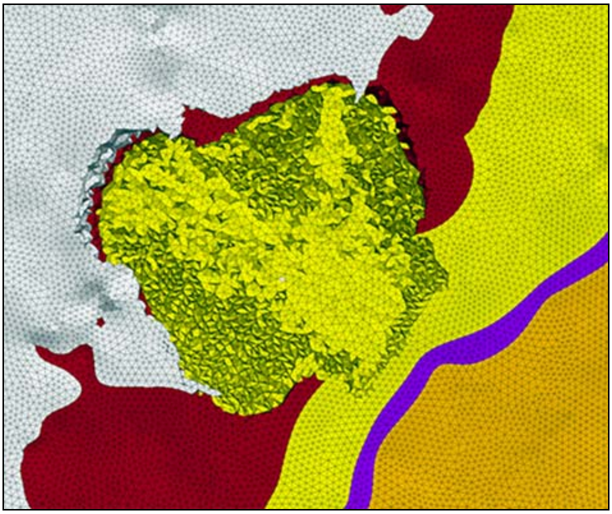

Figure 9.21. The final shape of the landslide obtained from 3D numerical calculations

Source: Cała et al. 2013a

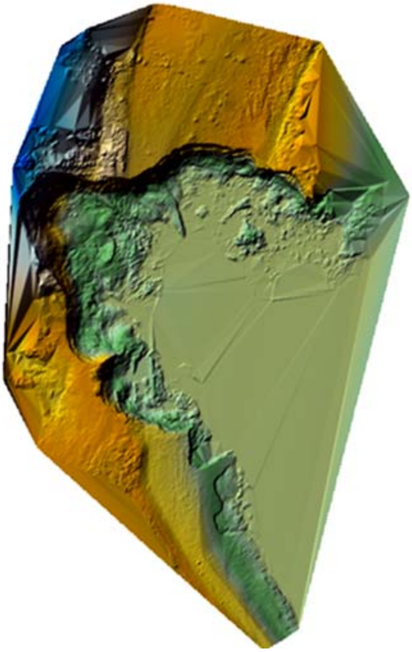

Figure 9.22. Image of the scan of the landslide-caused depression

Source: Cała et al. 2013a

The concept of the reclamation of the landslide area in the Piaseczno open pit

It has been shown that the renewal of reclamation activities would require the improvement in the strength properties of the soil forming the slope. The results of the stability analysis have identified an area, where it is necessary to compact the dump soils (Cała et al. 2012, 2013 a). To achieve this, the following technologies have been suggested (Cała et al. 2013 b):

- Micro explosions – to ensure the appropriate state of soil compactness of the slope of the inner heap (slope of the open pit). This is an especially effective method for increasing the bearing capacity of the soil substrate in the conditions under examination.
- Hydrotransport – to move approximately 350 000 m^3 of soil from the neighboring heap to the core of the landslide reservoir so as to obtain a stability profile of the slope in the vicinity of where the landslide took place.

The proposed reclamation methods will make it possible to avoid using machinery to shape the slope, which would involve a serious risk of the recurrence of the landslide. At the same time, a newly formed heap slope will be permanently stable at the present and target level of water in the reservoir (Cała and Karwat 2013). However, the authors recognize that in order to confirm this conclusion it will be necessary to test the geotechnical parameters of the soil after the slope has been profiled in the area of the landslide (probing) and to carry out a stability analysis thereof.

The possibility of a landslide occurring on such a scale on the slopes of the Piaseczno open pit during reclamation works is very unlikely. This is on account of the small inclines of the slopes and the results of the stability analysis. Perhaps, for the first time in Poland, we have witnessed such an unusual, two-stage progression of the landslide. It is difficult to answer the question on whether this accident could have been anticipated. The answer could be split up into two parts (thus reflecting the two stages of the landslide). The likelihood of a correct prediction of such types of landslide flows in 2011 was very low. However, with the benefit of having at one's disposal a back analysis of this occurrence, one could venture the conclusion that the likelihood of an effective prediction of the landslide risk is substantially higher than merely a few years ago. More about this case as well as ones with similar consequences, which happened in post-mining area in Lautzitz (Germany) can be found in Cała et al. (2013 c).

9.4. Possibilities for waste dump revitalisation

Modes of mining and processing waste revitalisation depend, first and foremost, on their shape and the technical possibilities of implementing new functions.

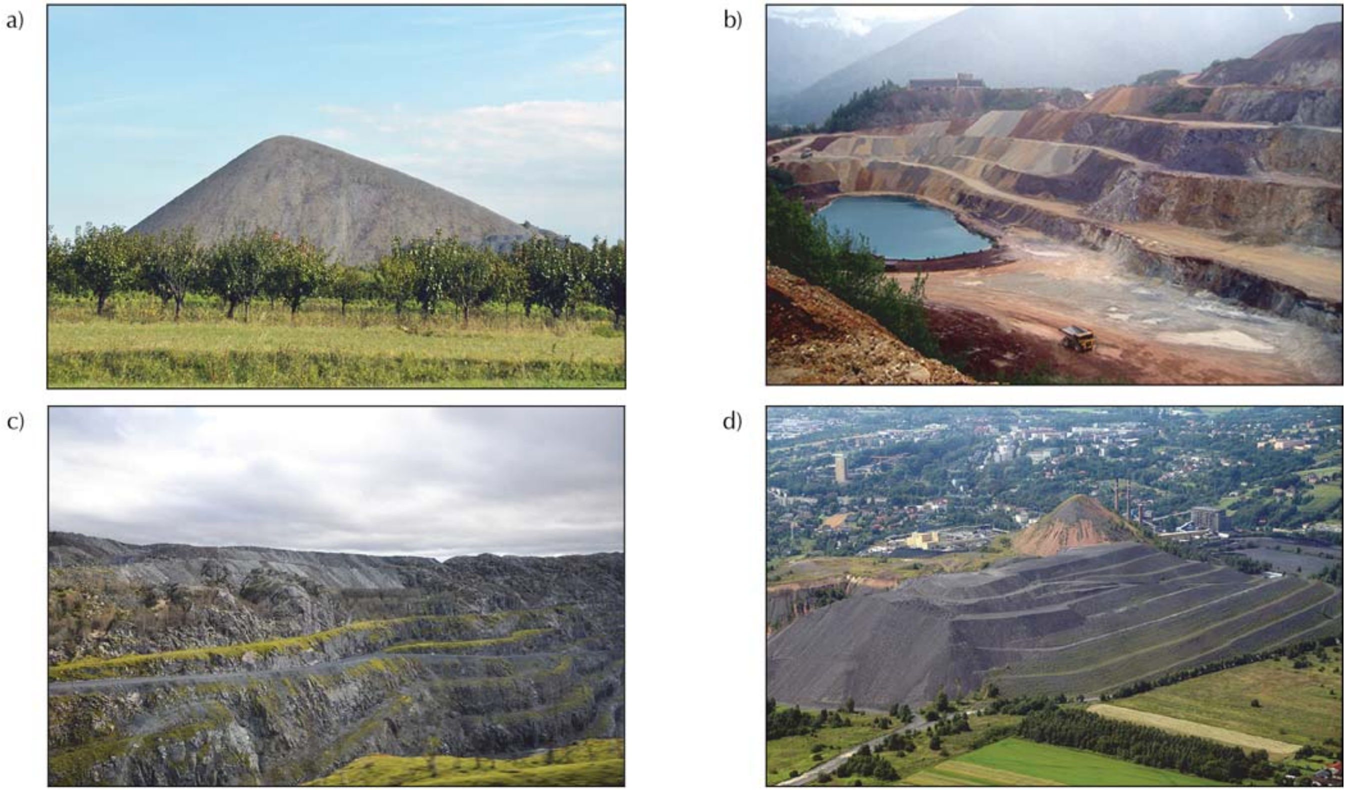

Figure 9.23. Different ways of storing mining waste: a) Copper Mine in Germany – conical waste heap, b) Erzberg Iron Mine in Austria – wastes are incorporated into the slope of the conical mine, c) Titania Mine in Norway – wastes are stored among hills surrounding the open pit mine, d) Rydułtowy-Anna Hard Coal Mine in Poland – waste rock is formed from the beginning as a earth structure intended for recreational functions

Photo: a, b, c) A. Ostręga, d) Rydułtowy-Anna Hard Coal Mine

The shape of the waste dumps is usually determined by the period when they were built (e.g. the technology applied) and the rigors of the environment (the need to fit into the surrounding landscape), as shown in the examples (Figures 9.23 a–d).

In European (post)mining regions one can find many heaps attractively regenerated and used for recreational, cultural and other purposes. Those artificial hills are perfect for sports activities like ski slopes, especially when they are located far from any mountainous region.

One such example is the waste heap in Bottrop (Germany), which on the initiative of the RAG Immobilien – Montan-Grundstücksgesellschaft mbH (now RAG Montan Immobilien), Deutsche Steinkohle, City of Bottrop and five-time winner of the Alpine World Cup Marc Girardelli was adapted for the Alpincenter[25] (Figure 9.24). This indoor ski slope, which has a length of 640 m and width of 30 m offers the opportunity to ski and snowboard all year round.

The waste dump-cum-ski resort hosts many other attractions, such as a toboggan run, a rope garden, an indoor paintball playing field as well as an indoor skydiving turbine. Sports facilities include a full range of social and catering services.

Figure 9.24. Alpincenter on the waste dump; Bottrop, Germany
Photo: A. Ostręga

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[25] In October 2004 Alpincenter Bottrop was taken over by Van der Valk Germany.

Similar examples of waste heaps becoming attractions can be found in Estonia's Ida Viru County region. A former oil shale semi-coke heap near the town of Kiviõli is in the process of redevelopment and is being adapted into a ski slope (Figure 9.25). Social services like a hotel, restaurant and ski services are being built in the surrounding area. This is a private investment with substantial financial support from different enterprises, including Kiviõli Keemiatööstus (a company extracting oil shale and producing oil shale oil in Kiviõli). The current land owner of the closed shale heap is the state.

Figure 9.25. Oil shale semi-coke heap near the town of Kiviõli adapted for recreational use as a ski slope; Ida Viru County, Estonia
Photo: A. Ostręga

Interesting results in the regeneration of waste heaps have been achieved in the German Ruhr Area and it is worthwhile to present them even though this region was not represented in the Min-Novation project. The scale of the mining and smelting activities carried out in the Ruhr area can still be seen. Numerous landfills were regenerated in such a way that they became characteristic landmarks of the Ruhr Area and considered a key piece of heritage from the industrial period. Some projects have been implemented in the framework of the International Building Exhibition – IBA Emscher Park (1989–1999). The process of regenerating other landfills has been successfully carried out. Regenerated heaps constitute a separate chapter on the path of the Route of Industrial Heritage (www.route-industriekultur.com).

In order to remove hazards such as endogenous fires and landslides, as well as adapt for new functions, waste dumps have been rebuilt. Their slopes have been vegetated and equipped with walking and cycling paths or stairs. The plateau or conical peaks are often covered with waste rock, which allows visitors to learn about the material from which they were constructed (Figures 9.26–9.28).

The most characteristic feature in the regenerated landfills in the Ruhr Area are sculptures designed by artists or architects, which are placed on top of the waste disposal sites, making a journey to the summit worthwhile. They are also characteristic landmarks in the Ruhr Area, especially when they are illuminated at night. One such sculpture is Tetrahedron, placed on the top of the Beckstraße heap (Figure 9.26). This 60 m high structure with three viewing platforms is also known as the "steel crown". The art installation was designed by Association of Engineers (Ingenieurgemeinschaft) Christ and Bollinger and light illumination by artist Jürgen LIT Fischer (Radomski 1999).

Figure 9.26. Tetrahedron installation on top of the waste dump; Bottrop, Germany
Photo: A. Ostręga

The south-east part of the vast Rungenberg waste dump at the Hugo/Ewald Coalmine in Gelsenkirchen was designed by the architect Rolf Keller. The heap was crowned by two triangular black pyramids and each contains telescopes made of thick pipes of rusty steel, which emit a ray of light during the night. Hermann EsRichter from Oberhausen and Klaus Noculak from Berlin designed this illumination (www.route-industriekultur.de 2013).

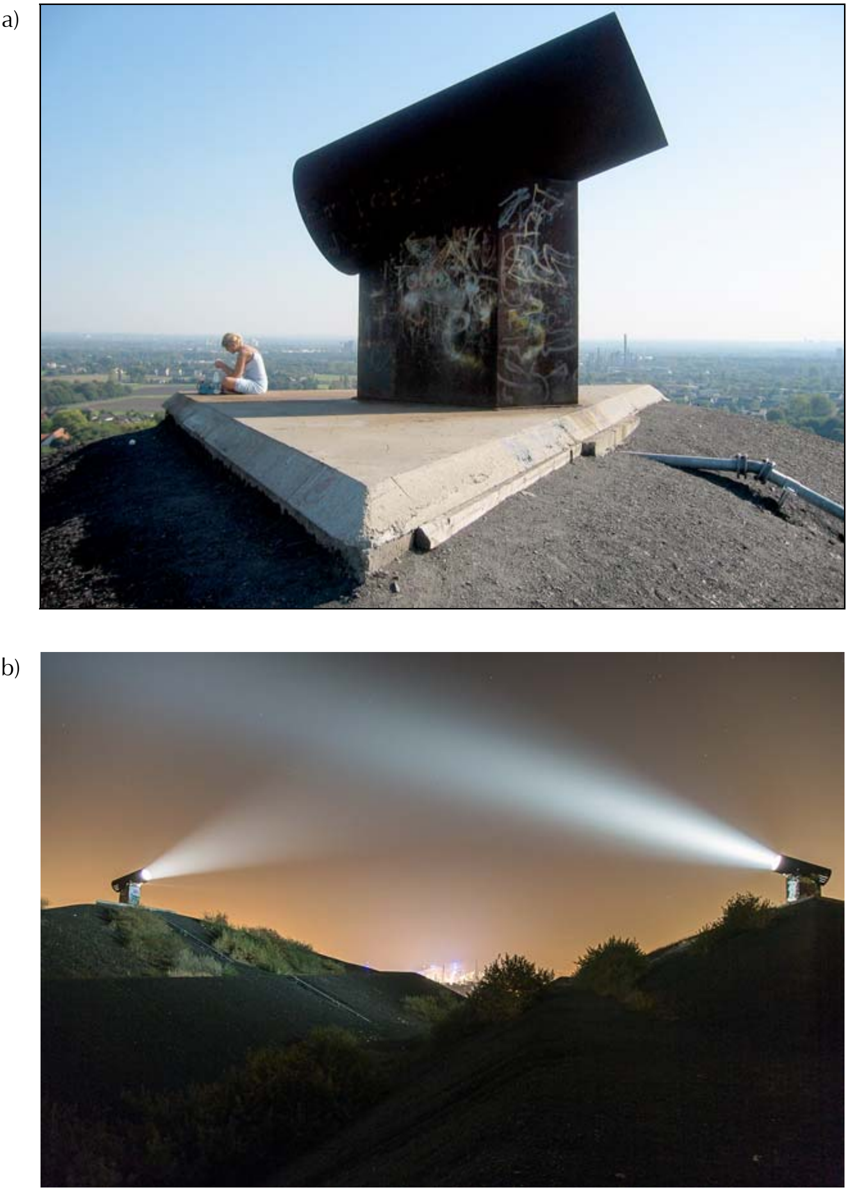

Figure 9.27. Rungenberg waste dump with close-up of telescope (a) and night illuminations (b); Gelsenkirchen, Germany
Photo: a) A. Ostręga, b) G. Walter, RIK www.route-industriekultur.de

Many completed projects concerning waste dump regeneration closely follow the history of the region and the people working in the mining and metallurgical industry. A steel sculpture placed on a plateau in the shape of a huge curving ellipse at the Schurenbach heap is called "Slab for the Ruhrgebiet" (Figure 9.28). It is a symbol of a once powerful industry defined by the local coal mines and steel plants. This heap was piled up with rock waste coming from the Zollverein Colliery in Essen. The steel slab is 14.50 m high, 4.20 m wide, 13.50 cm thick and weighs 70 t. The sculpture was designed by the American architect Richard Serra (Uberman and Ostręga 2004).

Figure 9.28. Schurenbach heap– bird's-eye view and "Slab for the Ruhrgebiet" – sculpture placed on top; Essen, Germany
Source: ©2013 Google, photos: A. Ostręga

The Haniel heap located next to the Prosper-Haniel Colliery has been growing ever since operations began in 1974. In 1995 the Way of the Cross, a symbol of close relationship between the church and the coalmining industry in the Ruhr Area was officially opened. This special Way of the Cross was created by Tisa von Schulenburg, an artist and nun, the artist Adolf Radecki and apprentices at the Prosper-Haniel Colliery. Individual Stations of the Cross are presented along the slope of the heap and each one contains a copper plate depicting the sufferings of Christ and a piece of mining equipment (Figure 9.29 a, b). The tall cross erected at the top of the heap is made of colliery timber by mining apprentices and their supervisors.

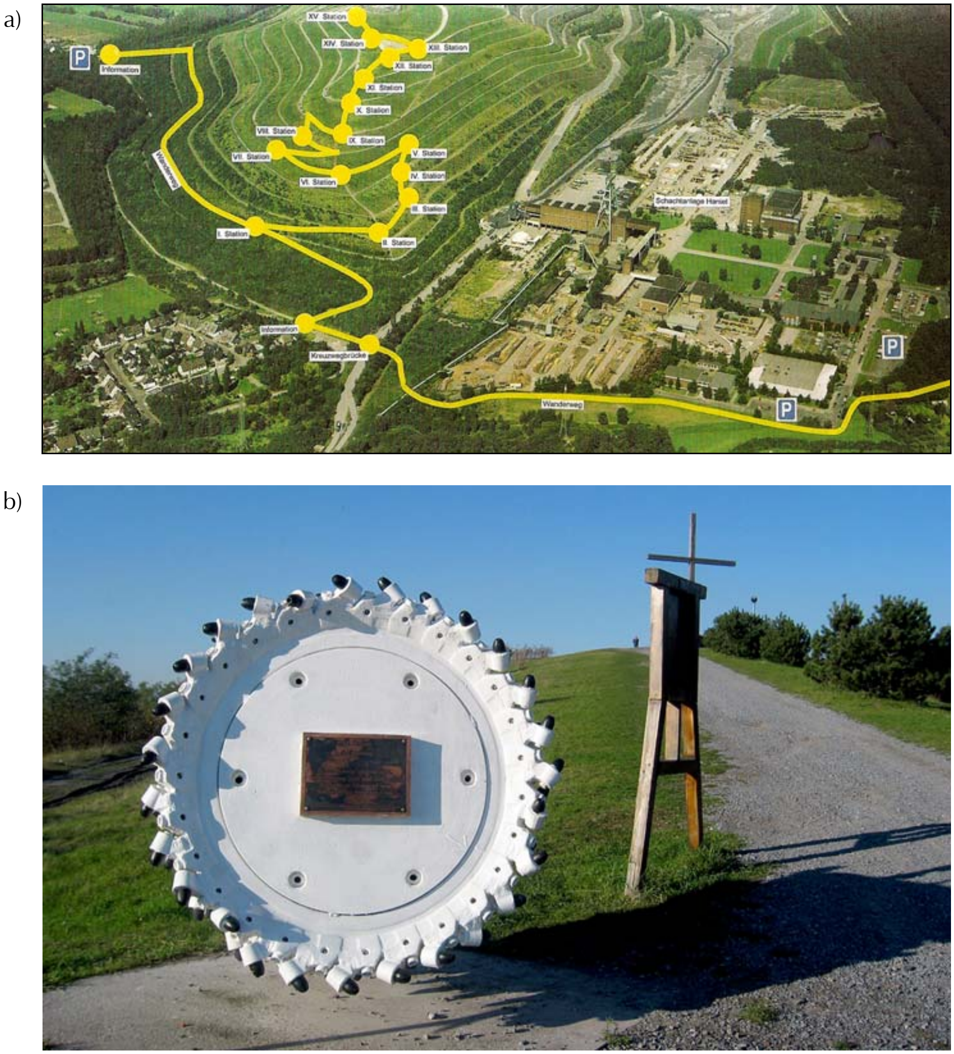

Figure 9.29. Prosper-Haniel waste dump: a) Way of the Cross, b) one of the stations decorated by element of combine-harvester; Bottrop, Germany
Source: a) Kreuzweg Bergwerk Prosper-Haniel, b) photo: A. Ostręga

Beside the Way of the Cross, another feature with a more cultural function was implemented on the other end of the plateau, namely an amphitheatre modelled on classical Greek lines with a seating capacity of 800 persons. Those two functionalities, religious and cultural reference points are separated from each other by an archaic installation "Totems", consisting of over 100 specially prepared (colored) railway sleepers, designed by the Basque painter and sculptor Agustín Ibarrola (www.route-industriekultur.de 2013).

Another example on display is the work of the artist Otto Piene, who re-designed the Rheinpreußen heap and installed a 30 metre tall steel tower illuminated in red in the form of an oversized collier's safety lamp (the pit lamp). In addition, thirty-five illuminated masts with red light were implemented around the 70 m high heap. The idea behind creating this landmark was to highlight the contribution made by millions of colliers and steel workers to the economic development of the area, especially those, who worked at the Rheinpreußen colliery located in Moers.

Figure 9.30. Rheinpreußen waste heap:
Miner's safety lamp tower and the heap slope illuminated in red at night;
Moers, Germany

Photo: A. Ostręga (large),
G. Walter, RIK www.route-industriekultur.de (small)

The above presented examples referred to the revitalisation of already closed waste dumps and it was noted that prior to this a number of technical and environmental activities (reclamation) had to be performed. Nowadays, a different approach to masses of soil and rocks associated with the mining and processing operation is becoming more prevalent. These rocks and soils are not regarded as useless matter (waste), but as raw material for the construction of various useful engineering and landscape structures.

A case in point is Northumberlandia, located to the west of the town of Cramlington (UK). In 2007, in addition to planning permission for the Shotton Surface Mine (hard coal), permission to build an art installation using overburden was also granted. In 2010, when the design stage was completed, on the land adjacent to the mine and donated by the landowner (Blagdon Estate), Banks Groups[26] created a new landscape for the community to enjoy while the mine is still in operation. World-renowned artist Charles Jencks was invited to design a new landmark feature called Northumberlandia – the Lady of the North (Figure 9.31). It is a reclining female figure set into the local landscape and built with 1.5 Mt of material (predominantly crushed and compacted stone, clay and soil), which was taken from the surface mine and then blasted with "hydro seed". The landform is 400 m long, 254 m wide and 34 m high. This unique piece of art is surrounded by a community park with free public access. The construction has been privately funded by the Banks Group and Blagdon Estate. Northumberlandia was officially opened on 3 September 2012. Investors estimate that some 200 000 visitors per year are likely to visit the site (www.banksgroup.co.uk/banks-group 2013).

Figure 9.31. Northumberlandia – the Lady of the North built with overburden from the surface mine; Cramlington, Great Britain
Source: Courtesy of the Land Trust

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[26] Banks Mining, which operate the mine belongs to Banks Group.

Estonia also has its share of sites, especially in the north-east of the country, which have the potential to become local and regional attractions. Waste rocks (limestone) coming from processing at the Ojamaa Oil Shale Mine are going to be used for constructing pyramids – Aidu Pyramids (Figure 9.33). Ojamaa Mine is operated by the Viru Keemia Grupp AS (VKG), Estonia's largest producer of oil shale[27] and relevant chemicals (Viru Keemia Grupp AS 2011). The Ojamaa mine was officially opened in 2012 and will be operating over the next 30 years. At the moment, limestone materials (waste) are sufficiently small in quantity that they can all be utilized in construction and other industry branches. However, it is likely that limestone quantities will increase in 2013–2014 and so a new concept was designed for revitalising the post-mining area and especially likewise making good use of the huge amount of waste rock. Aidu Pyramids will be built using nearly natural material (limestone) on the area of the closed Aidu open cast oil shale mine (Figure 9.32). The waste heap will make way for houses, museums, sports and recreation facilities, restaurants, beaches, wine cellars and other attractions. In effect, the oil shale mine's waste-material will be arranged in such a way as to give something useful back to local people instead of leaving them with a waste heap (Urmas 2013).

Figure 9.32. Ojamaa internal overburden dump on the Aidu open cast mine area in 2013, the location of the future pyramids park; Estonia
Photo: A. Ostręga

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[27] VKG produces 57% of Estonia's shale oil (660 000 t).

Figure 9.33. Aidu Pyramids – functional diagrams; Estonia
Source: http://kta.ee/aidu-pyramid 2030

The land, where the waste heap is located is owned by the state. The pyramid park will however be built with the financial support of the VKG company and using its equipment (trucks and excavators). Infrastructure such as sports facilities, museums or restaurants will be implemented by public or private investors.

The construction of useful structures also becomes important, when the capacity of the existing mine waste dumps is exhausted. Such a situation took place in Libiąż (Małopolska region, Poland) at the Janina Hard Coal Mine, which belongs to the Southern Coal Concern JSC (Południowy Koncern Węglowy S.A.). In this situation, it was decided to purchase a plant for the production of aggregates, which was included in a coal enriching plant technology and from it selected waste rock is mixed with a binder (ash, cement, lime). Given this, a strategic decision was made to adapt the mining waste in the Janina Hard Coal Mine to make it possible to erect public facilities there using the "PKW JSC aggregate" as the base material (Paw 2013).

Using aggregates for revitalisation of a post-mining site owned by Janina Hard Coal Mine is one example of the new strategy of the Southern Coal Concern JSC. The objective is to build a complex of structures on top of the inactive waste dump using aggregates that make up with the mining waste from current production. The end result will be three hills (Figure 9.34).

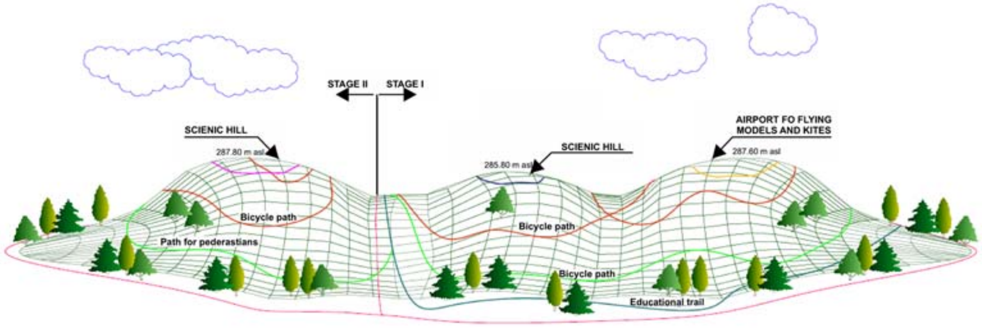

Figure 9.34. Three hills built with aggregates produced on the basis of waste rock and different binders at the Janina Hard Coal Mine area; Libiąż, Poland
Source: Janina Hard Coal Mine

Following biological reclamation, redevelopment of the site will involve setting up a range of sports, recreational and educational facilities. The idea is to create an attractive place for the local community, also as a way to give back to the community after more than a century of mining activity in the Libiąż area, which inevitably has had an influence on the environment and quality of life. An educational trail, which will weave over and through the landfill and focuses on the local mining tradition will in a way be a means of cultivating the memory of generations of mining families.

It is worth pointing out that the aggregates and materials used to construct the described facilities and buildings have all the necessary technical approvals and hygiene certificates issued on the basis of a variety of tests.

It is worth noting, that all stages of the investment will be carried out by a mining company, despite the fact, that this goes beyond their statutory obligations. In accordance with the planned timetable for the construction of the hills, they will be completed by 2015, the reclamation will last until 2017, while the redevelopment (revitalisation) is expected to end by 2019. Afterwards, the recreational complex will be opened to the the local community and general public.

9.5. Conclusion

Reclamation and revitalisation of waste dumps and post-mining sites are complex processes. Their scope depends on many different factors, both internal such as the characteristics of the given dump or site and external as in the different methods of clearing and adapting the land. The presented examples of waste dump regeneration prove that they are often adapted for utility functions. This is why special attention has to be paid to their stability. The presented case study from the Piaseczno Sulphur Mine, where a landslide in the area of the inner overburden dump took place during the reclamation process shows, that this problem affects not only large landfills, but also relatively flat and extensive overburden dumps.

Advance planning of the target redevelopment of mining and processing waste dumps is the most appropriate route to take. It allows engineers to shape the structures in the right way and from the very beginning. Later on, expensive work associated not only with the formation, but also with stabilising the structure in case it is designed for intensive use and human presence, can be avoided.

The presented examples of heap revitalisation show a wide range of possibilities that would not be achievable if the site were not an earlier landfill. Recently, a further step in managing landfills in an effective way was taken. Waste, overburden or aggregates made with waste are used as a building material (see examples of Northumberlandia, Aidu Pyramids and Three Recreational Hills). The idea that guided the mentioned undertakings was a willingness on the part of mining companies to give something back to the local community after decades of mining activity, something that was both useful and valuable instead of mountains of waste. Obviously, the mining enterprise in taking on such an investment stands to reap certain benefits, such as financial savings derived from having to manage the waste on an ongoing basis and improving their public image. The methods of reclamation and examples of revitalisation presented in this chapter prove, that it is possible to introduce and implement life-cycle thinking in the case of mining waste.

10. Conclusions and recommendations

At the time of writing this publication, the High Level Steering Committee of the European Innovation Partnership on Raw Materials (EIP RM) approved the Strategic Implementation Plan, which will guide concerted efforts to secure a sustainable supply of raw materials for the European economy. While greater mining waste prevention, recovery and reclamation is not singled out as a target area of action, individual recommendations of the EIP RM drive the point that waste from the extractive industry is as much an asset as a liability and waste management is an essential part of the concept of a more 'circular' economy, which underpins the Partnership and other EU-wide initiatives dealing with natural resources. This then is the backdrop to the actions that have been undertaken in the Min-Novation project and the themes that have been addressed in the present publication.

Several conclusions are to be drawn from the monograph as a whole:

1) The key outputs of the project: the Baltic Mining Waste Management Business Database, the Compendium & State-of-the-Art of Mining Waste Management Technologies and the Pilot Investments outlined in chapter 3 make abundantly clear that **there is a burgeoning mining and processing waste-to-resource market in the Baltic Sea Region, a wide selection of approaches to mining waste management, technologies, which can be adapted to improve the prospects of mineral recovery and reuse but also region-specific waste streams largely untouched and waiting for the right solution**.
2. **The basic legal framework, which is supposed to drive greater waste resource and recovery as well as reuse is mostly in place in the Baltic Sea Region countries**

represented in this project. However, there are still outstanding issues, which suggest that mining waste management overall is not adequately incentivised, e.g. there is little chance that the engines of growth in the national economies – the SMEs – will take up this line of business.

a) Some examples provided in chapter 5 clearly indicate that the **regulations are not keeping up with the growing interest in extractive waste and the new market opportunities**. This is best seen in the absence of criteria for determining when a waste disposal site from a former mine should be protected as industrial heritage and when secondary raw materials can be recovered from it (this is the case in Sweden, to a lesser extent in Poland). This example also illustrates that industrial heritage is likewise not to be ignored, because it is becoming an ever more prominent element of cultural heritage.

b) Other examples show **the importance of designating material as 'waste' to the prospects of a waste-to-resource market** e.g. a common methodology for testing waste rock materials in order to exclude them from the waste stream.

c) Finally, **an excess of laws and regulations governing waste management inevitably means that at some point they become mutually inconsistent and instead of providing clarity, introduce confusion and act as a disincentive for taking up this form of business activity**. A case in point is Poland, where despite the fact that the foundation of waste management law is the well-known waste management hierarchy, businesses cannot count on support for recovery operations and from a financial standpoint landfilling is made to be the most affordable and optimal route.

3) Extractive waste management is important at each stage of the mine life cycle following construction e.g. during production, closure and post-closure operations. The achievements highlighted in chapter 6 and 9 prove that **a lot of efforts have already been made to ensure proper waste management incorporates prevention, recovery as well as reclamation and revitalisation**.

4) **Mining waste management can nonetheless be an economically feasible and profitable activity**. A case study from Poland presented in chapter 8 shows how each of the participants in the mining waste management process stands to benefit from it. The important thing to recognise, however, is that **until there is a set of analytical tools to assess the environmental benefits of waste management (recovery, reuse), the argument for more public support for it will be much more difficult to make**. This applies to both government support and community support.

5) Waste dumps are not just about what's inside the dump. As shown in more detail in chapter 9, the dumps as structures can become a part of the local landscape and enrich or even define a region's identity, whether they present themselves as high

pyramid-like cones rising out of the fields and meadows or flat but extensive structures, sometimes with sculptures and light illumination, which can be visited. They also can be redeveloped to serve a variety of functions, including ski slopes in otherwise flat areas. In order to make waste dumps fit for new uses, different methods of reclamation and stability analysis have to be performed to avoid environmental and landslides risk.

The 3 years of co-operation in the Min-Novation project have made it possible to define new fields of activity, which aim to advance the societal and market value of mining waste. Several ideas for future initiatives include unifying definitions with respect to mineral resources and waste classification and carrying out a comprehensive inventory of waste dumps, which would assess their potential for the economy, environmental risk as well as natural and cultural protection valours. There is also a need to develop new recovery technologies for some categories of waste, especially in metal processing and manufacturing and this represents another initiative worth undertaking.

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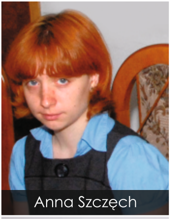
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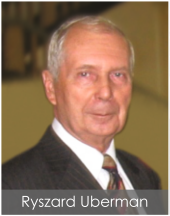
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The authors of this monograph are representatives of organizations and institutions from Estonia, Finland, Norway, Germany, Poland and Sweden, which took part in the Min-Novation project as well as guest authors co-operating with Project Partners in the field of extractive waste management. This made it possible to address all the important topics relevant to waste management in the mining sector today.

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