Mining Waste Directive 2006/21/EC

European Implementation Assessment

Study


The authorisation to draw up the report triggered the automatic production of this European Implementation Assessment by the Ex-Post Impact Assessment Unit within the Directorate for Impact Assessment and European Added Value, DG EPRS. This in-house supporting study looks at the implementation of the EU policy on the management of waste from extractive industries, and of Directive 2006/21/EC in particular. The research paper gives an overview of the available data on the practical implementation of the directive. It also sheds light on the prospects for extractive waste management in the context of the 'circular economy' concept.

Abstract

In the aftermath of two major accidents involving the spill of hazardous extractive waste, the Mining Waste Directive 2006/21/EC was adopted at EU level with the aim to prevent, or reduce as far as possible, the adverse effects from extractive waste management on health and the environment.

The deadline for transposition of the directive by the Member States expired on 1 May 2008. Research indicates that all Member States (EU-27) have experienced transposition problems in terms of 'timing' or 'quality' or both.
It appears that the majority of Member States have adopted the measures needed to implement the provisions of the directive, but the practical implementation of some aspects remains problematic.

The quality of available data does not allow for the complete picture of practical implementation of the directive to be fully outlined and assessed. While EU legislation on the management of extractive waste is still relevant to real needs, the levels of effectiveness and efficiency across the EU may vary from one Member State to another.

This European Implementation Assessment makes recommendations for action aimed at improving the shortcomings identified.
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List of abbreviations

BAT - Best Available Techniques

BREF - 'Best Available Techniques' Reference Document

CEN - European Committee for Standardization

DG ENV – Directorate General for Environment of the European Commission

EESC - European Economic and Social Committee

ENVI - Committee on the Environment, Public Health and Food Safety of the European Parliament

EP - European Parliament

EPRS – European Parliamentary Research Service

EU - European Union

IMPEL - EU network for the implementation and enforcement of environmental law

MEP - Member of the European Parliament

PETI - Committee on Petitions of the European Parliament
Executive summary

The initial aim of this European Implementation Assessment (EIA) was to research and assess the practical implementation of the transposed Mining Waste Directive (MWD). Usually, the main task of an EIA is to assess implementation against the standard set of key assessment criteria for evaluation: relevance, coherence, European added value, effectiveness and efficiency. However, in the course of this desk research work, it became clear that the available data on practical implementation, the quality of which is discussed in detail in the paper, did not allow this evaluation task to be fully accomplished. Therefore, the analysis only takes a snapshot of the state-of-play of practical implementation, as suggested by the little data available, and assesses only some of the criteria for evaluation.

The deadline for the transposition of the directive into the national legal orders of the Member States expired on 1 May 2008. However,

- in 25 Member States, transposition (in terms of ‘timing’ (‘non-communication’)) was delayed and completed only in 2011;

- 18 Member States experienced problems in terms of ‘quality’ (‘non-conformity’) because they failed to correctly and completely transpose the directive. These included the two Member States that were on time with the transposition. More specifically, at the time of writing, four Member States have still not completed the correct transposition of the directive - almost nine years after the deadline for transposition.

**Thus, every Member State (EU-27) has experienced some kind of transposition problems in terms of ‘timing’ or ‘quality’ or both.**

A key finding of this paper is therefore that **all Member States (EU-27) faced transposition problems, for reasons related to late and/or wrong transposition.** Consequently, proper implementation of the directive cannot be expected in practice for the time-being in all Member States.

It is hence recommended by this EIA that the process of transposition of the MWD (from a ‘quality point of view’) be completed as soon as possible in those Member States that are still undergoing ‘non-conformity’ infringement procedures.

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1 This is a set of established evaluation criteria, which generally correspond to those also used by the European Commission in its work on evaluation of EU policies.
2 This conclusion is true for the 27 countries which were Members States of the European Union on the date of expiry of the deadline for transposition of the directive (1 May 2008); it does not, therefore, refer to Croatia, which joined the EU on 1 July 2013. Croatia is the only country which, according to the available data, has transposed the directive correctly and completely in due time. See more details in Table 1 in Part 2 of this study.
3 At least not in the four Member States that are still subject to ‘non-conformity’ infringement procedures as of end of November 2016.
Furthermore, although the Commission has adopted almost all the required implementing measures enabling the practical implementation of the MWD, one key document – the guidelines on inspections – is still missing.\(^4\) The lack of such guidelines is problematic because it may lead (as evidenced by the available data) to differences in the approaches followed by Member States as regards inspections.\(^5\) Thus, if this key element of enforcement is not given uniform application, one could expect that the compliance of operators with the requirements of the directive would also vary across the EU. As a result, the objectives of the directive cannot not be equally achieved in all Member States, i.e. effectiveness may vary from one Member State to another. Furthermore, the lack of a uniform inspections approach across the EU implies differences in terms of compliance and enforcement costs, and hence different levels of efficiency of the implementation of the directive from one Member State to another. This EIA therefore recommends\(^6\) that the Commission should adopt the guidelines on inspections as soon as possible.

The current reporting system under the MWD, and the triennial reporting by Member States under Article 18(1) of the MWD in particular, is not fit for purpose because it does not allow for the full picture of practical implementation to be outlined, monitored and assessed at EU level. More specifically, the data collection tool (questionnaire), which is currently used for reporting by Member States, suffers from several deficiencies. They need to be corrected as a matter of priority and urgency, so as to feed the monitoring and evaluation of practical implementation with reliable data. In this respect, a number of recommendations have been made\(^7\). In particular, given that the reporting on the third implementation period (2014-2017) will start in May 2017, the Commission should take measures to ensure that the exercise will not follow the proven deficient reporting system and that it will be synchronised with its fitness check initiative aimed at improving monitoring and reporting of EU environmental (including waste) policies.

The available data indicates that the majority of Member States have adopted the measures needed to implement the provisions set out in the directive. However, the practical implementation of the relevant provisions on permits and inspections

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\(^4\) It should be noted, however, that in 2001 the European Parliament and the Council adopted Recommendation 2001/331/EC laying down minimum criteria for environmental inspections in the Member States, OJ L 118, 27.4.2001, p. 41-46. It is applicable to any kind of environmental inspections, including to extractive waste facilities.

\(^5\) However, while the availability of guidelines might contribute to achieving a level playing field, it is not in itself a guarantee for uniform application of EU law.

\(^6\) See the details in Part 3 of the EIA study.

\(^7\) See the details in Part 3 of the EIA study.
(in particular, the different approaches followed by the Member States referred to above) is problematic.

This EIA was able to assess implementation only against the relevance, effectiveness and efficiency criteria. While EU legislation on the management of extractive waste in the EU is still relevant to real needs, one could expect that the levels of effectiveness and efficiency across the EU may vary from one Member State to another. Both the effectiveness and efficiency of the reporting exercise are reduced as a result of the deficiencies of the data collection tool.

Furthermore, an integral part of this EIA is an externally commissioned expert 'desk-research' paper, which puts the management of extractive waste in the context of the 'circular economy' concept and gives further insights into currently used extraction and waste management technologies and their possible alternatives.

The study concludes that a 'circular economy' will not obviate the need for mining and gives relevant arguments. It shows that, when changing processes to avoid hazards or reduce environmental impacts, a comprehensive life-cycle impact and cost assessment needs to be done. In terms of currently used extractive and waste management techniques, the majority of the processes discussed are considered mature and safe, provided they are implemented following 'best practice' recommendations. However, for existing operations there may be discrepancies between the implementation as designed and as built. The reasons for this include economic pressures that may lead to 'cutting corners' and an inadequate regulatory oversight redressing such situations. Another reason is that many facilities have existed for years or even decades and were not constructed according to what is considered today as 'best practice'. These may constitute legacy situations that are technically difficult and costly to resolve.

The review of current and anticipated research programmes and projects at EU-level (which can be considered to reflect similar activities at national level) shows a strong focus on resource efficiency, together with the avoidance of mining residues that need to be managed as waste.

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8 See the details in Part 2 of the EIA study.
9 See the details in Part 3 of the EIA study.
10 The study was drafted by Dr. W. Eberhard Falck between February and May 2016, at the request of the Ex-Post Impact Assessment Unit of DG EPRS. It is published under Annex I to this EIA study under the title: 'Exploring the alternatives to technologies involving high environmental and health risks related to the improper management of the waste from extractive industries: Challenges, risks and opportunities for the extractive industries arising in the context of the "circular economy" concept'.
11 Last update: December 2016.
A number of policy options have been identified that can be formulated as objectives to be achieved considering the global economic context.
Introduction

The Mining Waste Directive in its context

Waste from mining and quarrying activities (extractive waste) accounts for 29% of the total waste volume generated in the EU, making it the second biggest waste stream in the EU after waste from construction works (33%). Part of this waste is hazardous, thus involving higher risks for health and the environment.

In 1998 and 2000, major accidents in facilities containing extractive hazardous waste and their negative (also trans-boundary) effects showed the necessity for the management of extractive waste to be regulated at EU level. In 2006, the Mining Waste Directive (MWD) was adopted. It provides measures, procedures and guidance to prevent, or reduce as far as possible, any adverse effects on the environment and human health resulting from the management of extractive waste. The directive lays down more stringent requirements for what are known as 'Category A' facilities, the improper management of which could give rise to 'major accidents', i.e. those leading to a serious danger for human health and/or the environment. While extractive waste accounts for one third of the waste generated in the EU, the directive did not set any targets as regards extractive waste volumes.

The deadline for transposition of the directive expired on 1 May 2008. As from this date Member States are held responsible for ensuring that all requirements of the directive are met.

Extractive waste activities, as well as the waste that they generate, have been of particular interest to the European Parliament (EP) in recent years: several parliamentary questions have been addressed to the European Commission and several citizens' petitions were considered by the Committee on Petitions. Furthermore, in 2010 the European Parliament called for a general ban on the use of cyanide – a chemical often used for the extraction of gold – in mining technologies. In 2012 the EP adopted two resolutions dealing with, on the one hand, the environmental impacts, and, on the other, the industrial and energy

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13 Around 2% according to Eurostat data quoted in Commission report COM(2016)553 on the implementation of the Mining Waste Directive. See the report in detail in Part 2 of the EIA. The different risks related to extractive waste are considered in detail in Annex I to this EIA study.
14 It appears that the majority of Member States have not set up such targets at national level either. See more details in the European Environmental Agency's report 'Waste prevention in Europe - the status in 2014'.
15 EP resolution on a general ban of the use of cyanide mining technologies in the EU of 5 May 2010. In its follow-up response to EP's resolution from 6 July 2010, the Commission declined the Parliament's call for such a ban.
aspects of shale gas and oil, which also fall under the scope of the MWD.\textsuperscript{16} In 2015, a resolution on the lessons learned from the red-mud spill that occurred in Hungary in 2010 identified the MWD as 'an area of particular concern'.\textsuperscript{17}

\textit{The Implementation Report and the European Implementation Assessment}

As part of its scrutiny activities, the ENVI Committee initiated an Implementation Report aimed at assessing the implementation of the Mining Waste Directive. This European Implementation Assessment (EIA) aims at supporting the work of the Committee on its report. It draws its conclusions mainly from the currently available evidence on practical implementation, i.e. the data collected via the official reporting mechanism under the directive together with other external studies commissioned by the European Commission,\textsuperscript{18} as well as petitions submitted to the European Parliament. It should be noted, however, that the available data does not allow for the complete picture of practical implementation to be revealed and assessed.\textsuperscript{19}

\textbf{Part 1} of this EIA study outlines the legal framework of the EU policy on management of waste from extractive industries. \textbf{Part 2} presents the practical implementation of the MWD as revealed by the available data. \textbf{Part 3} analyses the key findings presented in the previous part, and gives recommendations; it also assesses practical implementation against the following criteria for evaluation: relevance, effectiveness and efficiency.

\textit{Extractive waste management in the 'circular economy' concept}

Furthermore, this EIA sheds light on the prospects for mining waste management in the context of the 'circular economy'.\textsuperscript{20} The 'circular economy' is a concept aimed at 'closing the loop' of product life-cycles through greater sharing, leasing, reuse, repair, refurbishment and recycling, and bringing benefits for both the environment and the economy. Although the extraction of primary earth resources

\begin{itemize}
\item \textsuperscript{16} EP resolution on industrial, energy and other aspects of shale gas and oil, and EP resolution on the environmental impacts of shale gas and shale oil extractive activities (both resolutions were adopted on 21 November 2012).
\item \textsuperscript{17} EP resolution on lessons learned from the red mud disaster five years after the accident in Hungary adopted on 8 October 2015.
\item \textsuperscript{18} The relevant studies are publicly available on the European Commission's website.
\item \textsuperscript{19} The quality of reporting in the field of EU environment policies was addressed by the Fitness Check on monitoring and reporting launched by the Commission in 2016, with the aim to identify and improve the current situation by bringing effectiveness and efficiency to the reporting and monitoring process. See the details in Part 2 of the EIA study.
\item \textsuperscript{20} See in particular Annex I to this EIA study.
\end{itemize}
and the management of remaining waste would fit into this concept, the MWD was not scheduled for revision as part of the Commission's 2015 'Circular economy' package. Thus, putting extractive waste management in the context of the 'circular economy' concept was considered important to this EIA, as this policy evolution would affect the way mineral resources are extracted and treated, and hence the way extractive waste is managed, i.e. it would impact on the practical implementation of the MWD.

Therefore, an integral part of this EIA is an externally commissioned, expert 'desk research' paper entitled 'Exploring the alternatives to technologies involving high environmental and health risks related to the improper management of the waste from extractive industries: Challenges, risks and opportunities for the extractive industries arising in the context of the circular economy concept'.

The study, which is published under Annex I to this EIA, gives an overview of the challenges, risks and opportunities for extractive waste management arising in the context of the 'circular economy' concept, taking into account the economic and governance context, in which the extractive industry operates. Furthermore, the study outlines alternatives to technologies involving high environmental and health risks related to the improper management of the waste from extractive industries. It gives particular attention to the costs associated with these alternatives. The paper also reviews completed and ongoing research initiatives aimed at developing technologies reducing the environmental and health risks stemming from the management of extractive waste and optimizing the use of resources.

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21 For example, residues are contained in some types of waste remaining after the use of various mining techniques for the extraction of primary mineral resources; their re-use might be economically and environmentally valuable.

22 However, extractive waste is dealt with in the action plan for the circular economy contained in the package, where the Commission took two main commitments. See more details in Part 2 of this study.

23 Drafted by Dr. W. Eberhard Falck between February and May 2016 at the request of the Ex-Post Impact Assessment Unit of DG EPRS. See Annex I to this EIA.

24 For the extraction of metal ores, industrial minerals and coal.
1. EU policy on extractive waste management - legal framework

Legal regulation is the main policy instrument of EU policy on management of waste from extractive industries. The Mining Waste Directive (MWD), together with several implementing measures stemming from it, constitute the relevant legal framework.

1.1. Background of the Mining Waste Directive

In 1998 and 2000 major accidents involving the spill of hazardous extractive waste occurred in Europe: in Aznalcóllar (Spain), Baia Mare and Baia Borsa (Romania). They had lasting adverse effects on nature, economies and societies and involved significant costs for remediation. These accidents raised concerns as regards the appropriateness of the then available policies, both at EU and national level, to effectively meet the challenges related to the management of extractive waste.

At the time, the management of waste from the extractive industries was subject to national provisions as well as to some EU requirements laid down in several legislative acts in the field of environment. However, they proved insufficient to prevent and tackle the major accidents mentioned above and their effects.

In 2000 the European Commission addressed the raised challenges in a communication, which put forward the idea of the need for a set of minimum harmonised requirements on the management of extractive waste at EU level. In a resolution adopted in 2001 the European Parliament recognised that the major accidents referred to above had revealed the inadequacy of the rules governing the mining industry in the Member States and the candidate countries, and the need to review EU environmental policy to take due account of the mining sector. The EP highlighted that the EU was lacking a coherent and comprehensive legislative framework governing the mining industry and the management of mining waste. It supported the view of the Commission that sector-specific EU rules on mining waste management were needed.

#### References

25 Directive 2006/21/EC of the European Parliament and of the Council of 15 March 2006 on the management of waste from extractive industries and amending Directive 2004/35/EC, OJ L 102, 11.4.2006, p. 15-34. The directive is also commonly referred to as the ‘Mining Waste Directive’ (MWD), a title which has also been used for the purpose of this EIA. However, it should be noted that the directive encompasses waste from all types of extractive activities.

26 The history of major accidents involving extractive waste can be tracked back several decades, with the Aberfan (Wales) and Stava (Italy) accidents occurring in 1966 and 1985 respectively.

27 For example, the then Waste Framework Directive 75/442/EEC.


In 2003, the European Commission put forward a proposal for a directive\textsuperscript{30} on the management of waste from the extractive industries. The main objective of the proposal was to establish a set of minimum harmonised standards aimed at improving the management of extractive waste in the EU, thus ensuring a level playing field across the EU. The proposal covered all sectors of the extractive industry (including quarrying) but did not set targets as regards the volumes of the extracted waste.

The MWD was eventually adopted in 2006 after the European Parliament and the Council of the EU reached an agreement at the conciliation phase of the co-decision legislative procedure. The Committee of the Regions\textsuperscript{31} and the European Economic and Social Committee\textsuperscript{32} adopted consultative opinions.

The directive is addressed to the Member States which should take appropriate measures to ensure that its requirements are met on their territory. The deadline for transposition of the requirements of the directive by the Member States into their national legal orders was 1 May 2008.

1.2. Policy objective and general requirements

Extractive waste is what results from the prospecting, extraction, treatment and storage of mineral resources and the working of quarries and is subject to discards.

The main objective of the MWD is to prevent, or reduce as far as possible, any adverse effects on the environment and any risks to human health resulting from the management of extractive waste.

The MWD requires Member States to:

- take the necessary measures to ensure that extractive waste is managed without endangering human health and without using processes or methods which could harm the environment,\textsuperscript{33} without causing a nuisance through

\begin{footnotes}
\item[32] Opinion of the European Economic and Social Committee (EESC) on the proposal for a directive of the European Parliament and of the Council on the management of waste from the extractive industries from 11 December 2003. In recent years, the EESC has also been active in the field. In 2011, it adopted an own-initiative opinion on the processing and exploitation, for economic and environmental purposes, of industrial and mining waste deposits in the EU. Among other issues, this also addressed the management of extractive waste.
\item[33] In particular, without risk to water, air, soil, fauna and flora.
\end{footnotes}
noise or odours and without adversely affecting the landscape or places of special interest;

- take the necessary measures to prohibit the abandonment, dumping or uncontrolled depositing of extractive waste;

- ensure that the operators of extractive waste facilities take all necessary measures to meet the main objective; this includes the management of any waste facility, also after its closure, and the prevention of major accidents involving that facility and the limiting of their consequences for the environment and human health.

The operators of facilities should use the 'best available techniques' (BATs). BATs represent the most effective and advanced stage in the development of activities and their methods of operation. The MWD does not prescribe the use of any technique or specific technology, as the choice would depend on the technical characteristics of the waste facility, its geographical location and the local environmental conditions. BATs are drawn up by the Commission in the form of a Reference Document, i.e. BREF ('Best Available Techniques' Reference Document).

1.3. Scope of application

As a general rule, the directive covers the management of extractive waste directly resulting from prospecting, extraction, treatment and storage of mineral resources and the working of quarries. However, the directive does not apply in a series of cases, including: waste which is generated by the prospecting, extraction and treatment of mineral resources and the working of quarries, but which does not directly result from those operations; waste resulting from the offshore prospecting, extraction and treatment of mineral resources; and, injection of water and re-injection of pumped ground water. Some of the requirements of the MWD do not apply to inert waste, unpolluted soil resulting from the prospecting, extraction, treatment and storage of mineral resources and the working of quarries, and to the waste resulting from the extraction, treatment and storage of

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34 As, for example, areas falling under the Natura 2000 network of protected nature areas, stretching across all 28 EU countries, both on land and at sea.

35 The Commission adopted the BREF in 2009, OJ: JOC_2009_081_R_0004_01. The document is currently being revised. See more on this in Part 2 of the EIA.

36 The exploration or production of hydrocarbons using high-volume hydraulic fracturing (such as shale gas) also falls under the scope of the MWD. In 2014, the Commission adopted Recommendation 2014/70/EU (OJ L 39, 8.2.2014, p. 72-78), which lays down minimum principles for those Member States wishing to extract such resources. It is complementary to existing EU environmental legislation applicable to the sector, including the MWD.
Member States may reduce or waive certain requirements of the directive for non-hazardous non-inert waste, unless deposited in a 'Category A' waste facility.

The waste falling under the scope of the MWD is not subject to the Directive on the landfill of waste.

1.4. Obligations throughout the life-cycle of a waste facility

The main policy instruments on which the MWD relies for the achievement of its objective are: measures, procedures and guidance.

The following presentation does not necessarily follow the order established by the directive, but rather the logic of the life-cycle of a waste facility: design, construction, management, closure and after closure of a waste facility.

1.4.1. Application for a permit for a waste facility

Before it starts operating, every waste facility under the MWD must first be authorised. The mining waste operator is required to submit an application to the relevant national competent authority. As a minimum the application must contain the following information:

- the identity of the operator;
- the proposed location of the waste facility, including any possible alternative locations;

See more details, in Article 2(3) of the MWD.

Idem.


As a general rule, the Member States should ensure that the extractive waste facilities which were already in operation on 1 May 2008 (the deadline for transposition of the directive) comply with the provisions of the MWD by 1 May 2012. For some waste facilities, the directive sets out other deadlines and derogations, laid down in Article 24.

The competent authority is required to inform the public of the fact that an application for a permit has been submitted, as well as about the modalities of public participation in the procedure. See more details on 'public participation' below.

Furthermore, when a Member State, whose competent authority has received an application for a permit for a 'Category A' facility, is aware that this facility is likely to have significant adverse effects in another Member State, the former Member State is required to submit all relevant information to the latter. This information must also be submitted, if the 'likely to be affected' Member State so requests.
- a ‘waste management plan’ aimed at the minimisation, treatment, recovery and disposal of extractive waste, taking into account the principle of sustainable development;
- adequate arrangements by way of a financial or equivalent guarantee;
- the information to be submitted by the operator under the Environmental Impact Assessment Directive, if such an assessment is required under that directive.

The competent authority must only grant the permit, if it is satisfied that the applicant complies with the relevant requirements of the MWD and that the management of waste does not conflict directly or interfere with the implementation of other relevant waste management plans.

The MWD allows for any permit issued under this directive to be combined with those required by other EI legislation, thus avoiding the unnecessary duplication of information and the repetition of work. So, the details specified above can be covered by one single permit or several permits, provided that all requirements regarding permits (under the MWD) are complied with.

The competent authorities should periodically reconsider, and where necessary up-date, the permit conditions – for example, if there were substantial changes in the operation of the waste facility or the waste deposited, or based on the results of inspections.

The permit issued by the relevant competent authority must contain all the information provided by the applicant, but must also clearly indicate whether the waste facility is of ‘Category A’ or not. This is important given that the facilities under ‘Category A’ are associated with higher risks, in particular, risks of major

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43 Under the ‘Environmental Impact Assessment' Directive, projects related to extractive mining and quarrying activities are mostly covered by Annex II to the directive, i.e. Member States determine whether environmental impact assessment is necessary on a case-by-case basis, or on the basis of thresholds or criteria set by the Member State. In such cases, Member States must take into account certain criteria related to the characteristics and location of the relevant projects, as well as the characteristics of the potential impact.


accidents', i.e. leading to a serious danger for human health and/or the environment.

**Classification of extractive waste facilities under the MWD**

A waste facility shall be classified as 'Category A', if

- a failure or incorrect operation, e.g. the collapse of a heap or the bursting of a dam, could give rise to a major accident, on the basis of a risk assessment taking into account factors such as the present or future size, the location and the environmental impact of the waste facility; or
- it contains waste classified as hazardous under the Directive on **dangerous substances**,\(^{46}\) or
- it contains substances or preparations classified as dangerous under the Directive on **dangerous preparations**.\(^{47}\)

All waste facilities that do not fall under the above scope, are considered as 'non-Category A' waste facilities under the MWD. The classification is made by the competent authorities according to the above criteria.

Given the potentially higher risks for serious danger for human health and/or the environment, the MWD lays down more stringent requirements for 'Category A' facilities.

**1.4.2. Design, construction and management of an extractive waste facility**

*Construction of a new and modification of existing waste facility*

The competent authority must ensure that the operator commits to several requirements when constructing a new waste facility or modifying an existing one. For example, the waste facility must be appropriately designed, constructed, managed and maintained. It must also be suitably located, taking into account the relevant EU or national obligations on protected areas, as well as geological, hydrological, hydrogeological, seismic and geotechnical factors. The facility must also be equipped with relevant documentation and suitable arrangements for regular monitoring and inspections,\(^{48}\) as well as for rehabilitation of the land and the closure and after-closure of the facility.

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\(^{48}\) Furthermore, records of the monitoring and inspections must be kept in order to ensure the appropriate hand-over of information, especially if the operator changes.
Management of a waste facility

Under the MWD, the Member States shall take measures to ensure that the relevant waste facility is managed by a competent person, and that technical development and training of staff are provided. The operator is required to notify the competent authority of any events likely to affect the stability of the waste facility as well as any significant adverse environmental effects revealed by the control and monitoring procedures of this facility. This information must be notified to the competent authorities without undue delay and in any event not later than 48 hours after the events have occurred. If necessary, the operator shall implement an 'internal emergency plan', and follow any instructions given by the competent authorities regarding the corrective measures that must be taken. The costs of all these measures are to be covered by the operator.49

Waste management plans

An important instrument as regards management of waste facilities is the 'waste management plan'. This is drawn-up by the operator and covers the minimisation, treatment, recovery and disposal of extractive waste, taking into account the principles of sustainable development.

Waste management plans reflect the 'waste hierarchy' principle on which EU waste management policy is based. According to this principle, 'waste prevention' is the most desired and 'waste disposal' is the least desired option.

The objectives of the 'waste management plan' are:

- to prevent or reduce the production of waste and its harmfulness;
- to encourage the recovery of extractive waste by recycling, reusing and reclaiming of such waste where this is environmentally sound in accordance with existing EU environmental standards and the requirements of the MWD itself;
- to ensure short and long-term safe disposal of extractive waste.

49 At least once per year, or more frequently, the operator must report to the competent authority all monitoring results thus demonstrating compliance with the permit conditions and increasing the knowledge of waste and waste facility behaviour. On the basis of this report the competent authority may decide that validation by an independent expert is necessary.
The achievement of the above three objectives is subject to concrete actions by the operator. For example, the prevention and reduction of extractive waste, which is the most desired option, should be accomplished by the operator, *inter alia* by considering waste management in the design of the facility and in the choice of the method used for mineral extraction and treatment, e.g. considering the use of less dangerous substances for the treatment of mineral resources. Another option could be putting topsoil back in place after the closure of the waste facility or, if this is not feasible in practice, re-using topsoil elsewhere.

If the extractive waste is to be deposited, which is the least desired option in terms of extractive waste, the 'safe disposal' objective requires that a facility design is chosen, which:

- requires minimal and, if possible, ultimately no monitoring, control and management of the closed waste facility;
- prevents or at least minimizes any long-term negative effects, for example, attributable to migration of airborne or aquatic pollutants from the waste facility;
- ensures the long term geotechnical stability of any dams or heaps rising above the pre-existing ground surface.

The directive also specifies the content of the 'waste management plan'. For example, the plan must specify the classification of the facility ('Category A' or not) and the waste characterization. The plan must contain estimate of the total quantities of extractive waste that are expected to be produced during the

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50 The rules on how extractive waste should be characterized are laid down in Commission Decision 2009/360/EC of 30 April 2009 completing the technical requirements for waste characterization laid down by the MWD, OJ L 110, 1.5.2009, p. 48-51.
operation phase of the facility. It must also describe the operation generating such waste and give information on any subsequent treatment to which it will be subject.

Competent authorities must approve the 'waste management plans', based on procedures decided by the Member States, and monitor their implementation. The 'waste management plan' must provide sufficient information, so that the competent authority can evaluate the operators' ability to meet the objectives of the plan. The plan must be reviewed every five years, and amended, in case of substantial changes to the operation of the waste facility or to the deposited waste itself. The operator must notify the competent authority of any amendments in the 'waste management plan'.

1.4.3. Closure and after-closure of an extractive waste facility

Closure of a waste facility
The closure of a given extractive waste facility may only start if:

- the competent authority has given authorisation for closure of the waste facility at the request of the operator, or
- the competent authority has decided (in the form of a reasoned opinion) that the facility should be closed, or
- the conditions laid down in the permit have been met.

For a waste facility to be considered 'finally closed', four conditions need to be met. They all refer to actions undertaken by the competent authorities, which must have:

- carried out a final on-site inspection, and
- assessed all the reports submitted by the operator, and
- certified that the land affected by the waste facility has been rehabilitated, and
- communicated to the operator their approval of the closure.

After-closure of a waste facility
Under the MWD, the operators have obligations also after the final closure of a waste facility. In particular, the operator is held responsible for the maintenance, monitoring, control and corrective measures of the waste facility during the after-closure phase. The period of this obligation should be determined by the competent authority, taking into account the nature and duration of the hazard.
The operator may be required by the competent authority to control the physical and chemical stability of the waste facility and to minimise any negative effects, especially as regards surface and underground water. The operator is also obliged to inform the competent authority of any events or developments likely to affect the stability of the waste facility as well as any significant adverse environmental effects revealed by the relevant control and monitoring procedures.

Where needed, the operator must implement the 'internal emergency plan' and all other instructions given by the competent authority as regards the corrective measures that need to be taken. All relevant costs must be covered by the operator.

The operator is obliged to report to the competent authority all monitoring results, thus demonstrating compliance with the conditions of the permit. This information is also valuable as regards the knowledge of the waste and the behaviour of the facility holding it. The frequency of reporting is to be determined by the competent authority.

Inventory of closed waste facilities

Every Member State must draw up an inventory of closed waste facilities located on its territory. The inventory must list, in particular, the waste facilities (including abandoned ones) causing serious negative environmental impacts or having the potential of becoming in the medium or short-term a serious threat to human health or the environment. The inventory must be carried out by 1 May 2012, periodically up-dated and made available to the public. The establishment of the inventory could be subject to specific methodologies. The directive requires that the methodologies are developed on the basis of the technical and scientific information which the Member States are required to exchange under the directive. These methodologies are also used for the rehabilitation of the closed (or abandoned) waste facilities listed in the inventory. When used for rehabilitation purposes, the methodologies determine the steps for the establishment of the most appropriate risk assessment procedures and remedial actions having regard to the variation of geological, hydrogeological and climatological characteristics across Europe.

1.5. Other obligations

1.5.1. Prevention measures

Major-accident prevention and information

The MWD lays down requirements as regards the prevention of ‘major accidents’, i.e. those leading to a serious danger to human health and/or environment, whether immediately, on-site or off-site. The rules on ‘major accidents’ prevention and information apply to ‘Category A’ facilities with the exception of those
facilities falling under the scope of the 'Seveso' Directive.\textsuperscript{51} In particular, in order to prevent such accidents and limit their adverse (including trans-boundary) effects, Member States are obliged to identify the major-accident risks, and to take these risks into account in every phase of the life-cycle of the waste facility, i.e. to incorporate the relevant features in the design, construction, management, closure and after-closure of the facility.

In order to meet these requirements, the operator of the 'Category A' facility is obliged to draw up a 'major-accident prevention policy' for the management of extractive waste. The operator must also put into effect a 'safety management system' to implement the prevention policy, and an 'internal emergency plan', which specifies the measures to be taken on site in the event of an accident. Both the prevention policy and the safety management system must be proportionate to the major-accident risks, which the waste facility implies. The operator must appoint a safety manager responsible for the implementation and periodic supervision of the major-accident prevention policy.

The competent authorities are also involved in the prevention of major accidents. In particular, they should draw up the 'external emergency plan' for the respective 'Category A' facility, which specifies the measure that should be taken off-site in the event of an accident.

The main objective of both the external and internal emergency plans is \textit{inter alia} to contain and control major accidents and other incidents, so as to minimise their effects by limiting the damage to human health and the environment.

When a 'major accident' occurs, the operator of the waste facility concerned must immediately provide the competent authority with all the information required to help minimise its consequences for human health and to assess and minimise the extent of the environmental damage. Furthermore, if the 'major accident' involves a 'Category A' waste facility classified as a facility likely to have significant adverse effects on the environment/human health in another Member State, then this information must be immediately transmitted to the latter Member State as well.

Prevention of water status deterioration, air and soil pollution

Under the MWD the operator is obliged to take measures in order to prevent the deterioration of current water status\(^{52}\) as well as the prevention and reduction of dust and gas emissions. The competent authorities must ensure that the latter obligation has been met by the operator. As regards water, the MWD lists several prevention measures that can be taken, such as collecting and treating contaminated water and leachate from the waste facility to the appropriate standard required for their discharge.

Special requirements are laid down with regard to the presence of cyanide in tailing ponds. In particular, the operator must ensure that the concentration of weak acid dissociable cyanide in the pond is reduced to the lowest possible level by using ‘best available techniques’. The MWD sets specific limits, depending on when the facility was granted a permit. Standards on sampling and analysis of weak dissociable cyanide discharged into tailing ponds have also been established.\(^{53}\)

1.5.2. Financial guarantee and environmental liability

Financial guarantee

The MWD lays down requirements for the ‘financial guarantee’, which is required from the operator of the extractive waste facility. This policy instrument aims at ensuring that all obligations under the permit, including the after-closure costs, are covered, and also that there are funds readily available at any given time for the rehabilitation of the land affected by the waste facility, as described in the waste management plan and required by the permit. The guarantee can take the form of a financial deposit, including industry sponsored mutual guarantee funds. It is calculated by the competent authorities based on criteria defined in the directive and is periodically adjusted taking into account any rehabilitation work that needs to be carried out on the land affected by the waste facility.\(^{54}\)

If the competent authority approves the closure of a waste facility, it issues a special written statement releasing the operator from the ‘financial guarantee’ obligation with the exception of after-closure obligations of the operator.


\(^{53}\) CEN/TS 16229:2011, European Committee for Standardization.

\(^{54}\) Guidelines for the establishment of the financial guarantee were laid down in Commission Decision 2009/335/EC of 20 April 2009 on technical guidelines for the establishment of the financial guarantee in accordance with the MWD, OJ L 101, 22.4.2009, p. 25-25.
Environmental liability
The management of extractive waste is also subject to the relevant rules regarding 'environmental liability',\(^{55}\) which at EU level is based on the 'polluter-pays' principle. It aims at preventing and remediating environmental damage by attributing responsibilities to the relevant key players. It relates in particular to two situations: first, where environmental damage has not yet occurred, but there is an imminent threat of such damage occurring (preventive action), and, second, where environmental damage has occurred (remedial action).

1.6. Enforcement

The enforcement of the requirements of the MWD lies with the competent authorities of the Member States.

Inspections by the competent authorities
The competent authorities must inspect the waste facility throughout its life-cycle, i.e. prior to and during deposit operations, as well after the closure of the facility.\(^{56}\) In particular, the inspections must ensure that the operator complies with the conditions of the permit. The frequency of inspections is to be determined by the Member States. The operators are also obliged to keep up-to-date records of all waste management operations. These records must be made available during inspection procedures. When there is a change of operator during the management of a waste facility, the outgoing one must ensure that the incoming operator receives all relevant information and records regarding the facility.

Penalties
The rules as regards the penalties imposed in cases of non-compliance with the requirements of the MWD are to be laid down by the Member States, which must also ensure that the penalties are implemented. The penalties must be effective, proportionate and dissuasive.

1.7. Monitoring and evaluation of the implementation

The monitoring of the implementation of the MWD formally relies on data reported by the Member States. The directive itself does not contain a 'review clause', which means that an evaluation exercise would not be a legal obligation but an \textit{ad hoc} decision of the Commission.


\(^{56}\) According to Article 22(1)(c) of the MWD, the Commission must adopt technical guidelines for inspection.
The Member States are obliged to report on the implementation of the MWD at intervals of three years, starting from 1 May 2008, because, formally speaking, as from this date the transposed directive has started creating legal obligations for the Member States. So far, two reporting exercises have been completed: first reporting period (2008-2011), and second reporting period (2011-2014).

Other obligations for the Member States to report under the MWD refer, *inter alia*, to permits, and to certain events that are likely to affect the stability of the facility (in operation and after closure) and any significant adverse effects revealed by the control and monitoring procedures of the facility.

### 1.8. Public participation

In line with the Aarhus convention, the MWD lays down the modalities of public participation in some of the decision making procedures it establishes. The directive uses two notions: the 'public' and the 'public concerned'. In particular, the 'public concerned' is entitled to participate in the 'permit granting' procedure as well as in the preparation and review of the 'external emergency plans' for 'Category A' facilities. Under these two procedures, the 'public concerned' may be entitled to express comments to the competent authority before the decision is taken. The results of the consultation(s) must be duly taken into account when the relevant decisions on 'permit granting' and 'external emergency plans' are taken by the competent authorities.

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57 For statistical purposes, and, if requested, the information contained in the permit must be made available to the relevant national and EU statistical authorities. Sensitive information of a commercial nature shall not be made public. The information that must be notified to the European Commission is detailed in Annex I to Commission Decision 2009/358/EC of 29 April 2009 on the harmonization, the regular transmission of the information and the questionnaire referred to in Articles 22(1)(a) and 18 of the Mining waste Directive, OJ L 110, 1.5.2009, p. 39-45.

58 This information must first be notified by the operator to the national competent authorities, and then to the Commission. In its turn, the Commission must make this information available to the Member States upon request. Under certain conditions, the Member States must make this information available to members of the 'public concerned' upon their request. The information that must be notified to the European Commission is detailed in Annex II to Commission Decision 2009/358/EC.


60 While 'the public' means virtually everybody (natural and legal persons), the 'public concerned' means those affected or likely to be affected or having an interest in some of the relevant decision-making procedures under the directive.

61 The detailed arrangements for such participation are left with the Member States so as to enable the 'public concerned' to participate effectively.
1.9. Actors involved in the implementation of the Mining waste Directive

As shown above, the key actors involved in the practical implementation of the MWD are:

- the European Commission (ensuring that the directive is correctly and completely transposed by the Member States in due time; enabling the practical implementation of the directive via the adoption of several implementing measures; monitoring the practical implementation of the directive at EU level);

- the operators of facilities (ensuring compliance with the requirements of the MWD);

- the competent authorities of the Member States (ensuring both compliance and enforcement of the requirements of the MWD);

- the public concerned (expressing their legitimate interest in the achievement of the objectives of the directive).

Within the limits of the available data, Part 2 of this EIA makes an attempt to present the practical implementation of the above policy (legal) framework.
2. Implementation of the Directive

This part of the EIA summarises the available data on transposition of the MWD and its practical implementation.

2.1. Transposition of the Mining Waste Directive by the Member States

In this section, the transposition of the directive is considered in terms of 'timing' (i.e. have the Member States transposed the directive within the deadline set by the directive itself), and, 'quality' (i.e. have the Member States correctly and completely transposed the requirements of the directive into their national legal orders).

Transposition of the MWD in terms of 'timing'
The deadline for transposition of the directive by the Member States was 1 May 2008. Almost all Member States (25 out of 27)\(^62\) were late. The Commission launched 25 'non-communication' procedures (Table 1 below), which were subsequently closed upon receipt of the notification for transposition by each Member State concerned. According to Commission information, the last cases of non-communication of national measures transposing the directive (from the 'timing' point of view) were (formally) closed in 2011.

Transposition of the MWD in terms of 'quality'
Once the transposition of the directive at national level had been completed, the Commission assessed the quality of the transposition. Given that almost all Member States were late with the transposition (as shown above), the assessment of the quality of transposition for almost all Member States was also delayed.\(^63\)

According to Commission data, 18 Member States had not correctly and/or completely transposed the directive into the relevant national legal order. For all of them, formal 'non-conformity' infringement procedures were launched by the Commission (Table 1 below). Only six cases were closed after the first step ('letter of formal notice') of the infringement procedure, while the rest (which is the majority of 'non-conformity' cases) reached the second step ('reasoned opinion'). The first cases of 'bad quality' transposition were addressed by the Commission already in 2010 (via the relevant 'EU pilots'),\(^64\) and were gradually closed in the

\(^{62}\) At the date of expiry of the deadline, the EU Member States were 27.
\(^{63}\) It should be noted that, generally, the assessment (by the Commission) as to whether the requirements of an EU directive were correctly and completely transposed by the Member States is a time-consuming process.
\(^{64}\) The 'EU pilots' are pre-infringement procedures aimed at settling problems with the Member States without undertaking formal infringement procedure.
following years. As of November 2016, there are four ongoing 'non-conformity' cases (Table 1 below), for which the Commission has some concerns regarding the 'quality' of transposition.

Table 1: Overview of infringement procedures regarding the Mining Waste Directive

Source of data: European Commission (last update: end of November 2016)

<table>
<thead>
<tr>
<th>Member State</th>
<th>Non-communication</th>
<th>Non-conformity</th>
<th>Bad application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>x</td>
<td></td>
<td>x</td>
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<tr>
<td>Bulgaria</td>
<td>x</td>
<td>open</td>
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<td>Czech Republic</td>
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<td>x</td>
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<tr>
<td>Denmark</td>
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<td>open</td>
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<td>Germany</td>
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<td>Estonia</td>
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<td>Ireland</td>
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<td>Greece</td>
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<td>Spain</td>
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<td>open</td>
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<td>France</td>
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<td>Italy</td>
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<td>Austria</td>
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<td>Poland</td>
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<td>x</td>
<td></td>
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<tr>
<td>Portugal</td>
<td>x</td>
<td>x</td>
<td></td>
</tr>
</tbody>
</table>
### Legend:

- x - the case was closed
- * non-communication - the Member State has failed to notify the fact that it has transposed the directive
- ** non-conformity - the Member State has incorrectly and/or incompletely transposed the directive
- *** bad application - the Member State has badly applied the requirements of the directive

### 2.2. Implementing measures by the European Commission

Article 22, (1) and (2) of the MWD lays down obligations for the Commission to adopt certain implementing provisions related in particular to guidance and standards, for example, on sampling and analysis methods needed for technical implementation of the directive.

So far, the Commission has adopted all implementing measures under Article 22(1) and (2)\(^{66}\) with the exception of the technical guidelines for inspections under Article 22(1)(c). This fact is acknowledged by the Commission in its report on the implementation of the MWD published on 6 September 2016.\(^{67}\)

As pointed in Part 1, a key element in enabling the practical implementation of the MWD are what are known as the 'Best Available Techniques'. These are considered as examples of 'good practices'; the operators of extractive waste

\(^{65}\) As of end of November 2016, DG ENV proposes that the 'non-conformity' infringement against the UK should be closed.

\(^{66}\) For the adoption of some standards (for example under Article 22(2)(a) concerning cyanide), the Commission was supported by the European Committee on Standardization (CEN). In addition, for the adoption of some of the other measures, the Commission relied upon external expertise. For example, an [external report](https://www.eea.europa.eu/publications/2016-06-28-02) provided the necessary technical and scientific information for the preparation of the criteria for classification of extractive waste facilities (under Article 22(2)(d)). The development of technical guidelines for the establishment of the financial guarantee under Article 22(1)(b) was also supported by [external expertise](https://www.eea.europa.eu/publications/2016-06-28-03).

\(^{67}\) See more on the report COM (2016) 553 later in Part 2 of this ELA study. As announced by the Commission on 28 November 2016, during the exchange of views between the ENVI Committee and the Commission on the report in question, the guidelines on inspections are expected to be adopted by 2018.
facilities and the competent authorities should take them fully into account in order to achieve the main objective of the directive. As mentioned earlier, the Commission adopted the 'Best Available Technique' Reference document (BREF) on the management of tailing and waste-rock in mining activities already in 2009.68 The document is currently being revised in the light of new technological developments and challenges in the field69.

2.3. Practical implementation of the Mining Waste Directive by the Member States

As mentioned in Part 1, under the MWD,70 Member States are obliged to report on the practical implementation of the directive. Every three years, the Member States submit the relevant information by filling in a questionnaire71 aimed at checking whether they have met the requirements of the directive.

Within nine months of receiving the answers of the Member States to the questionnaire, the Commission is required to publish a report on the implementation of the MWD for the respective triennial reporting period.

2.3.1. Commission report under Article 18(1) of the Mining Waste Directive

On 6 September 2016 the European Commission published its first report under Article 18(1) of the MWD.72 It covered the first two triennial periods of implementation of the directive: first period (1 May 2008 - 30 April 2011) and second period (1 May 2011 - 30 April 2014).

The key findings included in the Commission report73 are the following:

68 Reference document (BREF) of 4 April 2009 on the management of tailing and waste-rock in mining activities. OJ: JOC_2009_081_R
69 A draft BREF for the management of waste from the extractive industries' was issued by the Commission in June 2016. The process of revision of the BREFs is expected to be finalized in 2017.
70 Article 18(1) of the MWD.
71 See the questionnaire in Annex III to Commission decision 2009/358/EC. The questionnaire is divided in two parts: 'part A' and 'part B'. 'Part A' includes questions that should be answered by Member States once for the first reporting period, and 'Part B' - questions that should be answered during the first and all subsequent reporting periods. Part A should be filled in also for every following period, if there were changes in the information submitted under this part for the first reporting period.
72 COM (2016) 553 final. The report draws its conclusions based on the results of two external studies, which assessed the completeness of the answers submitted by the Member States: i) study for first reporting period (1 May 2008 - 30 April 2011) and ii) study for the second reporting period (1 May 2011 - 30 April 2014).
73 On 28 November 2016 the ENVI Committee of the European Parliament held an exchange of views with the Commission on the report. During the debate, which is available as a video recording, the Commission gave additional details. These are also reflected in the presentation of key findings under this section of the EIA study.
On the quality of data submitted by Member States

The Commission found that the three-year reporting system established under the directive had its limits. The data submitted by the Member States 'is not alone enough to give a clear, sufficiently detailed and reliable picture of the implementation of the directive in practice' (p. 7). The Commission had to use additional sources of information. Member States tend to report what measures were adopted at national level and not how these measures were implemented in practice.

Regardless of the quality of available data under the official reporting mechanism, the Commission identified several deficiencies regarding the practical implementation of the MWD, which are summarized below. A distinction is made between 'Category A' waste facilities, to which stricter requirements apply, and the potential health and environmental risks they would involve in case of accidents, and all other 'waste facilities' under the directive.

On the provisions applicable to all types of facilities under the MWD

According to the Commission, not all figures provided by the Member States as regards the number of facilities, falling generally in the scope of the Directive, are plausible. As shown below, this conclusion holds true also for 'Category A' facilities. This assessment is based on cross-checking with other data sources indicating the volumes of extractive waste generated in the Member States. First, the figures (reported by Member States under the official reporting mechanism) vary significantly from one Member State to another, and, second, they are relatively low compared to the waste volumes generated at national level (as indicated by other sources of information). For instance, six Member States\(^{74}\) have reported that there are no facilities in their territories falling under the scope of the MWD; however, other sources of information confirm that extractive activities do take place in some of these countries and that waste is being generated, including hazardous waste in some cases. Furthermore, apparently, only a small number of facilities covered by the 'Seveso' Directive have been reported as extractive waste facilities.\(^{75}\) Therefore, the Commission concluded that the scope of the directive was not understood and applied uniformly by the Member States.

\(^{74}\) Denmark, Latvia, Lithuania, Luxembourg, Malta and the Netherlands.

\(^{75}\) As clarified by the Commission during the exchange of views with the ENVI Committee on 28 November 2016, a possible explanation for the low level of extractive waste facilities reported by the Member States (i.e. falling under the MWD) is that the permits issued under the MWD may be combined with permits required under other pieces of legislation, in particular, the 'Seveso' directive on the control of major-accident hazards involving dangerous substances. It could be that the non-reported facilities were classified as 'Seveso' installations and not as extractive waste facilities under the MWD. However, according to the Commission, this is an issue that clearly requires further investigation.
Problems were also identified regarding inspections of ‘non-Category A’ facilities. For the Commission, Member States have differing interpretations of the inspection requirements laid down in the MWD. This holds true especially for the measures adopted by the Member States as regards the nature, frequency, arrangements, responsible authorities, and the number of inspections carried out during the second reporting period.

Only a few (seven) Member States have reported on cases of non-compliance (‘bad application’) identified during the second reporting period. The reported cases of ‘non-compliance’ relate mainly to operation of waste facilities without a permit, or failure of the operator to comply with the conditions laid down in a granted permit.

On the provisions on 'Category A' waste facilities
The Commission found that most Member States have adopted general measures to implement the requirements of the MWD as regards 'Category A' facilities. In particular, these measures concern: waste management plans, major accidents prevention and information, and practical measures to ensure the transmission of information. In the second reporting period, there has been an overall improvement regarding the establishment of the measures taken relating to these provisions.

However, according to the Commission, the practical application of national measures needs to be improved in several areas: identification of 'Category A' facilities, preparation of external emergency plans, issuing permits, and inspections.

Ten Member States have reported that they do not host 'Category A' facilities on their territories. However, in some of these Member States hazardous waste from extractive industries is being generated, which means that there could be 'Category A' facilities on their territories. Therefore, according to the Commission, not all Member States have yet finalized the process of identification of 'Category A' facilities.

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76 Bulgaria, Estonia, Greece, Poland, Romania, Finland and the United Kingdom.
77 In addition, during the exchange of views with the ENVI Committee on 28 November 2016, the Commission wondered whether the low figure of ‘non-compliance’ cases is an indication of a high level of compliance or whether situations of lack of compliance were not identified due to insufficient inspections capacity. According to the Commission, this issue would require further investigation.
78 During the exchange of views with the ENVI Committee, the Commission described the implementation gap concerning 'Category A' facilities as 'particularly worrying'.
79 Belgium, the Czech Republic, Denmark, Estonia, Latvia, Lithuania, Luxembourg, Malta, the Netherlands and Austria.
80 The identification follows the criteria laid down in Commission Decision 2009/337/EC of 20 April 2009 on the definition of the criteria for the classification of waste facilities in accordance with Annex III of the MWD.
For the Commission, improvements are also necessary (as a matter of priority) as regards granting of permits in several Member States for all 'Category A' facilities that they are hosting on their territories. Furthermore, the establishment of external emergency plans for this type of facilities has not yet been finalized. According to the reports of the Member States, some 25% of the 'Category A' facilities in the EU do not have such plans, which must be developed by the competent authorities of the Member States and should specify the measures to be taken off-site in the event of an accident.

The information submitted by the Member States also reveals differences in their understanding as regards inspections of 'Category A' facilities and between the regimes followed in practice, especially in relation to the number of inspections, which varies considerably from one country to another.

The Commission came up with the following conclusion as regards both 'Category A' and 'non-category A' facilities: *while most Member States have put a general framework in place, there are still a number of issues to be addressed. Differences between Member States show that further effort is needed to ensure that all Member States understand and apply the basic concepts of the directive in a similar way, in order to guarantee the effectiveness of the provisions across the EU* (p. 6).

**On accidents (during the first two reporting periods)**

According to the Commission, during the first two reporting periods five accidents have occurred in extractive waste facilities hosted by two EU Member States. The Commission considers the reporting of accidents by Member States to be an area associated with implementation gaps. According to the Commission, more information would be needed in order to assess whether the objectives of the directive with regard to the reduction of risks of major accidents have been achieved.

Upon further request by EPRS, the Commission confirmed that the five accidents referred to above happened on the territory of Hungary (one accident) and Finland (four accidents in two extractive waste facilities).81

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81 These five accidents occurred as follows: one accident in Hungary (Ajkai Timfoldgyar alumina near the Kolontár village in Hungary) in 2010, and four accidents in Finland (one in Lappeenranta in 2013, and three accidents in Talvivaara in 2010, 2012 and 2013).

It should be noted, however, that the fact that the Commission is not aware of other (not signalled) accidents does not necessarily mean that other accidents (whether publicly visible or not) have not happened elsewhere.
Main conclusions of the Commission's report and next steps

In general, the Commission found that most Member States have set up the general framework necessary for the implementation of the requirements of the MWD, although more issues need to be addressed. More efforts are needed to ensure that the practical implementation of the adopted measures ensure the achievement of the objectives laid down in the directive as regards the protection of environment and human health. This conclusion holds true for all 'waste facilities' falling under the scope of the MWD, including 'Category A' facilities.

A key issue outlined by the Commission is the lack of uniform interpretation and application of key requirements of the directive, especially as regards identification of extractive waste facilities, granting of permits and inspections. In order to help Member States in implementing the directive consistently, the Commission committed in its report first, to adopt 'guidelines on the implementation of the provisions set out in the directive', and, second, to develop 'guidelines for inspections'.

The effectiveness of the 'three-year' reporting system, including on major accidents, is also questioned by the Commission. It suggests that data could be collected via a different channel, namely via the requirements of Article 7(5) of the MWD, which regulates the transfer of information contained in the granted permits to the relevant national and EU statistical authorities. Collecting further information, on practical implementation would help the Commission in its efforts to:

- support the implementation of and compliance with the directive, in particular by more effectively identifying the gaps in the actual implementation of the directive and designing possible measures to address them;

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82 As announced by the Commission during the exchange of views hosted by the ENVI Committee on 28 November 2016, the Commission intends to adopt both sets of guidelines in 2018. In particular, for the adoption of the ‘guidelines on the implementation of the provisions set out in the directive’ the Commission will seek the cooperation of Member States' experts to identify possible areas where the directive is being interpreted differently by the Member States. For the development of the ‘guidelines on inspections’, the Commission will possibly cooperate with the EU network for the implementation and enforcement of environmental law (IMPEL).

83 As announced by the Commission during the exchange of views with the ENVI Committee on 28 November 2016, a 'compliance promotion' initiative was launched in 2016 to identify gaps in the implementation of the MWD and also to identify best practices in the implementation, which will then be shared by the competent authorities of the Member States. In this context, the feasibility of setting up an inventory of extractive waste facilities is one of the options being explored. Another objective of the ‘compliance promotion’ initiative is to consider how ‘prevention’ aspects have been taken into account in waste management plans.
- identify best practices on the implementation of the MWD.\textsuperscript{84}
- explore new ways to manage reporting and simplify processes, and to envisage, if necessary, amending the current method of data collection,\textsuperscript{85} in line with the objectives of the Fitness Check on Environmental Monitoring and Reporting.\textsuperscript{86}

The Commission intends to consider ways of disseminating the results of its assessment of the information provided by the Member States and promoting the exchange of information on extractive industries, including best practices.

In its ‘EU Action plan for the circular economy’\textsuperscript{87} the Commission announced two initiatives involving waste from extractive industries. In particular, the Commission committed to two targeted actions:

- to include guidance on best waste management and resource efficiency practices in industrial sectors in the ‘Best Available Techniques’ reference documents (BREFs), and also to issue guidance and promote best practices on mining waste, and
- to take a series of actions to encourage recovery of critical raw materials (also from mining waste), and prepare a report including best practices and options for further action.

In this respect, it should be noted that at the end of 2015 the Commission launched a study aimed at giving a comprehensive overview of the implementation of the MWD. Among other things, the results of the study should support the Commission in its ‘compliance promotion’ initiative. According to the latest update from the Commission, an interim report for the study is expected to be presented to stakeholders at a workshop in March 2017 (which is part of the ‘compliance promotion’ initiative). Thus, the study is expected to help identifying targeted actions to improve compliance at national level.

General information on ‘compliance promotion’ is available \url{here}. More details on the scope and timing of the study are given in Part 3 of this EIA.

\textsuperscript{84}See the previous footnote.
\textsuperscript{85}i.e. changes in Commission Decision 2009/358/EC which established the questionnaire. In fact, during the exchange of views with the ENVI Committee on 28 November 2016, the Commission announced that its experience with the reporting mechanisms under other waste directives is not very positive. Therefore, in its ‘circular economy’ package, the Commission has proposed to remove some of the reporting mechanisms, in particular under the Waste Framework Directive, the Directive on packaging and the Directive on landfill. However, the Commission considered that the reporting mechanism under the Mining Waste Directive is needed, because it relates to important elements, especially as regards the reporting of accidents.\textsuperscript{86}

\textsuperscript{86}The ‘Fitness Check on Environmental Monitoring and Reporting’ is a Commission initiative launched in May 2016 under its Better Regulation agenda. Its aim is to reduce administrative burden for Member States and economic operators, and to develop more modern, efficient and effective monitoring and reporting for EU environment policy, including waste management policies. The exercise covers almost 60 pieces of legislation and approximately 170 reporting obligations, including under the MWD. The results of this initiative are expected in spring 2017 when the Commission will publish a communication on the next steps to be taken.

\textsuperscript{87}‘EU Action plan for the circular economy’.
In its report of 6 September 2016, the Commission explained that it is working on preparing guidance and promotion of best practices in the mining waste management plans.\textsuperscript{88}

2.3.2. Other sources beyond the Commission's report under Article 18(1) of the Mining Waste Directive

2.3.2.1. Further cases of bad application

Upon request of EPRS the Commission submitted data on 'bad application' of the directive, i.e. cases in which the Member States have failed to satisfy the requirements of the directive in practice. There were many such cases, which the Commission first addressed with the 'EU pilot' instrument. Most of them were closed when the Commission received satisfactory explanations from the Member States. However, in six cases, the Commission launched formal infringements for 'bad application' (Table 1 above). Two of these procedures are on-going.\textsuperscript{89} As shown in Table 2 below, three of these cases are related to the failure of the respective Member States to draw up and publish an inventory of closed mining waste facilities.\textsuperscript{90} In addition, there is one on-going 'pilot' (i.e. a formal inquiry, following the reception of a complaint) regarding mining in Spain.

<table>
<thead>
<tr>
<th>Member State</th>
<th>Status</th>
<th>Origin</th>
<th>Procedural steps</th>
</tr>
</thead>
<tbody>
<tr>
<td>Belgium</td>
<td>closed</td>
<td>Own initiative of the Commission</td>
<td>Pilot open in June 2012 regarding the failure to draw up and publish an inventory of closed mining waste facilities. Case closed in 2013.</td>
</tr>
<tr>
<td>Germany</td>
<td>closed</td>
<td>complaint</td>
<td>No sufficient evidence for the alleged infringement could be found. Case closed in 2009.</td>
</tr>
<tr>
<td>Spain</td>
<td>open</td>
<td>Own initiative of the Commission</td>
<td>Two letters of formal notice were sent to Spain in 2014 and 2015 regarding saline heaps resulting from potash exploitation in the region of Catalonia. The reply of</td>
</tr>
</tbody>
</table>

\textsuperscript{88} As confirmed by the Commission, during the exchange of views with the ENVI Committee on 28 November, these two initiatives are subject to further work by the Commission.

\textsuperscript{89} As of end of November 2016.

\textsuperscript{90} Other Member States experienced this problem as well and were also addressed via 'EU pilots' which were subsequently closed upon adequate reaction from the Member States concerned.
2.3.2.2. Petitions

Since 2008, the EP Committee on Petitions (PETI) has received almost 80 petitions referring to mining activities with alleged violation of EU environmental law. However, it should be noted that only 28 of these are directly related to the Mining Waste Directive, the implementation of which is the focus of this study.\textsuperscript{92} In one

\footnote{\textsuperscript{91}Case C-104/15, OJ C 146, 4.5.2015, p. 29–30
\textsuperscript{92}The advanced search of the PETI electronic database was done by 'keyword' 'mining', which gives the broadest possible search. As of 25 November 2016, when the PETI electronic database was last searched, the system displayed 79 petitions submitted after 1 May 2008 (when the deadline for transposition of the directive expired and the practical implementation of the directive by the Member States was supposed to start). In total, 28 petitions relate directly to the MWD (i.e. the Directive and in particular its number '2006/21/EC' is mentioned in the relevant 'Notice to Members' which is drafted and regularly updated by the secretariat of the PETI Committee, in order to inform Members on the latest developments regarding the investigations of the alleged violations as long as the petition is open). The other 51 petitions relate to mining activities in general, for which the petitioners allege violation of EU environmental law in general; most of the allegations in this group
case only – Petition 0145/2012 on mining activities in Lapland and the east of Finland (including in the 'Talvivaara' mine) – the allegations of the petitioner were confirmed. In fact, the Commission was already working on the case.

The section below gives more factual information on the Talvivaara case.

Petition 0145/2012 on mining activities in Lapland and the east of Finland

In the 'summary of petition', it is said that the petitioner has serious concerns about the mining activities in Lapland and the east of Finland (including the Talvivaara mining project), which, according to him, pollute water, air and soil in the areas concerned. In his view, a number of the activities take place in 'Natura 2000' protected areas, and others threaten the traditional reindeer culture. The petitioner provides a number of examples of existing and planned mining projects where, among other things, radioactive materials are extracted. He requests an investigation of these activities and the corresponding pollution, especially in 'Natura 2000' areas.

The Commission was asked by the PETI Committee to follow-up on the petitioner's allegations. As of November 2016, the Commission has submitted two follow-up reports – a first one in 2012 and a second one in 2014.

In its first follow-up report of 24 October 2012, the Commission referred to the answers it had given to several parliamentary questions on mining activities in Finland submitted by Members of the European Parliament between 2010 and 2012, as, they provided useful information on the issues for the petitioner, in particular because some specifically referred to the mining activities mentioned in the petition.

of petitions refer to breaches of EU environmental law in general, such as, for example, 'Natura 2000', 'environmental impact assessment' and 'uranium mining' legislation.

Once identified, the relevant 28 petitions were further researched with the following key question: 'Has the Commission confirmed or rejected (in its answer to the PETI request for follow-up information) the allegations of the petitioner(s) as regards breach of the MWD?' In 27 cases, the Commission did not confirm breach of the MWD. In one case only - Petition 0145/2012 - the allegations of the petitioner were confirmed.

93 It should be recalled that, based on the information submitted by the Commission upon EPRS request, Talvivaara is associated with three of the five accidents which have occurred in the EU between 1 May 2008 and 30 April 2014.

The parliamentary questions (and respective answers) refer to: the use of cyanide\(^{95}\), the conversion of the Talvivaara mine into a uranium mine\(^{96}\), and discharges from the Talvivaara mine.\(^{97}\) In its answers to the written questions, the Commission confirmed its follow-up position on the EP resolution of 2010 on the general ban on the use of cyanide mining technologies, i.e. that it does not intend to propose such a ban. As regards Talvivaara (on both conversion to uranium mine and discharges), the Commission declared that it was aware of the situation and that it was already proceeding with the verification of the compliance of these mining activities with the relevant EU legislation. In particular, the Commission has:

- started an infringement procedure against Finland for failure to transpose correctly and completely the MWD\(^{98}\), i.e. a 'non-conformity' infringement procedure. As cross-checked with the Commission answer to parliamentary question E-004384/2012, in the 'letter of formal notice' addressed to Finland on 25 June 2012, the Commission asked the country to clarify how several provisions of that directive have been transposed. In this respect, the Talvivaara mine was mentioned as an illustrative example of possible bad implementation of the Mining Waste Directive resulting from a transposition deficiency;

- asked the Finnish authorities (under an 'EU pilot' enquiry) to provide information on the Talvivaara mine, which would allow the Commission to verify whether the relevant activity should fall under EU directives in the field of environment\(^{99}\), and whether this activity complied with these directives. Having cross-referenced with the answer given by the Commission to Parliamentary question E-004384/2012, should the

\(^{95}\) Parliamentary question E-006197/2012 on the use of cyanide in mines (no specific reference to Talvivaara).

\(^{96}\) Parliamentary question E-1571/2010 on conversion of the Talvivaara mine into a uranium mine; parliamentary question P-003955/2011 on opening a uranium mine without the appropriate permits (which also refers to Talvivaara).

\(^{97}\) Parliamentary question E-004384/2012 on discharges from the Talvivaara mine and the lack of intervention by the Finnish authorities.

\(^{98}\) The Commission first addressed the issue of 'non-conformity' via an 'EU pilot' open in 2010. In June 2012 the 'EU pilot' turned into a formal 'non-conformity' infringement (first step of the procedure with a 'letter of formal notice'), which subsequently turned into a 'reasoned opinion' and was eventually closed in 2014.

information provided by Finland show that the Talvivaara mine might have been authorised and/or operated in violation of EU environmental law, the Commission would then consider launching a legal action.

It should also be noted that in its answer to parliamentary question E-003955/2011, the Commission confirmed that the current operation in Talvivaara relevant to uranium extraction 'meets the MWD'. In its first follow-up report the Commission also addressed the alleged violation of the 'Birds' and 'Habitats' Directives, which, however, are not in focus of this EIA study.

In its **second follow-up report** of 30 July 2014, the Commission informed the PETI Committee that the infringement procedure launched in June 2012 against Finland for failure to transpose correctly the directive has reached its second stage and, in December 2012, become a 'reasoned opinion' to which Finland replied in December 2013:

In addition, as regards the situation in Talvivaara, the Commission referred again to the answers it gave to two parliamentary questions. In particular, the Commission confirmed that it had opened an 'EU pilot' enquiry aimed to ascertain the compliance of the exploitation activities taking place in the mine with the provisions laid down by relevant EU legislation, including of the MWD. Further

100 In fact, the data on transposition submitted by the Commission upon request of DG EPRS, suggests that the 'reasoned opinion' was sent on 23 January 2013.
101 The Commission eventually closed the 'non-conformity' procedure in 2014.
102 Parliamentary question E-004384/2012 on discharges from the Talvivaara mine and the lack of intervention by the Finnish authorities, and Parliamentary question E-1125/2014 on continued environmental permit infringements by the Talvivaara mine and lack of action by the Finnish authorities.
to the accident that occurred at the mine on 4 November 2012, the Commission has requested additional information from the Finnish authorities. According to the Commission, “whilst the Finnish authorities have confirmed the breach of certain permit conditions, these breaches are being addressed by the competent authorities. According to information provided on the relevant permits and their on-going revision, sufficient measures are being put in place by the Finnish authorities to ensure compliance with EC law”\(^\text{104}\). In particular, in April 2014, a new environmental permit was granted for all activities taking place on the site, in accordance with applicable environmental legislation. The permit also covered the requirements under the MWD, notably the obligation to draft a ‘waste management plan’. The gypsum pond has been re-classified under the 'Landfill of waste' Directive\(^\text{105}\). According to the Commission, other measures are being put in place to ensure full compliance with EU law, and in particular: the permit will be reviewed on a triennial basis; regular inspections will be carried out; a 'safety management system' and an 'internal emergency plan' were established and updated in 2012; the requirements of the 'European Environmental Liability' Directive have been complied with; additional sediment monitoring of water bodies took place and the results appeared to cover an appropriate range of substances\(^\text{106}\).

In the light of the above measure taken by Finland regarding Talvivaara, the Commission closed the 'EU pilot' case in November 2013.

However, at its meeting of 18 April 2016, the PETI Committee considered that the Commission and the relevant Finnish authorities should submit more information. The PETI Committee is expected\(^\text{107}\) to proceed further with the examination of the petition once it has received the requested information.

### 2.3.2.4. Implementation of the 'European Environmental Liability' Directive

In April 2016, the Commission published the results of the evaluation of the implementation of the 'European Environmental Liability' Directive (ELD).\(^\text{108}\) The main objective of the ELD is to prevent environmental damage if there is an imminent threat, and to remedy it, if such damage has already occurred.

\(^\text{104}\) As evidenced by Commission’s answer to Parliamentary question E-1125/2014.


\(^\text{106}\) As evidenced by Commission’s answer to Parliamentary question E-1125/2014.

\(^\text{107}\) As at 25 November 2016, when the PETI database was last searched.

In its report covering the period between 2007 and 2013, the Commission concluded that the current situation regarding the establishment of liability systems for preventing and remedying environmental damage by the Member States remains in legal and practical terms diversified, and that further steps would be needed to establish a European level playing field. Given that 'environmental liability' is one of the key obligations of operators under the MWD, one could expect that the implementation of this tool towards the management of extractive waste would also follow diversified approaches across the EU. This points to different results regarding the prevention and remediation of environmental damages from one Member State to another.

2.3.2.5. Implementation of Commission Recommendation 2014/70/EU on hydraulic fracturing

As already mentioned, the management of waste resulting from the exploration and production of hydrocarbons (such as shale gas) using high-volume hydraulic fracturing also falls under the scope of the MWD. In 2014, the Commission published a non-binding recommendation addressed to those EU Member States which would wish to carry out such activities. In particular, the recommendation set up minimum principles, which Member States are invited to follow, if they are authorising such activities.

In February 2016, the Commission published a study assessing how 11 Member States have applied the principles laid down in its recommendations as well as selected EU legal requirements regarding planning, licensing and permitting levels.

The main finding with relevance to the implementation of the MWD is that (some of) the above countries follow divergent approaches when they apply the MWD to the management of waste from the exploration and production of hydrocarbons (such as shale gas) using high volume hydraulic fracturing. In particular, the following elements of the MWD are concerned: the definition of extractive waste, waste facility, and extractive waste legislation applied to underground injection of waste for disposal.

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109 At least those covered by the studies that supported the work of the Commission on its report.
110 These Member States are: Denmark, Germany, Spain, Lithuania, Hungary, Netherlands, Austria, Poland, Portugal, Romania, and the United Kingdom. In their responses they confirmed that they have granted or were planning to grant authorisation for the exploration or production of hydrocarbons that may require the use of high-volume hydraulic fracturing (in onshore and/or offshore operations). At present, based on available information, there is no on-going commercial production of hydrocarbons using high-volume hydraulic fracturing in the EU.
111 Those for which information was available. See in details pp. 49-51 of the report.
3. Key findings and recommendations: Final assessment of implementation

This part analyses the key findings presented in the previous part, and gives recommendations. It also assesses practical implementation against the following criteria for evaluations: relevance, effectiveness and efficiency.

3.1. Key findings and recommendations

3.1.1. As regards the transposition of the Mining Waste Directive by the Member States

Finding

- The full practical implementation of the MWD was delayed by transposition problems

The deadline for the transposition of the directive into the national legal orders of the Member States expired on 1 May 2008. However,

- transposition (in terms of 'timing' ('non-communication')) was delayed in 25 Member States, and completed only in 2011;

- furthermore, 18 Member States experienced problems in terms of 'quality' ('non-conformity') because they failed to correctly and completely transpose the directive, including the two Member States that were on time with the transposition; more specifically, almost nine years after the deadline for transposition has expired, the correct transposition of the directive has still not yet been completed by four Member States.

Thus, every Member State (EU-27)\textsuperscript{112} has experienced some kind of transposition problems in terms of 'timing' or 'quality' or both.

Therefore, a key finding of this paper is that all Member States (EU-27) faced transposition problems, for reasons related to late and/or wrong transposition. As a consequence of this situation, proper implementation of the directive cannot be expected in practice for the time being in all Member States.\textsuperscript{113}

\textsuperscript{112} This conclusion holds true for the 27 countries which were Members States of the European Union on the date of expiry of the deadline for transposition of the directive on 1 May 2008; it does not therefore refer to Croatia, which joined the EU on 1 July 2013. Croatia is the only country which, according to the available data, has transposed the directive correctly and completely in due time. See more details in Table 1 in Part 2 of the study.

\textsuperscript{113} At least not in the four Member States that are still under 'non-conformity' infringement procedures as per end of November 2016.
**Recommendation**

- It is recommended that the process of transposition of the MWD (in terms of 'quality') is completed as soon as possible in the four remaining Member States, thus ensuring a 'level playing field', i.e. that the same requirements are applied in all Member States.

**3.1.2. As regards the practical implementation of the Mining Waste Directive - adoption of implementing measures by the European Commission**

**Finding**

- The lack of guidelines on inspections at EU level may hamper the effective and efficient implementation of the MWD

The Commission has adopted most of the implementing measures as required by Article 22 of the MWD, and has thus made it possible for several of the requirements of the directive to be practically implemented. However, the Commission has not yet adopted the guidelines on inspections as required by Article 22 (1)(c).114

As witnessed by the triennial reporting under Article 18(1) of the directive, the Member States follow different approaches as regards inspections. This may also be due to the lack of guidelines on inspections at EU level, which, if available, would contribute to the uniformity of the approaches followed by the Member States, and, hence, to a level playing field across the EU. If inspections, as a key element of enforcement, are not given uniform application, it is to be expected that the compliance of operators with the requirements of the directive may also vary across the EU. As a result, the objectives of the directive cannot be equally achieved by all Member States, i.e. effectiveness varies from one Member State to another.

Furthermore, no level playing field can be ensured across the EU, especially as far as the operators of extractive waste facilities are concerned. More stringent and frequent inspections in some Member States would imply higher compliance costs for the operators of extractive waste facilities hosted on their territory than for the operators active in Member States.

114 It should be noted that the MWD does not set deadlines for the adoption of these guidelines, so the Commission is not in breach of the directive. Furthermore, as already mentioned, there is a general Recommendation (2001/331/EC) applicable to all types of environmental inspections, including inspections of extractive waste facilities. This document was subject to review, which might have affected the Commission's agenda on the adoption of the specific guidelines under Article 22 (1)(c) of the MWD on inspections of extractive waste facilities.
States where inspections are less frequent. The same holds true for the enforcement costs for the competent inspection authorities. Thus, the lack of a uniform inspections approach across the EU implies differences in terms of compliance and enforcement costs, and hence different levels of efficiency of the implementation of the directive across Member States.

Although the Commission has not yet adopted the guidelines on inspections, some preparatory work has been done by DG ENV.\textsuperscript{115}

**Recommendation**

- The Commission should adopt guidelines on inspections as soon as possible

The implementing measures under Article 22(1)(c) should be adopted as soon as possible. This would allow for a uniform approach on inspections to be followed by the Member States, thus contributing to uniform enforcement and compliance of the directive by competent authorities and operators of facilities, and similar level of effectiveness and efficiency as regards the achievement of the objectives of the MWD.

One should note the commitment made by the Commission in its report of September 2016 to adopt the guidelines on inspections. Subsequently, the Commission announced\textsuperscript{116} its intention to adopt the guidelines in 2018.

### 3.1.3. As regards the practical implementation of the Mining Waste Directive - reporting on the implementation of the Mining Waste Directive by the Member States and the Commission

**Finding**

- The reporting system under Article 18(1) is not effective and efficient

The current reporting system under the MWD, and in particular the triennial reporting by Member States under Article 18(1) of the MWD, is not fit for purpose because it does not allow for the full picture of practical implementation to be outlined.

\textsuperscript{115} In 2007, a first piece of external expertise was delivered by an external contractor, including a few recommendations. In 2012 a report was submitted by external contractors; Annex II to that report contains draft guidelines for inspections. In fact, the 2012 report delivered expertise on other elements falling under the scope of the MWD, namely, on inventory and rehabilitation of abandoned facilities (under Article 20 of the directive), and on review of the BREFs on the management of tailings and waste-rock in mining activities. See more details on DG ENV webpage on mining waste.

\textsuperscript{116} During the exchange of views with the ENVI Committee on 28 November 2016.
Furthermore, the current reporting system does not allow for assessment of implementation because its design does not reflect the set of key assessment criteria for evaluation: relevance, coherence, European added value, effectiveness, efficiency.

Thus, on the one hand, the reporting exercise is not effective (practical implementation could not be outlined and assessed), and, on the other, it creates unnecessary burden for Member States and the Commission services, which goes against efficiency.

Furthermore, additional research was launched by the Commission to compensate for the limits of the current reporting system;\textsuperscript{117} such activity costs money and therefore also fails to contribute to efficiency.

In its report on implementation, the Commission has made its approach towards reforming the reporting system under the MWD subject to the objectives of the fitness check on environmental monitoring and reporting launched in May 2017. It should be noted, however, that the fitness check results, and the relevant next steps, will be published only in the spring of 2017 when Member States will start reporting on the third implementation period (2014-2017). This creates a certain risk that the reporting exercise might again follow the deficient reporting mechanism. Furthermore, changing the questionnaire (if this were to be the approach adopted by the Commission) would take time.\textsuperscript{118}

**Recommendation**

- **The current reporting system should be improved as a matter of priority and urgency**

In the perspective of maintaining a reporting mechanism under the MWD\textsuperscript{119}, and as envisaged by the Commission in its fitness check initiative, the reform of the reporting system should seek effectiveness and efficiency.

It should be changed in such a way as to allow for practical implementation of the MWD to be assessed against the set of ‘key

\textsuperscript{117} See more on this below.

\textsuperscript{118} The adoption of the questionnaire was subject to a ‘comitology’ procedure, i.e. it involved the participation of a committee of Member States’ experts, which has given an opinion on the draft questionnaire and has influenced the process of its adoption. Thus any amendment of the questionnaire would again involve the participation of Member States, and would take time.

\textsuperscript{119} During the exchange of views with the ENVI Committee on 28 November 2016, the Commission expressed the view that the reporting mechanism under the MWD is needed.
assessment criteria’ for evaluations: relevance, coherence, European added value, effectiveness and efficiency.

However, gathering the full picture of implementation and its assessment would require data to be collected not only from Member States (to which the directive is formally addressed), but also from all relevant stakeholders: i.e. those with legal obligations under the MWD, but also those having a legitimate interest in the achievement of its objectives.

Given that the results and next steps on the fitness check on monitoring and reporting are expected in spring 2017, when Member States will start reporting for the third implementation period under the directive, the Commission should make sure\(^\text{120}\) that the third reporting exercise does not follow the current, deficient reporting system, and will be duly synchronised with the results and new monitoring and reporting approach to be taken (as from spring 2017) under the fitness check.

Finding

- Deficient data collection tool (questionnaire) under the MWD

(i) The questionnaire leaves room for different interpretations by the respondents (Member States)

Although the questionnaire aims at identifying practical implementation, i.e. specific 'measures/actions taken' to meet the requirements of the directive, the results from the two reporting periods show that Member States have reported on the adoption of measures at national level and not on the execution of these measures in practice. This means that the questions leave room for interpretation, which does not always go in the required direction; this is the case, for example, as regards reporting on inspections.

(ii) The questionnaire does not oblige the Member States to report on extractive waste facilities under the MWD

The Commission found that not all figures provided by the Member States, as regards the number of facilities falling generally under the scope of the MWD, are plausible. This assessment was made based on discrepancies in the number of extractive waste facilities (falling under the scope of the MWD, including 'Category A' ones) reported by Member States, and the\(^\text{120}\) It should be recalled that Member States would also be involved in the amendment of the questionnaire.
volume of extractive waste (including hazardous waste) generated in the EU. Therefore, the Commission concluded that the scope of the directive was not understood and applied uniformly by the Member States. It also found that not all Member States have yet finalized the process of identification of ‘Category A’ facilities.

The above discrepancies in figures are not surprising, given that there is no formal obligation for the Member States to report on facilities. The relevant question in the questionnaire leaves to the discretion of the Member States the decision as to whether to report or not.\textsuperscript{121} So, formally speaking, one cannot expect that Member States, first, will report at all, and second, if they do decide to report, that the picture they provide will be accurate, since the question only requires submission of ‘estimations’ of numbers. Therefore, what appears to be a ‘lack of understanding of the scope of the MWD’ and ‘unfinished process of identification of “Category A” facilities’, might be due to the deficiencies of the questionnaire, which does not oblige the Member States to provide exhaustive data. Furthermore, Member States are not required to indicate the location of the facilities on their territories or to provide the names of the relevant operators. Nor are they required to locate the facilities where ‘non-compliance’ (‘bad application’) was detected (by the inspectors). These deficiencies in the questionnaire do not ensure transparency, and do not allow for the full picture of implementation to be revealed, thus making monitoring and assessment of the implementation difficult, if possible at all. In particular, the questionnaire does not allow for an EU database/inventory of extractive waste facilities to be created. As a result, the facilities located on EU territory cannot be monitored at EU level, and hence the practical implementation of the MWD cannot be fully outlined and assessed.

(iii) The submitted data is not always up-to-date

The data provided is not always up-to-date; this is the case, for example, with regard to the links to some national inventories of closed and abandoned facilities that are not regularly maintained.\textsuperscript{122}

Recommendation

- The data collection tool (questionnaire) should be improved

\textsuperscript{121} Part B, question 1 (b). ‘If possible, … please provide an estimate of the number of extractive waste facilities on the territory of the Member State’. Again, it should be remembered that the questionnaire was adopted under a ‘comitology’ procedure, involving the Member States. How exactly the wording of this question has been amended and agreed is subject to further research.

\textsuperscript{122} Finding of the study assessing the national reports for the second reporting period (p. 84).
(i) The questionnaire should not allow for different interpretations

The tool should not allow for ambiguous interpretations to be made by the respondents. In this respect the development of ‘fill-in’ instructions accompanying as a minimum all the questions which have generated misunderstandings during the first and second reporting exercise, might be appropriate. For example, as regards inspections, the questionnaire should be revised in a way as to require, without ambiguity, that the Member States report the actual number of inspections that have been carried out and not the number of inspections that should be executed as required by law. Furthermore, Member States should be obliged to indicate the location of the facilities where non-compliance was detected. The current ‘fill-in’ instructions attached to the table included in the annex to the questionnaire also need to be revised.

In particular, given that the third reporting exercise will start as from 1 May 2017 (and probably before the next steps due under the fitness check are completed), the development of ‘fill-in’ instructions might be instrumental in improving the reporting for the third reporting period, at least as regards avoiding misinterpretations of the questions.

(ii) The questionnaire should oblige the Member States to report on extractive waste facilities

Member States should be obliged to report exhaustive and reliable data on extractive waste facilities hosted on their territories, including the location of facilities where inspectors have detected non-compliance. As a minimum, this data should include the following elements: location of the waste facilities, name of the operators, the category of the facility, the type of waste deposited, the status (in operation', 'in closure', 'after-closure', 'abandoned'), the number of inspections done per year of the relevant facility, as well as a short summary of the key findings of the inspectors on compliance. The suggested approach would allow for a database of extractive waste facilities in the EU to be established which would facilitate the monitoring and evaluation of the practical implementation of

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123 Recommendation of the study assessing the national reports for the second reporting period (p. 83).
124 i.e. the table where data on facilities is to be filled-in, if the member states do decide to report this information. See in details Annex III to Commission decision 2009/358/EC.
125 Recommendation of the study assessing the national reports for the second reporting period (p. 83).
126 As announced during the exchange of view with the ENVI Committee on 28 November, the Commission will explore the feasibility of establishing an inventory of extractive waste facilities, which would deserve a positive assessment.
the MWD. This would also raise transparency. Therefore, if the questionnaire is to undergo changes, the possibility of using it as a tool to create and easily up-date such a data-base should be given consideration.

The idea of the Commission on data collection via a different procedure (i.e. reporting of data contained in the permits granted by the competent authorities under Article 7(5) of the MWD), could also be considered an appropriate solution to the current situation as regards reporting on facilities.

(iii) The questionnaire should ensure that only up-to-date information is submitted

For example, the wording of the question related to national inventories of closed and abandoned facilities should clearly require that only the link to the current version of the inventory is provided by the respondents.127

(iv) Other recommendations

In terms of further extending the information collected via the questionnaire, Member States should indicate the approaches that they follow to integrate extractive waste facilities and EU water legislation.128

Finding

- Irregular reporting by the Commission

Based on the responses given by the Member States to the questionnaire under Article 18(1) of the MWD, the Commission should publish a report to inform the public on its implementation. This report should be published after the completion of each three-year period of implementation. So far, two reporting periods have elapsed but the Commission has published129 only one report covering both the first and the second reporting periods.130

The fact that the reporting under the questionnaire does not bring the necessary data on practical implementation was known by the Commission already at the end of 2012 when the study assessing the completeness of Member States' reports for the first reporting period, and its

127 Recommendation of the study assessing the national reports for the second reporting period (page 83).
128 Ibid (p. 83).
recommendations on further research, were available. However, the Commission did not publish a report on the implementation of the MWD for the first reporting period, as required by the directive, thus losing precious momentum for reviewing, and duly reforming, the system for the second reporting exercise which started in May 2014. It is true that the findings from the first reporting exercise came far too late for the Commission to meet the deadlines for the publication of its report. It is equally true, however, that the Commission could have published its report with a delay, instead of skipping the obligation under the MWD, and leaving the public without information as regards this economic activity which has significant environmental, health and social implications.

As a result, during the second reporting period, the Member States had to report under the same deficient reporting tool. Although generally improved, the data submitted by the Member States was again not fit to outline the full practical implementation of the directive. Therefore, in order to compensate for the deficiencies of the official reporting system, at the end of 2015 the Commission launched an external study aimed at providing a comprehensive overview on the practical implementation of the MWD. Thus, the ineffectiveness of the current reporting system, which has proven its inadequacy twice, has involved further costs, which also goes against efficiency. It is not clear though, from the information available, whether this piece of research would allow for evaluation of the

131 The final report under the study assessing Member States’ answers for the first period was available already in December 2012, as evidenced by its cover page. According to the authors of the study: ‘A more in-depth analysis requires to go much beyond the national implementation reports (i.e. the responses to the questionnaire), because in fact they in general only show what Member States’ national provisions are requiring operators and state institutions to do in order to comply with the MWD – but not whether the national requirements are met in reality. Such an analysis would require, first, an in-depth investigation of the national administrative, legal and enforcement practices, and therefore, second, analyses of various different sources of information including academic and civil society knowledge (NGOs) by means of literature and document review as well as interviews. However, such an analysis was beyond the scope of this project.’ (p.10).

132 Delays in the publication of such reports are witnessed in other cases, for example the Commission report under the 'European Environmental Liability' Directive.

133 The scope and research tasks of the external study were presented by the external contractor during a meeting of the Commission ‘Expert group on waste (Mining Waste Directive)’, which took place on 21 March 2016. The scope is presented below on the basis of the PowerPoint presentation made by the external contractor during the meeting. In particular, the study aims at indicating possible difficulties in the directive’s implementation and, if possible, establishing the root causes. The study addresses the specific provisions relating to the management of ‘Category A’ facilities, the use of cyanide technologies, the stability of tailing dams and ponds, as well as the reprocessing of mining waste. The results (to be finalized by mid-2017) should allow the Commission to prepare the necessary measures to support the implementation process (e.g. through compliance promotion exercises, drawing up of best available techniques and best practices, etc.).
practical implementation against the standard set of key assessment criteria for evaluations: relevance, coherence, European added value, effectiveness and efficiency.

Recommendation

- The Commission should comply with the requirements of the MWD as regards reporting under Article 18(1)

As long as the current reporting system is in place, the Commission should stick to its obligation\(^ {134} \) to report on the implementation of the MWD after the completion of each implementation period (even if it is published behind schedule),\(^ {135} \) which would allow for measures for improvement of the reporting system, and practical implementation itself, to be taken in due time.

3.1.4. The practical implementation of the Mining Waste Directive by the Member States

Finding

- As regards the implementation of provisions applicable to all facilities (including 'Category A' facilities)

The majority of Member States have adopted the legal measures needed to implement the provisions set out in the directive.

However, whether extractive waste facilities are adequately identified/classified, especially as regards 'Category A' facilities which involve higher risks, is indeed an important question with implications for the practical implementation of the directive: if a waste facility was wrongly classified as not falling in the scope of the MWD, or not falling in the right category of facility under the MWD (i.e. 'Category A'), it would mean that, in practice, this facility would not be subject to the more stringent requirements of the MWD applicable to 'Category A' facilities, with all the risks and safety consequences that this would involve.

Furthermore, the practical implementation of the following aspects is problematic:

- Member States have adopted different approaches on inspections, especially as regards their nature and frequency, as well as

\(^ {134} \) Under Article 18(1) of the MWD.

\(^ {135} \) As was the case of the report of 6 September 2016 (COM (2016)553), which according to the MWD, had to be published by the end of October 2015.
arrangements, responsible authorities, and the number of inspections carried out during the second reporting period.

- In some cases, operators fail to comply with the conditions laid down in the granted permits, or some facilities operate without permits;\(^{136}\) for 'Category A' facilities the problem refers to issuing of permits for 'Category A' facilities by the competent authorities.

- External emergency plans are missing for around 25% of the 'Category A' facilities.

**Recommendations**

- **The Member States need to address the above issues as a matter of priority**

  Further research with focus on the level of completeness of the process of identification/classification of extractive waste facilities (especially those of 'Category A') located on EU territory is necessary, as indicated by the Commission itself. This new knowledge would help the process of finalizing the adequate classification of extractive waste facilities under the MWD, which is a *sine qua non* for genuine practical implementation of the directive. Proper identification of facilities would also allow for due monitoring and evaluation at EU level of the practical implementation of the requirements of the directive.

  For the sake of uniformity of inspections, the Commission should adopt the guidelines on inspections, as required by Article 22(1)(c), as soon as possible.

  The competent authorities should adopt external emergency plans for 'Category A' facilities wherever they are still missing.

**Finding**

- **Insufficient institutional capacity for practical implementation of the directive\(^{137}\)**

  The institutional resources of some Member States' competent authorities are not always sufficient, especially as regards the remits of the different competent authorities operating at national level, staff, etc.

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\(^{136}\) The finding is relevant for the second reporting period.

\(^{137}\) Finding of the study assessing the national reports for the second reporting period (p. 77).
**Recommendation**

- **Member States' institutional capacity needs to be enhanced**

  The institutional capacity of Member States necessary for the correct practical implementation of the MWD should be enhanced, with focus on human and financial resources, as well as on the strict division of competences between the various authorities implementing the directive in a Member State. Enhancing the institutional capacity of competent authorities would improve the practical implementation of the directive.

  In this respect, the idea of the Commission to issue general guidance on the implementation of the directive would deserve a positive assessment, because it would give valuable help to competent authorities and their staff.

**Finding**

- **There are several initiatives aimed at cataloguing permitted mining facilities at local or regional level, but not extractive waste facilities**

**Recommendation**

- **Existing databases should be extended to cover extractive waste facilities**

  Databases (especially those funded by the EU) in the field of mining should be extended to cover not only mining facilities but also extractive waste facilities; for example, the EU funded **MINERALS4EU** portal could be upgraded to provide geo-location data for mining waste facilities with suitable categorization (for example, 'Category A', closed, abandoned, operating extractive waste facilities, etc.).

**Finding**

- **No systematic, pan-European public directory of closed and abandoned mines (or mining waste facilities) exists**

  The research of additional sources also found that no systematic, pan-European public directory of closed and abandoned mines (or mining waste facilities) exists. Information is nevertheless available at national level on closed waste facilities, including abandoned waste facilities, located on the territory of Member States, which cause serious negative

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138 As identified by the study assessing the national reports for the second reporting period (p. 84).
139 The **MINERALS4EU portal** is an EU-funded project in the field of raw materials. It gives a view of the geographical location of mines and deposits throughout Europe.
140 As identified by the study assessing the national reports for the second reporting period (p. 107).
environmental impacts or have the potential of becoming, in the medium or short term, a serious threat to human health or the environment.

**Recommendation**

- The information on best practices on inventories of closed and abandoned facilities should be shared between the Member States.

Finally, the *Opinion* of the European Economic and Social Committee of November 2011 sets out some ideas on the approaches that the Committee considers should be taken towards the management of mining waste with emphasis on closed and abandoned facilities.

### 3.2. Final assessment against the set of key assessment criteria

Based on the above key findings, the assessment against (only) three of the key criteria for evaluation was possible, namely, on relevance, effectiveness, and efficiency.

**Relevance**

As mentioned, the main objective of the MWD is to prevent or reduce as far as possible the adverse effects of the management of extractive waste on human health and the environment. According to Commission data, there were five known accidents on the territories of two countries during the first and second implementation periods. The fact that accidents with adverse (also trans-boundary) effects happen on EU territory means that legal regulation at EU level with the above objective is still relevant.

**Effectiveness**

It could be expected that the lack of uniformity in the 'enforcement' approaches demonstrated by Member States (especially as regards inspections) would lead to discrepancies in the 'compliance' approaches followed by the operators of facilities. As a result, the objectives of the directive cannot be equally achieved in all Member States, i.e. the effectiveness may vary across Member States.

**Efficiency**

The lack of a uniform approach to inspections across the EU implies also differences in terms of compliance and enforcement costs, and hence different

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141 According to Commission sources, complementary information may be provided at the above-mentioned workshop under the Commission's 'compliance promotion' initiative that is scheduled for March 2017.

142 For more details, see section 4 of the opinion.
levels of efficiency of the implementation of the directive from one Member State to another.

Both the effectiveness and efficiency of the reporting exercise are reduced by deficiencies in the data collection tool.

The available data does not allow for the 'coherence' and 'European added value' criteria to be assessed and therefore further research would be necessary.
Conclusion

This European Implementation Assessment showed that Member States (EU-27)\(^{143}\) have experienced problems regarding the transposition of the Mining Waste Directive in terms of 'timing' or 'quality' or both. As a consequence of this situation, proper implementation of the directive cannot be expected in practice for the time being in all Member States.\(^{144}\)

The available data (collected via a deficient data collection tool) is scarce. Thus, on the one hand, the reporting exercise is not effective (practical implementation cannot be outlined, monitored and assessed at EU level), and, on the other, it creates unnecessary burden for Member States and the Commission services, which goes against efficiency. In particular, there is no database on extractive waste facilities at EU level, and such a database could not be created based on the current reporting mechanism. This makes the monitoring of facilities at EU level, and, hence, the assessment of practical implementation, difficult.

Although it appears that the majority of Member States have adopted the measures needed to implement the provisions set out in the directive, the little available evidence demonstrates that there are practical problems with external emergency plans (for 'Category A' facilities), as well as with permits and inspections (for all types of facilities, including 'Category A' ones).

The lack of guidelines on inspections is problematic because it may lead (as evidenced by the available data) to differences in the enforcement approaches followed by Member States. Thus, if this key element of enforcement is not applied in a uniform way, one could expect that the compliance of operators with the requirements of the directive may also vary across the EU. As a result, the objectives of the directive are not being equally achieved in all Member States. Furthermore, the lack of uniform 'inspections' followed across the EU implies differences in terms of compliance and enforcement costs.

Finally, this EIA was able to assess implementation against only the relevance, effectiveness, and efficiency criteria. While EU legislation on the management of extractive waste in the EU is still relevant to real needs, one could expect that the levels of effectiveness and efficiency across the EU may vary from one Member State to another.

\(^{143}\) This conclusion holds true for the 27 countries which were Members States of the European Union on the date of expiry of the deadline for transposition of the directive on 1 May 2008; it does not, therefore, refer to Croatia, which joined the EU on 1 July 2013.

\(^{144}\) At least not in the four Member States that are still under 'non-conformity' infringement procedures as of end of November 2016.
Based on the above key findings the EIA proposed corresponding recommendations.
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Annex I

Exploring the alternatives to technologies involving high environmental and health risks related to the improper management of the waste from extractive industries:

Challenges, risks and opportunities for the extractive industries arising in the context of the "circular economy" concept.

Study
by
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December 2016
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Executive summary

In April 2015, the Committee on the Environment, Public Health and Food Safety (ENVI) of the European Parliament (EP) requested authorisation to draw up an own-initiative implementation report on Directive 2006/21/EC on the management of waste from extractive industries (Mining Waste Directive). This briefing paper supplements the supporting EPRS European Implementation Assessment (EIA) study on the implementation of the Mining Waste Directive. Thus, the results of this combined work should allow the EU legislator to take evidence-based decisions as regards the rules governing extractive waste management at EU level.

Chapter 1 of the study outlines the background, while Chapter 2 details the four Research Questions that were posed, namely:

1 - Which are the mining and milling technologies that would potentially involve high environmental and health risks, if the waste they generate is improperly managed?
2 - Are there technologies, alternative to those identified under research question 1, that would pose lower environmental and health risks?
3 - What funding opportunities are there for research and development of technologies aimed at reducing the relevant environmental and health risks?
4 - What are the challenges, risks and opportunities for extractive waste management arising in the context of the 'circular economy' concept taking a systemic view?

Chapter 3 describes the scope of the study and the methods used.

Chapter 4 discusses the challenges, risks and opportunities of the extractive industries with respect to the management of mining and milling residues. The management of such wastes is put into the context of global supply chains and of taking a systemic view that considers economic and environmental costs. A number of suggestions are made for how the 'circular economy' paradigm could be considered in policy making and regulations on wastes from extractive industries.

Chapter 5 reviews in general the current mining and milling practices and their associated waste management options. It is noted that tailings management facilities pose the greatest risk. However, selection of low-energy environments, strict supervision, and regular inspections can help to reduce the risk of dam failure. Disposing tailings as paste entails higher energy requirements, but reduces the risk of catastrophic outflows. Solid mine residues in general pose lower risks.
Some mineral commodities are amenable to heap- or even \textit{in situ}-leaching, which particularly in the latter case dramatically reduces the amount of waste generated. An often overlooked aspect in mining and milling waste management is that some sites, such as tailings ponds, will require perpetual management and regulatory oversight. Strategies for the respective long-term stewardship are discussed.

Chapters 6, 7 and 8 discuss mineral commodities of interest, either because of the high volumes produced, or because their processing residues are known to be problematic. Where appropriate, strategies to reduce the amount of waste or to make residues more amenable to safe management are highlighted. Here also a systemic view is taken, balancing various types of risks and (environmental) costs. Chapter 9 highlights the difficulty of obtaining reliable cost data for the management of mining and milling residues. A comprehensive cost analysis is difficult due to the difficulty of deconvoluting the various internal and external cost elements. The major problem, however, is the commercial sensitivity of such data, for which reason the industry is reluctant to disclose them on an individual basis.

Chapter 10 provide a comprehensive overview over relevant completed and on-going publicly funded research projects. There is also a considerable body of industry research, but due to its 'commercial-in-confidence' nature, it is difficult to obtain information on it. Based on what is being published in research and professional journals, one can assume that the majority of it is process-related. In general, industry is averse to make step-changes and prefers evolutionary developments to minimise business risks. This chapter also reviews open and future calls for Commission-funded research that may have the scope of having research topics included that are of relevance to the present topic. Points where the future Commission research agenda can be influenced are also pointed out.

The Report is completed by concise conclusions (Chapter 11), a listing of references used (Chapter 12), and a list of abbreviations (Chapter 13).
1. Background

In April 2015, the Committee on the Environment, Public Health and Food Safety (ENVI) of the European Parliament (EP) requested authorisation to draw up an own-initiative implementation report on Directive 2006/21/EC (CEU, 2006) on the management of waste from extractive industries (Mining Waste Directive). The European Parliamentary Research Service is to deliver a European Implementation Assessment (EIA) study to support Members' work on the implementation report.

The Mining Waste Directive (CEU, 2006) provides for measures, procedures and guidance to prevent or reduce as far as possible any adverse effects on the environment, in particular water, air, soil, fauna and flora and landscape, and any resultant risks to human health, brought about as a result of the management of waste from the extractive industries. Major accidents were among the main triggers of the Directive which Member States were obliged to transpose by 1 May 2008.

The directive imposes on Member States the obligation to ensure that the operators of waste facilities from extractive industries take all measures necessary to prevent or reduce as far as possible any adverse effects on the environment and human health brought about as a result of the management of this waste. This includes the management of any waste facility, also after its closure, and the prevention of major accidents involving that facility and the limiting of their consequences for the environment and human health. According to the directive, these measures shall be based, inter alia, on so-called 'best available techniques'. However, the directive does not prescribe the use of any particular technique or specific technology. The use of such techniques should be decided depending on the technical characteristics of the waste facility, its geographical location and the local environmental conditions.

Following incidents involving extractive industry waste management facilities, the European Parliament has expressed its concerns as regards technologies involving high environmental and health risks related to the improper management of such facilities. Against this background and within the context of the on-going ENVI Committee work on the above-mentioned implementation report and on the 'circular economy' package, it has become important to the EP to acquire scientific knowledge on:

- alternative technologies to those involving high environmental and health risks related to the improper management of waste from extractive industries, as well as the conditions and costs related to their usage;
- the opportunities and challenges for extractive waste management arising in the context of the 'circular economy' concept.

This briefing paper supplements the EPRS EIA study on the implementation of the Mining Waste Directive. Thus, the results of this combined work will allow the EU legislator to take evidence-based decisions as regards the rules governing extractive waste management at EU level.
2. Specific questions addressed

This research paper addresses, *inter alia*, the following questions:

**Research Question 1**: Which are the technologies that would potentially involve high environmental and health risks, if the waste they generate - from the prospecting, extraction, treatment and storage of mineral resources and the working of mines - is improperly managed?

- 'Risks' refer to “... any adverse effects on the environment, in particular water, air, soil, fauna and flora and landscape, and any resultant risks to human health, brought about as a result of the management of waste from the extractive industries” (CEU 2006, Article 1).
- 'High' environmental and health risks refer to technologies generating extractive waste whose improper management would lead to major accidents, leading to a serious danger to human health and/or environment.
- 'Improper management' of waste from extractive industries means any activity that does not respect the requirements of Directive 2006/21/EC (CEU 2006). Improper management may involve design flaws in the waste management concept and inadequate implementation, and/or inadequate regulatory control and oversight.

Existing technologies, feeding into the following main extractive waste streams, should be explored and assessed against the 'high environmental and health risks' criterion:

- metalliferous ores
- industrial minerals
- coal mining

**Research Question 2**: Are there technologies, alternative to those identified under Research Question 1, which would potentially involve lower environmental and health risks (compared to the risks involved by the technologies identified under Research Question 1), even if the waste they generate - from the prospecting, extraction, treatment and storage of mineral resources and the working of quarries - is improperly managed?

Alternatives to technologies that may have a 'high' environmental or health risk should be explored, as well as alternatives to all other technologies identified under Research Question 1. In addition, the specific conditions for the use of the technologies identified under Research Question 2 should be explored.
Furthermore, examples on the usage of the identified alternatives (and their particular conditions of use) should be cited.

If available, information on the cost elements related to the use of the identified alternative technologies will be listed and assessed as to their contribution to the overall costs should be quoted as well.

**Research Question 3**: What funding opportunities (including at EU level) are there for research and development of technologies aimed at reducing the environmental and health risks related to the management of the waste from the prospecting, extraction, treatment and storage of mineral resources and the working of mines?

In particular, the results/progress of completed/on-going R&D projects aimed at developing such technologies should be reviewed and summarized.

**Research Question 4**: What are the challenges, risks and opportunities for extractive waste management arising in the context of the 'circular economy' concept taking a systemic view?
3. Scope and methodology of the study

The economic and governance context in which the extractive industries operate are discussed in Chapter 4, as these provide the boundary conditions for current and future developments. This chapter also provides a system view of the extractive industry with respect to Research Question 4. It must be noted that many of these processes take place outside the EU, as mining in the EU has considerably declined over the past decades. The research questions are first addressed by reviewing the processes of the extractive industries and their respective waste management practices from a generic point of view (Chapter 5). Many waste management practices are similar and independent of the actual ore or mineral mined and processes. As hazards, risks and potential impacts from such facilities are similar, they will be discussed in general below, covering waste rocks, tailings, heap leach residues, and in situ leaching (ISL) sites (Research Question 1). Extraction *sensu strictu* and processing are often integrated processes and for this reason it is not feasible to distinguish clearly between mining waste and milling waste. In addition, they often go into the same disposal facilities. This approach was chosen, because many challenges arise independent of the actual resource mined. In Chapters 6 to 8 an overview over each of the relevant mining sectors and their practices in waste management and ensuing hazards and risks is given. The purpose is to understand at which step of the extraction and processing it would be possible to introduce changes that would help to reduce these hazards and risks (Research Questions 1 and 2).

Chapter 9 discusses the cost of waste management and which elements might change as a function of changing processes in mining and milling with a view to make these more benign (Research Question 2).

Chapter 10 discusses the current and near future research landscape and dominant funding opportunities (Research Question 3).

The work on this study was carried out in form of a desk study. For this purpose, the author was able to draw on a rich body of references, 'grey' literature, as well as published academic research, accumulated for FP7 and H2020 projects in the area of minerals raw materials. It should be noted here, that particularly the so-called 'grey' literature, i.e. (research) reports published by various bodies, is of relevance, as it is usually the first tier of writing up experience and for immediate dissemination among the relevant scientific and technical communities. This was complemented by Internet-searches, particular for government and company documents. Wherever possible, Internet-accessible documents were referenced in order to facilitate verification and further information, if required.
In addition, the author was able to draw on a body of literature on mine waste management and mine long-term management that was prepared by himself while working at the International Atomic Energy Agency (IAEA) and the European Commission's Joint Research Centre (JRC) in Petten (NL). These reports were themselves based on extensive searches in the literature and on the results from experts' meetings.
4. Challenges, risks, and opportunities in the extractive industries with respect to waste management

4.1. Resource availability and quality

European mineral resources have been mined for centuries and many major mineralisations have been exhausted. This and increasing costs are among the reasons why a considerable fraction of the European needs are now imported from outside the EU. Utilising the still existing resources, particular for metals, in the EU poses a number of challenges and risks with respect to the management of the ensuing wastes.

In general, mining now has to turn to lower-grade and deeper resources. This results in more material to be extracted to produce the target metal in the case of lower-grade resources and to remove more overburden or construct deeper shafts, producing more waste in the case of deeper resources. In consequence, also the energy expenditure per unit of metal etc. produced increases and, hence, the related CO₂-footprint. CO₂ is a waste that is not actually managed, but currently released into the atmosphere.

Lower-grade ores also mean more effort for crushing and, where feasible, pre-concentration of the ore. A particular challenge to chemical processing is that process-efficiency generally decreases with decreasing concentrations of the target substance. The overall recovery rate in percentage of the total resource decreases as the ore-grade decreases. The lower ore/host-rock ratio means that more tailings will be produced per ton of target metal and this regardless of the milling technology applied.

4.2. Global supply chains

The European Union imports a large proportion of its needs of products from the extractive industry. This in turn means that a large proportion of the mining and milling wastes from mineral raw materials consumed in the EU actually arise outside the EU. In some cases, the materials are mined outside the EU, but processed in the EU, so that the corresponding milling wastes arise in the EU. Examples are iron and phosphate ore that are transported to Europe in bulk.

EU legislation would apply to mining companies headquartered in the EU, even when their mines are outside the EU. This would mean that their mining and milling waste management facilities outside the EU should comply with Mining Waste Directive. In practice, however, local legislation would apply and EU
standards are difficult to enforce. In practice this also means that considerable externalities to raw materials use in the EU can arise in form of risks and impacts particularly in developing and emerging countries, where standards of regulatory enforcement are lower.

When making regulations more stringent, law-makers have to be also aware of potential risk displacement effects. Globally operating companies may choose to move their mining and milling activities (if alternative locations for mineral resources are available) into countries with less regulatory constraints.

4.3. Technology development: collaboration vs. competition

In mining and milling as in other industry a major driver behind technology development are efficiency gains and, hence, cost reductions. This can lead to a significant dilemma in collaborative technology development. While technology development is desirable from a resources conservation point of view and to increase resources use efficiency, such development may be anxiously guarded by companies in order to maintain a competitive advantage. From a resources conservation policy point of view technological innovations have to be diffused fast through an industry in order to prevent their use to maintain or gain competitive advantage by individual companies. In practices, this may be difficult to achieve due to differing capitalisation of companies and other aspects that control the availability of funds for investment.

4.4. Life-cycle cost considerations

Industrial practices typically are the result of optimisation strategies that take into consideration a wide variety of cost factors, such as energy consumption, process materials, management of hazardous substances, waste management, etc. Historically, these cost calculations did not include environmental or societal costs. Thus, for instance the discharge of (fossil fuel-derived) CO₂, hence using the ambient atmosphere as a repository for carbon, was and still is largely free. In recent years, efforts were made to include such 'externalities' into the cost calculations for a wide variety of industrial activities for which inter alia a range of European Commission funded projects were conceived under the umbrella of ExternE (http://www.externe.info/externe_d7/).

It is important to recognise, that addressing any one of the cost elements in an industrial process will induce shifts in the other elements. For instance, technology changes with a view to reduce energy consumption may lead to more waste being generated or vice versa. Such shifts, may also being deferred in time, as higher
costs may arise further down the life-cycle, e.g. due to more difficult to manage wastes. Therefore, it is counter-productive to address only one aspect e.g. that of managing wastes, in isolation. Proposed process changes, e.g. to improve the safety of waste management, have to be assessed over their whole life-cycle and in their context in order to avoid any risk or impact displacement effects. Increasing levels of e.g. geotechnical stability in order to increase the safety of mining residues requires an increase in energy expenditure that may lead to environmental impacts. More stable dams with shallower slopes require more construction materials and will have a larger footprint. This illustrates that costs and benefits have to be weighed over the whole life-cycle of industrial activities such as mining.

Market prices for many mineral commodities are rather volatile and often determined by stock-market speculation. This induces mining and milling companies to approach the introduction of new technologies and processes with great caution. Up-front investments into new processes with a view to potential environmental risk reduction may pose a too high actual economic risk for many operations. There is also a business risk-driven hesitation to upgrade or improve running and stable production processes to obtain incremental benefits only (Chadwick, 2010a).

Ores are complex assemblies of the target mineral and other unwanted materials (gangue) that vary considerably from one mine to another. While certain types of processes are standardised in principle, their actual operational layout and parameters will vary with the ore to be processed. Monitoring and controlling milling processes, therefore, poses significant scientific and technological challenges. It has been recognised in the industry that optimised process control not only allows cost savings due to savings in energy expenditure, process materials used, and improved recovery rates, but also helps reduces the life-cycle environmental footprint of such operations. Much of the current research is, therefore, devoted on process optimisation.

One may also need to note that today's processes in general are very efficient in the recovery of the target mineral resource. Alternative processes with less potential environmental impact are often less efficient and, therefore, less impacts are offset by a less efficient resources use due to process losses.

### 4.5. Mining and circular economy policies

It is evident that mineral resources are limited by the natural endowment of our planet earth. Resources use statistics also seem to indicate that certain virgin mineral raw materials will become scarce, if consumption continues along the
present patterns (e.g. EC, 2010a; Chapman et al., 2013). For this reason increasing the efficiency of using these resources has been advocated over the past several years as one mitigating strategy. This includes recycling and re-use as strategy to support a circular economy paradigm.

For thermodynamic reasons, no process, including recycling, can be 100% efficient. A considerable amount of our materials' use is dissipative (EEA, 2016), resulting in losses to the environment or rendering the materials in a form that will require a considerable amount of energy to e.g. re-concentrate them. Figure 1 is a point in case, showing that in spite of a recycling efficiency in order of 90% over time an exponential loss of material in the anthroposphere occurs that will need to be replenished. Another example are corrosion losses of metals during normal use, e.g. in rusting cars that have to be made up by virgin iron, even, if all cars would be 100% recycled. Thus there will be always systemic losses that have to be replaced by mining of virgin materials. It is also logic, that an economic paradigm that is built on growth requires more materials being brought into the anthroposphere, including more mineral raw materials being mined. Visions for a circular economy try to overcome this development (EMAF, 2015; EEA, 2016).

![Figure 1 The cumulative loss of aluminium from the hard packaging cycle in Flanders over time (from EEA, 2016)](image-url)
As pointed out above, focusing on particular aspects of the life-cycle can be counterproductive, as it does not consider all risks and costs that may arise over the life-cycle and may overlook risk-displacement effects. Therefore, while a circular economy should be a guiding paradigm, costs and benefits need to be adequately balanced. For instance, from an environmental perspective, it would not make sense to travel by car for several kilometres to dispose of glass in a glass-bank. Such things, however, happen, when recycling is promoted without considering other environmental and economic costs within a relevant socio-economic setting. Full life-cycle cost-benefit analyses are required, when promoting changes in behaviour, such as recycling. In particular, energy costs have to be balanced against resources conservation interests.

It also remains an open political, philosophical, and ethical question to what extent policies of circular economy could and should be enforced or fostered through economic incentives (tax rebates or subventions). By coercing industry and consumers towards certain behaviours, we slowly move towards planned economies. If planning was 100% efficient and could foresee all stakeholder behaviours, such economy could be very efficient in terms of resource use. However, historical examples have shown this to be rather hubristic and even counterproductive. A discussion of these issues is beyond the remit of this report. Historically, recycling of certain materials has been part of everyday life and industrial practice before energy became so cheap and industrial processes so effective that it became cheaper to use virgin materials. Today, recycling of certain materials has become common practice again and is widely accepted in many EU Member States. Recycling has also become a global business, some of which however transcends legal boundaries. A variety of recycling industries in emerging and developing countries are built on illegal waste exports from the European Union. The EU has attempted to bar this in the area of waste electrical and electronic equipment (WEEE) by the amended Directive 2012/19/EU (CEU, 2012). Stocks of copper, silver, gold, and other materials are leaving the EU economy in this way and require (part) replenishment by mining.

However, some concepts of bringing unused stocks within society and industry into use again (e.g. EC, 2015; EMAF, 2015) will have a profound impact on our lifestyles, attitudes to material assets, and in consequence on social relations and definition of status within a society. These concepts can be summarized as a call to move from owning assets to renting or buying their services. It is again beyond the scope and remit of this report to muse about ways to implement such concepts and the probability of them becoming implemented in a world-wide context. While in certain Western world countries there may be enough build-up of socio-cultural pressure to make e.g. the ownership of individual cars a taboo, it is unlikely that this will happen among the fast-growing urban middle-classes in Asia, that
already outnumber their peers in Europe and Northern America. Moving from owning to renting and mobilising unused stocks could have indeed significant impact on the need for virgin mineral raw materials being extracted and would entail deep socio-economic changes. While such changes could be envisioned for Europe and certain other developed nations, whether this would have a significant global impact in the longer would be questionable considering the fact that resources use is shifting more and more to Asia in particular.

4.6. Mine wastes in the context of the 'circular economy' paradigm

As will become evident from the discussions in Chapters 6ff., the wastes from extractive industries may hold a considerable potential for further utilisation. Given the fact that mining wastes actually represent a considerable investment in terms of labour and energy as well as a cost in terms of providing for their management, industry does have an interest in utilising such wastes in a profitable way. Whether a waste can be sold off successfully depends on a number of technical and economic factors. It requires the availability of a beneficial use and of a related market, which depends on the respective quality requirements. The cost of supplying this market has to be lower than the alternative waste management costs. The resulting price has to be competitive with other suppliers of the same material, be it virgin or also waste or recycled.

SCOTT et al. (2005) have identified four possible scenarios that could turn mining wastes into viable industrial products:

- (1) the waste becomes a bulk product for a local market with little or no further processing;
- (2) the waste is a low unit-value product and a cost-effective alternative source of a mineral for a local industry;
- (3) the waste is the source for an industrial mineral commodity, traded nationally or internationally;
- (4) the waste contains a high unit-value, rare mineral for which there is a high demand internationally.

Distance to potential markets and the associated energy cost for transporting particularly low unit-value wastes prevent their utilisation in many cases from both, a business economy point of view and for sustainability considerations. Bulk wastes, such as overburden or gangue may find it difficult to find a market that can absorb the arising quantities, though the materials may be of suitable quantity. Unless a particular mine waste is covered by one of the four scenarios, the life-cycle environmental impact assessment will speak against utilisation.
However, economic viabilities are determined by current prices and cost, and not by long-term strategic and resources conservation considerations. Today, policy makers and regulators face the dilemma of how far they can and want to interfere with the prevailing paradigm of a ‘market’ economy. While a comprehensive extraction and utilisation of all (metal) value from an ore would make sense in terms of conservation of resources and minimisation of extracted volumes, it could make a given mine or mill uneconomic in a given price and cost regime. Costs in this discussion would also have to consider indirect environmental costs, such as the CO$_2$-footprint (c.f. Section 4.4). Making ‘comprehensive’ extraction mandatory in a regulatory regime for this reason likely would be counterproductive. It could be, however, formulated as a policy objective.

While ‘comprehensive’ extraction and utilisation of mining and milling wastes may not be commercially viable at a given time, it would seem important from a strategic supply and resources conservation point of view to manage such wastes in a way that renders them accessible in the future. The experience from the rapid scientific and technological development over the past hundred years shows that it is difficult to predict, which elements from the periodic table or which mineral might become of interest in the future. Therefore, it would be difficult to predict, which elemental or which minerals content would warrant the wastes to be managed in a way to render them accessible for future use. Geochemical abundances and other measures of frequency of occurrence or scarcity may serve as guidance. In order to facilitate the use of such potential resources for future generations, it may be of interest to policy makers and regulators to demand appropriate (chemical, mineralogical) analyses of the waste materials to be undertaken by the operator and deposited with a competent authority, such as the geological surveys or the EC-sponsored raw materials databases currently under development (c.f. Section 10.2) – very much like the results of geological investigations, such as drill-core logs would be deposited with the geological surveys. At the same time a three-dimensional map of the deposited material would facilitate later extraction. While segregation of different types of materials during deposition may be required in any case to avoid e.g. the generation of acid drainage (c.f. Chapter 5), it would also facilitate later recovery and thus could be made mandatory (within operational constraints due to available storage space or potential environmental impacts).

Providing for the future accessibility of mining and milling wastes may entail the risk that less stable and long-term safe solutions have to be chosen. Thus, while back-filling in principle is the preferred option for such wastes, it generally makes them practically inaccessible for later extraction, due to the geotechnical risks of re-opening old mine works. Such risks have to be carefully balanced against resource conservation and re-use needs. It will have to be a case-by-case decision.
4.7. Regulations and their enforcement

There exists a comprehensive body of regulations concerning mining and milling covering their environmental and other impacts at the EU and national levels. However, regulatory oversight and enforcement in many cases does not seem to keep pace with actual developments at sites. For this a variety of reasons can be cited, including inadequate governance as a cultural phenomenon in various parts of the world, lack of adequate understanding on the side of regulators, insufficient staffing levels, gradual erosion of capacities of mining regulators as mining activities are reduced in many countries, and others. Mining engineering departments in universities around Europe and many parts of the (western) world have been closed resulting in a lack of qualified new staff in both the industry and regulators. At the same time mine sites remain as legacies and long-term stewardship issues (see below).
5. Mining and milling residue management

5.1. Introduction

Annex III of the Mining Waste Directive (CEU 2006) sets out the broad criteria for determining the classification of waste facilities. Namely a waste facility shall be classified under category A if:

- a failure or incorrect operation, e.g. the collapse of a heap or the bursting of a dam, could give rise to a major accident, on the basis of a risk assessment taking into account factors such as the present or future size, the location and the environmental impact of the waste facility; or
- it contains waste classified as hazardous under Directive 91/689/EEC (CEU, 1991) above a certain threshold; or
- it contains substances or preparations classified as dangerous under Directives 67/548/EEC (CEU, 1967) or 1999/45/EC (CEU, 1999) above a certain threshold.

A report prepared for the European Commission (EC, 2007) discusses in detail the classification of mine waste sites based on the type of waste they receive or have received according to the European Waste Catalogue (EWC, EC 2000).

In general, the management of the wastes is guided by the principle of best available technique (BAT) for a given time and based on a life-cycle risk assessment (CEU, 2006). However, as many facilities already were put into operation well before these principles were formulated, they may not necessarily conform to these. This applies in particular to legacy sites, were operations have discontinued.

5.2. Waste rock dumps

5.2.1. Hazards overview

Overburden, barren rock, and material excavated from shafts, drifts, tunnels, etc. is usually brought to convenient and locations available to the mining company. The location is chosen to minimise transport costs. Deep mines aim to back-fill waste rocks as far as possible in order to avoid the cost of lifting. Depending on the geological structure of the mining area, these waste rocks can be highly variable.

Waste rocks materials are normally not further processed and have a wide size distribution and shape. This makes them geo-technically relatively stable and creates a porosity that provides for good drainage. There are, however, conditions under which these materials can become geo-mechanically unstable. The load imposed onto the underlying strata may exceed their bearing capacity and ensuing failure, which then leads to slope failures in the deposited materials. The slope of
active waste rock dumps is usually much steeper than the natural grade in the area in order to minimise their foot-print. Excessive wetting following periods of high precipitation can render such slopes unstable and prone to rill or gully erosion. As these residues will remain on the surface forever in most cases, re-grading will be needed once a dump becomes inactive. Due to the absence of top-soils, re-establishing of vegetation is difficult and requires special measures to develop a substrate that can support growth. Uncovered residues are also more prone to erosion, which can be a chronic slow process, but add considerably to turbidity and dissolved contaminants downstream.

Uncovered dumps may also give rise to dust formation, particular during dry seasons. The dust may be spread over nearby residential areas and settle on garden- or agricultural land. This dust may be ingested or toxic constituents, such as heavy metals, radionuclides, or arsenic may be washed out and taken up by edible plants.

A further problem is the formation of contaminated drainage waters due to the infiltration of atmospheric precipitation. A variety of minerals are unstable under atmospheric conditions and will begin to weather, mainly to oxidise. Most notable is the weathering of reduced sulfur-bearing minerals, such as pyrite, which leads to the formation of acid rock drainage (ARD). Such acidic drainage waters will lead to the further dissolution of minerals that may contain potentially dangerous elements or compounds, such as heavy metals, arsenic, or radionuclides. Re-vegetation reduces the amount of infiltrating precipitation and, hence, of acid drainage generation.

Solid processing residues, such as slags, may be disposed of in similar locations as mining residues, or in fact together with them.

Deposited materials may also include below-grade ores that have been separated out, but for which the processing is not commercially or technically viable at the time. Price increases of the target commodity may bring these back into the commercial loop. However, in some instances mines or processing plants may have closed before such conditions occur. In this case the below-grade ore piles will have to be treated similar to waste rocks in preparation for closure.

5.2.2. Mitigation

Modern mining methods aim to reduce the amount of unwanted extraction, by more targeted mining. This also results in cost savings, as less energy is required to move the materials from mine. Projects, such as I2Mine (www.i2mine.eu) investigate the technical option for bringing sorting and processing steps underground, resulting in less material to be brought to the surface. As mining has
to proceed to deeper and less rich formations, such strategies are needed in order to limit the amount of waste rock to be deposited on precious land surfaces. Improved sorting will also reduce the amount of material to be processed, thus reducing the amounts of tailings generated, of energy required, and of process chemicals required. Life-cycle (impact) assessments guide the respective research (Chadwick, 2010a).

Early re-vegetation of spoil heaps will reduce the amount of water infiltrated, the build-up of phreatic water tables that may compromise slope stability, reduce surface erosion by water and wind, and hence sediment loads in surface waters and dust generation. Less infiltration and air ingress also reduce the potential for ARD generation. Drainage systems will divert surface waters, collect seepage and eroded material in sediment traps.

Modern industrial societies utilise almost any element from the periodic system and potential ores other than the target one will be recognised. It is, therefore, less likely today that non-target materials of potential value will be dumped as waste. However, we have large quantities of historic mine wastes containing metals and other compounds of potential interest that were of no interest at the time of mining. While the re-working of mining residues is of relevance in the context of resource efficiency, it may meet with social licensing difficulties due to the fact that it re-introduces mining and processing into some areas. Re-working old mining residues would offer the opportunity for better disposal solutions (remediation), while paying (at least partially) for the works by selling the extracted valuable compounds.

It is good practice to keep different materials apart, particularly those of potential economic value in order to facilitate their later inclusion into the economic cycle. Record keeping with the respect to location and volumes deposited will greatly help in such instances.

5.3 Tailings

5.3.1. Arisings and management

Many wet processing procedures require a large surface area for the reactions to take place within a reasonably short time-frame. For this reason ores and other mineral materials are comminuted, i.e. crushed and ground to a fine grain-size, before being subject to the chemical treatment. As increasingly lower-grade, more finely dispersed ores have to be processed, the required grain-size tends to decrease. After processing to extract the target metal etc. a slurry, i.e. the tailings, remains that needs to be disposed of safely. While a slurry has certain handling advantages, i.e. it can be pumped, it poses a number of challenges at the disposal
site and also significant geotechnical risks, as evidenced by recurrent failures of tailings management facilities around the world.

The safety of tailings dams has been a concern for several decades now and this is reflected in a number of organisations, e.g. the International Commission on Large Dams (ICOLD, http://www.icold-cigb.org), and projects sponsored by the UN and the European Commission, e.g. TAILSAFE (http://www.tailsafe.com) addressing the subject. Tailings dams are often operated for years, if not decades and original design specifications may become lost due to staff and/or ownership changes. As a result, dams may be heightened to increase capacity thus exceeding the design specifications and safety margins of the original dam. Dam stability has been a major concern across various industries and extensive studies on their safety have been undertaken (ICOLD, 2001).

Since waste management is an unproductive activity from a commercial point of view, operators understandably seek the least costly option for constructing tailings ponds that is in compliance with the applicable mining and civil engineering regulations (DAVIES et al., 2000; IAEA, 2004b). This also governs the choice of disposal method and disposal site.

The use of natural depressions for tailings ponds is an obvious choice. In hilly and mountainous terrains, often a valley is chosen and blocked off with a dam, behind which the tailings were emplaced.

Sometimes small lakes are used for this purpose (sub-aqueous tailings disposal), or a mined-out pit. The rationale was that the temperature induced stratification of a deep lake, with cold waters remaining at the bottom would prevent the hazardous constituents from entering the biosphere. Keeping tailings permanently under water would also reduce the ingress of oxygen, preventing further generation of acid rock drainage.

Where suitable landscape features are not available, above-ground tailings ponds surrounded by dams ('turkey-nests') have to be built.

An option less often used, at least in certain industries, is backfilling the tailings into underground mines. Given the low solid-solution ratio of tailings, their volume is considerably larger than the mined-out volume, so that a thickening would be required (see below). However, even then only part of the tailings can be backfilled, since the density of the consolidated tailings is always lower than that of the original rock.
5.3.2. Hazard overview

Tailing ponds present a considerable engineering and long-term management challenge (IAEA, 2004b). Figure 2 illustrates the typical hazards associated with tailings ponds. Suitable dam materials and the construction of the retaining dams are important cost factors. Similar to hydropower and irrigation pond dams, these dams are in permanent contact with water and therefore need to be water-proofed. In order to distribute investments over time, dams are often built in stages and heightened according to operational needs. Different strategies to increase the height and minimise the use of additional building materials are used. Thus it is possible to build a new dam partly over the impounded tailings, if their dewatering has progressed sufficiently. An important factor to consider is the load-bearing capacity of the underlying strata. Dams also need to be keyed well into the sole and flanks of the valley in order to prevent them from being pushed out of place by the tailings mass, a typical failure mode. Injection curtains may be needed to prevent the flow of pore-waters around the dam and through the surrounding rocks, thus compromising the keying-in of the dams. Like all earth-dams, tailings dams are vulnerable to earthquakes. The engineered structures of tailings dams require constant monitoring and maintenance to ensure their integrity (IAEA, 2002c).

In the past, tailings ponds were typically built without bottom liners, using the permeability of the underlying ground to aid the dewatering. This means that untreated drainage waters entered the subsurface and reached the groundwater. Today, tailings ponds are constructed with liners and (bottom) drainage systems to collect the drainage water for treatment. A variant to this is the 'pervious surround' system developed in Canada (DONALD et al., 1997). Here the tailings are dewatered and mixed with lime to achieve a permeability lower than the surrounding rocks. This reduces the leaching-out of the material albeit at the expense of an increased energy and materials footprint. While this is feasible for tailings from some high-value metal ores, it is probably not economic for bulk residues, such as 'red mud'.
Certain tailings, e.g. from phosphate rock processing, are also being discharged into the sea, though this practice is at least being discouraged (IAEA, 2003), if not forbidden in many jurisdictions (IMO, 1972ff).

A critical issue to be dealt with for tailings ponds is the water management (ICOLD, 2001). The ponds will receive surface precipitation that adds to the water balance and must be drained. If a tailings pond was constructed in a valley, the water from the catchment area above its location has to be collected and bypassed, rather than led into the tailings pond. The necessary drainages and diversion channels have to be constructed and kept functional. Recent history has also shown that the design base for dimensioning such water management facilities can be an issue. If they are not sufficiently large, they may not be able to capture the large and prolonged storm events we may see in the future in some parts of the world. This will lead to raising water levels in the tailings ponds until the crowns of the retaining dams are overtopped. Failing water management systems, such as bottom drainages, surface water diversions, and decanting systems can lead to rising water levels in both tailings and retaining dams. This in turn can destabilize dams and lead to their structural failure. Constant monitoring water levels within the tailings and the dams, therefore, is an important instrument for early recognition of impeding problems.

Since such dams are not normally designed like coastal dykes with special erosion protection, overtopping will result in fast retrograde erosion and eventually failure.

Figure 2 The challenges to the integrity of a tailings pond (Source: W.E. Falck).
of the dam. This appears to have been the cause of some recent catastrophic tailings dam failures around the world.

5.3.3. Mitigation

While the basis for design specifications for safe tailings dams has been well researched, the actual implementations remains problematic. A well-constructed tailings dam would be as expensive as e.g. a drinking water reservoir of the same size. Therefore, it may be tempting to cut costs in order to improve the competitiveness of the mine/processing plant. Careful inspection by the authorities at all stages of the life-cycle is essential to assure a construction and operation as designed.

The main problem with tailings is that due to the very fine grain-size the solids settle very slowly, in order of years or even decades, so that their natural dewatering is a very slow process. This means that large volumes of tailings ponds have to be provided in which this process can take place. Lack of disposal volume is one incentive to (partially) dewater the tailings at the processing plants. The resulting paste tailings cannot be pumped anymore, but need to be transported to the disposal site by conveyor belts. Thickening the tailings in filter-presses comes at the price of a much higher energy expenditure, but results in a material that is geo-technically much more stable. Failure of the containment will also have less catastrophic consequences. Flocculation and settling can be also accelerated by certain additives, but this comes at the price of larger disposal volumes, as well as higher life-cycle material and energy expenditures. On the other hand, the dewatering in the plant may allow to recover some of the process chemicals and will allow to re-use the process water.

The amount of fines and slimes produced also depends on the comminution technique. Academic and industrial research aims to develop methods to liberate ore particles without crushing gangue unnecessarily. One promising method, for instance, is electro-fracturing (e.g. US Patent US 8840051 B2).

Back-filling tailings into mined-out voids is possible in principle, but requires the construction of isolating dams etc. underground. While slurries are easier to be transported, their emplacement meets with difficulties in horizontal mine workings. Conversely, thickened and paste tailings are more difficult and costly to transport, but could be more easily emplaced in horizontal mine workings. Symonds (2001, p. 44ff.) provides a cost comparison for e.g. potash tailings emplaced into tailings ponds, steeply inclined and sub-horizontal mine workings, which relate approximately 1:4:7. This indicates that bringing tailings back into a mine in many cases may not be an economically feasible option.
5.4. Heap-leaching residues

For low-grade ores the milling processes discussed above may not be sufficiently energy and process materials efficient. Such ores may be put onto so-called leaching pads, i.e. shallow ponds with drainage systems beneath. Depending on the type of ore, the material to subjected to heap-leaching requires less intensive crushing and grinding. Acid or alkaline leaching solutions are continuously sprinkled over the heaps of sub-grade ore, collected and then sprinkled over the ore again until a sufficiently high metal concentration is reached. The pregnant heap-leaching solution is processed into marketable forms of metals.

Leached-out ore is disposed off together with other mine-waste. If the heap-leach pads are not to be used further, the last charge may also be made safe in situ as for other mining residues. Heap-leaching residues in general are somewhat less challenging than many other residues: as the material has already been leached there is little potential for acid drainage generation and compared to tailings the material is more stable from a geotechnical point of view.

5.5. In situ-leaching sites

An alternative to the excavation of metal ores in deep underground or open pit mines is the leaching in situ (ISL). This techniques has been and is applied particularly for the recovery of uranium and copper. An ISL-mine consists of an array of injection boreholes through which the leachant is injected into the ore-body (Figure 3).
Figure 3 The principle of in situ-leach mining (Source: W.E. Falck).

Through another array of boreholes placed outside the injection boreholes the ‘pregnant’ solution is pumped to the surface and the metal value removed. The barren leachant is then re-injected into the ground. The hydraulic layout of the system is made such that leachant cannot escape into the surrounding aquifer. A well screen controls the inflow of groundwater into the mine area and prevents the outflow of contaminated fluids (IAEA, 2001) by maintaining a slight draw-done cone. Depending on the hydraulic characteristics of the material, enhancing the permeability of the ore-body may be required, e.g. through blasting or hydraulic overpressurisation (‘fracking’).

While this technology operates from the surface only, in the past a combination of underground mining and in situ-leaching has been used in German and Czech uranium mines. Hereby blocks (tens of metres of length) of the ore-body were hydraulically isolated by well-screen above and below, blasted to increase surface areas and then leached.

Depending on host rock and ore characteristics either acidic (most common) or alkaline (for carbonate rocks) leaching solutions are used. The leaching process may occur purely by inorganic chemical processes or be microbially mediated. The latter may occur naturally, but may also be stimulated to enhance recovery. The H2020 project BIOMORE (www.biomore.info/, 2015-2018) is aimed at improving this technology to mine lower grade ores.
The advantage of in situ-leaching is that only small amount of waste rock (mainly in the form of drill chippings) are brought to the surface, requiring little effort in waste management. Some wastes will arise in the form of neutralisation sludges from the processing of the 'pregnant' solution and during the closure of the array. The amount of waste water to be managed is also much smaller than in open-pit or even underground mines.

The disadvantage is the potentially long time period required to remediate an in situ-leach array, that is to remove the leachant from the aquifer. There can also be self-enhancing leaching processes that are difficult to stop and that may release non-targeted constituents from the ore or host rock (IAEA, 2005). However, typically, the aquifer within which an ore-body is located may have naturally elevated concentrations of constituents that would be of concern, if the waters were used as drinking or process waters.

5.6. Long-term stewardship

Any man made structure above ground has significant amounts of potential energy stored in it. The second law of thermodynamics mandates that this energy be dissipated unless more energy is spent on maintaining the status quo. In other words, such structures require maintenance for ever (IAEA, 2006b). When designing waste disposal sites it is, therefore, wise to minimise the amount of potential energy stored in them, by going underground, for instance (Figure 4).

![Figure 4](image)
The classical engineering paradigm in waste disposal is to design structures to contain wastes. This inevitably introduces chemical and physical potentials into the environment as the structures are made from alien materials and the wastes themselves are alien materials (Figure 5). Mining and milling residues management is not only an engineering task, but requires a good understanding of the long-term geological, geochemical and hydrological processes in the host geology. Adaptation to the local situation will help to extend the time horizon over which the various potentials will be dissipated, perhaps well beyond a time horizon over which active maintenance can be reasonably expected.

![Figure 5 Long-term challenges to a mine waste site (Source: W.E. Falck).](image)

Modern approaches to mining, including uranium mining, are based on a full life-cycle approach. In this, plans are made for the long-term management and the long-term safety of such sites right from early days of project development on. This allows, for instance, to introduce long-term stable engineering solutions, thus preventing costly re-engineering and remedial actions. Assessing all material flows over the life-cycle will help to reduce the amount of materials moved around, which will also result in cost savings. Modern mining process engineering under development (e.g. the I²Mine project, [http://www.i2mine.eu](http://www.i2mine.eu)) aims to reduce the amount of unwanted materials brought to the surface with a view to reduce the amount of material requiring long-term management. A life-cycle energy and material flow assessment will also help to reduce the overall impact of mining and milling operations.

Given that any engineered surface structure, such as tailings ponds or (covered) residue heaps will require periodic monitoring, surveillance and maintenance after their closure and after active mining has ceased (IAEA, 2002c), the question arises, who will be responsible for these. The same question arises for (near-)surface radioactive or hazardous waste repositories and has been debated extensively in
this context (OECD-NEA, 2007). Looking back in history, it is rather unlikely that a certain government structure or other institutions will survive beyond a 100 year time-frame. There are notable exceptions, where institutions and their infrastructure actively survived for hundreds of years, such as the Christian Church, the Academie Française, the British Monarchy, and others. There are also many counter-examples for institutions that persisted for centuries and then have disappeared, particularly over the past 50 years or so. One can note that there is always a special spiritual relationship between the public and the institution and perhaps also its physical infrastructure (OECD-NEA, 2007). It is, however, nearly impossible to deliberately create such spiritual long-term relationships, they are something that develops naturally, or not. Reflecting on these difficulties, organisations such as the OECD-NEA (OECD-NEA, 2010) and the IAEA (IAEA, 2006b) came to the conclusion that rather than focussing on long time-scales, it is better to focus on a horizon of two to three generations (=30-60 years), rather than on 'archaeological' (= 1000+ years), or even 'geological' (= 10,000+ years) time horizons. Finding a beneficial use for former mining and milling sites that are compatible with the requirements to ensure the integrity of their coverings. Such beneficial use has to be defined together with the host communities in a deliberative procedure (FALCK et al., 2014).
6. Metal ores

6.1. Iron

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<thead>
<tr>
<th>Hazards:</th>
<th>Counter-measures:</th>
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<tbody>
<tr>
<td>• Geotechnical failure of containment of semi-liquid process residues disposed of in tailings-ponds resulting in spills</td>
<td>• Reducing water content of tailings before disposal</td>
</tr>
<tr>
<td>• Dust generation from uncovered residues</td>
<td>• Covering of residues as soon as operationally feasible</td>
</tr>
</tbody>
</table>

The principal iron ore minerals are magnetite, haematite, with other iron minerals of minor importance commercially. World-wide high-grade iron ore deposits (‘direct shipping ores’, DSO) are becoming exhausted so that mining moves to lower grades. This inevitably increases the amount of gangue to be deposited as waste, namely tailings. The concentrated ore may be further processed into ‘pellets’, i.e. slag-formers, such as limestone and silicates (olivine), and mixed with bentonite as binder. These pellets improve the steel-making process in blast furnaces. Much of the steel-making takes place at locations removed from the mining locations, so that the respective residues usually do not occur together. The emissions and wastes from the iron and steel industry are subject of the EC Directive 2010/75/EU (CEU, 2010) and a best-practice application document (EU 2012).

The comminution and beneficiation of the large quantities of iron ores produced annually results in large quantities of tailings. Reduction in ore grade exacerbates the scale of the problem and increases the difficulty in managing them due to the smaller grain-sizes required to separate ore minerals from gangue. This is unavoidable and there are no alternatives to this process. Improved recovery rates will (slightly) reduce the amount of ore required to produce the same amount of iron and there are processes on the market to re-work existing tailings to extract residual iron, by e.g. using strong magnets to recover the only weakly ferromagnetic haematite (‘magnetation’ - http://www.magnetation.com). The H2020-project RESLAG (http://www.reslag.eu/) aims at a significant reduction of primary raw materials used and hence a significant reduction of waste to be disposed of (see also Ch. 10.2).

However, the main issue remains the geotechnical stability of tailings ponds. The main point here would be the introduction of paste technology to reduce the risk of catastrophic outflows.
6.2. Aluminium

<table>
<thead>
<tr>
<th>Hazards:</th>
<th>Countermeasures:</th>
</tr>
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<tbody>
<tr>
<td>• Geotechnical failure of containment of semi-liquid process residues ('red muds') disposed of in tailings-ponds resulting in spills</td>
<td>• Reducing water content of tailings before disposal</td>
</tr>
<tr>
<td></td>
<td>• Alternatives to the Bayer-process capable of using different types of ores with less gangue (long-term option only requiring further research)</td>
</tr>
<tr>
<td></td>
<td>• (Re-)processing of wastes (see <a href="http://bravoeip.eu">http://bravoeip.eu</a>)</td>
</tr>
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</table>

Discussion:
Aluminium (Al) is ubiquitous and occurs in many different rock types and minerals. Simpler minerals, however, facilitate its extraction. For this reason, aluminium is produced from bauxite, which is a mixture of different aluminium oxihydroxides (gibbsite, boehmite, diaspore) with iron oxihydroxides (goethite, haematite), clay minerals, kaolinite (Al₂Si₂O₅(OH)₄), and anatase (TiO₂). Bauxite is the result of extensive weathering of a range of rocks, including limestone and igneous rocks. It occurs as thick layers near the earth's surface and, therefore, is usually strip-mined in open pits. Greece is a minor producer in Europe, but the vast majority of the needs are imported from overseas.

The processing of bauxite consists of two major steps, namely the wet chemical separation of the aluminium from the accessories and the smelting of the resulting alumina (Al₂O₃) into aluminium metal. The bauxite is crushed and ground to a fine grain-size and the aluminium oxihydroxides are dissolved in sodium hydroxide solution (NaOH) at elevated temperatures (Bayer process). The residue from the process is the so-called 'red mud', a caustic slurry containing the accessorional minerals and metals. The caustic property (high pH) is mainly due to NaAlO₂, Na₂CO₃, and some NaOH that escapes its recovery process. These 'tailings' are usually disposed of in pond-like structures. The alumina resulting from the Bayer process is reduced to metal aluminium in the electrolytic Hall-Heroult process. This process has a particularly high CO₂ footprint due to the high electricity consumption and due carbon electrodes being oxidised into CO₂.

From a waste management point of view the main problem of aluminium production by the route of the Bayer processes is the generation of large quantities (typically 2-4 tons per ton aluminium metal) of caustic 'red mud'. Due to the fine-grained nature of the solids after the milling process, these muds dewater very slowly, requiring the material to be held in tailings ponds for extended periods of time.
Alternative processes that could use other aluminium ores with less accessories, thus resulting in less tailings, and that are less energy consuming are being explored (RHAMDHANI et al., 2013). The main possible routes from aluminium ore to aluminium metal are illustrated in Figure 6.

![Figure 6 A schematic diagram showing the process routes considered by Alcoa (RUSSELL, 1981; as quoted in RHAMDHANI et al., 2013).]

Direct carbochlorination or carbothermic processes would avoid the Bayer process. However, most research to date focused on improving or eliminating the Hall-Heroult process, still starting from alumina produced by the Bayer process (RHAMDHANI et al., 2013). The reason is that e.g. the chlorination process is not sufficiently specific in the presence of silicates and other metals contained in the ores, reducing the yield of aluminium chloride (which is a gas). In addition, extreme operating conditions (high temperatures and pressures) and highly corrosive constituents require expensive plants and are difficult to control. This entails industrial plant safety and environmental protection issues. Therefore, the Bayer process remains fundamental to produce pure alumina for subsequent aluminium metal extraction processes. While industry continues to pursue alternatives, the time horizon for any results is seen beyond 20 years (http://bauxite.world-aluminium.org/uploads/media/fl0000422.pdf).

The industry, hence, focused on improvements to the Bayer process with the objective to “Develop[e] methods to achieve a 1,000-year ecologically sustainable storage of red mud and other solid wastes in existing storages, and make substantial progress in storage for later reuse as well as achieve substantial progress in the reuse of the red mud” (AMIRA, 2001).

Research on inertisation (inorganic polymers or other new chemistries; use of sea water) and alternative uses (metal recovery, absorbent for CO$_2$, road base/levee
construction, soil amendment treatment for acid-generating materials/acid mine drainage, cement kiln additive, effluent treatment, bricks/building products) is to be undertaken according to this road-map. The sheer volume of red-mud that arises each year, however, will make it difficult to find sufficient alternative uses. There also remains the problem of existing stockpiles. Improving the Bayer process by looking into option to reduce the NaOH consumption and its loss into the red-mud would reduce to some degree the potential environmental impacts of these highly alkaline muds.

Research on improving the manageability of red mud focuses on an accelerated dewatering, which would render tailings-ponds less hazardous and prone to catastrophic failure (IAI, 2015). Bauxite residues initially contain around 15% solids and can be pumped. When solid contents rise above 28%, the muds exhibit thixotropic behaviour, meaning that they begin to flow, when agitated mechanically. When solid contents rise above 75%, the muds can be handled with excavating machinery. Filter presses and centrifugal separators can be employed for dewatering. Traditionally, the muds are disposed of in topographical depressions or constructed ponds. Some of the water will exfiltrate into the underlying geological strata, if these ponds are not lined. During the settling process excess water accumulates on the pond surface and either evaporates (in arid conditions) or must be drained away. The collected drainage water is pumped back into the plant for residual aluminium recovery. Drainage ditches can be dug into the surface of the ponds to accelerate drainage, but amphibious machines are needed due to the thixotropic behaviour of the muds. In the process of 'wet stacking' partially dewatered (ca. 30% solids) muds are discharged into the ponds. This denser mud will not re-suspend by atmospheric precipitation and rainfall run-off can be collected from the surface. In more arid areas 'dry stacking' can be practiced, where the mud contains up to 77% solids (IAI, 2015), but requires to be transported to the disposal site by conveyor belt, rather than being pumped. Dry stacked tailings constitute a lesser risk in case of dam failures, as they will not flow out. Enhanced exposure to atmospheric CO₂ will (partially) neutralise the residual alkalinity. Neutralisation will be required for re-vegetation, when tailings ponds are closed out and remediated. However, accelerated dewatering and solidification will entail materials (e.g. flocculants, neutralising agents) and energy expenditures that will reduce the overall energy efficiency of alumina production. Recently also a European Innovation Partnership (EIP) on the issue of bauxite processing waste has been started: http://bravoeip.eu (see Ch. 10.2 for more details).

Aluminium recycling has been already promoted for several decades and is being practised (with varying efficiencies) throughout the European Union.
6.3. Copper

**Hazards:**
- Geotechnical stability of tailings-ponds
- Acid tailings drainage,
- Toxicity of accessorial elements in the tailings
- SO₂-emissions

**Counter-measures:**
- Careful design, construction and maintenance of tailings-ponds
- Utilisation of residues such as gypsum as secondary raw materials
- Backfilling of residues into the mine
- Alternative processes, such as heap- and *in situ*-leaching.

**Discussion:**
The majority of the copper around the world is produced from sulfidic ores (UNEP, 2013). As with many other metal ores, depleting high-grade resources have to be replaced with lower-grade ones. This inevitably leads to larger volumes of material to be processed, resulting in turn in larger volumes of mining and milling wastes. Current average grades are below 1% (UNEP, 2013, Annex 5). This precludes direct smelting of ores and requires a pre-concentration step. Ores are ground to a very fine grain-size (the grain-size also decreasing with the ore-grade) and subject to floatation process to separate the actual ore minerals from the gangue. The resulting waste, the tailings, have to be disposed of in tailings ponds. The fine-grade materials prolong the dewatering phase, rendering the material inherently geotechnically instable for prolonged periods of time. As all tailings pond, this one poses a significant risk due to dam instability and ensuing spilling of the tailings. In addition to non-copper sulfides, such as pyrite, the tailings can contain considerable quantities of arsenic. Oxidation of these sulfides will result in acidic drainage, which in itself, when discharged into surface water bodies, will have detrimental environmental effects and, in addition, will lead to the dissolution of toxic metals and arsenic from the tailings.

In past the concentrated ore was subject to an oxidation process ('roasting') in order to convert the copper into its soluble oxide form for further processing while driving off sulfur and other volatile compounds (DAVENPORT et al., 2002). This results in the sulfur being released as SO₂, which in turn can lead to acid rain and the acidification of surface water bodies. Today, various direct smelting processes are preferred (CHADWICK, 2010a), by which accessories form a slag that collects above the heavier metal, which then can be tapped-off. Volatile SO₂ produced is captured for the production of sulfuric acid, which in turn is used for leaching processes.
Low-grade ores can also be subject to heap-leaching, whereby suitably ground ore is spread out in shallow basins ('leaching pads') and a leachant is sprinkled over it to be collected again for further processing. Ores for heap-leaching are usually less finely ground and, therefore, their management is less problematic than tailings from other processes. Carbonatic ores can be leached using sulfuric acid, while sulfidic ores employ bacteria that gain energy from the oxidation of the accessory iron-sulfides.

The process can also be induced underground by pumping leaching solutions through an array of injection boreholes into the ore body and recovery of the so-called 'pregnant' solution in another set of boreholes. A significant amount of the annual copper production is based on such leaching processes. In situ-leaching results in comparable small amounts of mining wastes, consisting mainly of waste rock from the drill holes and any neutralisation sludges from the leaching solution. However, in situ-leach fields may require lengthy environmental remediation processes. Heap-leaching recovers 60 to 70% of the metal content, but leaves behind acid-generating gangue minerals (depending on the process). These residues require careful management to prevent the formation of acid waste-rock drainage, but are geotechnically more amenable than the tailings from the other processes, thus posing less risks.

6.4. Nickel

<table>
<thead>
<tr>
<th>Hazards:</th>
<th>Counter-measures:</th>
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<tbody>
<tr>
<td>Geotechnical stability of tailings-ponds</td>
<td>Careful design, construction and maintenance of tailings-ponds</td>
</tr>
<tr>
<td>Acid tailings drainage,</td>
<td>Utilisation of residues such as gypsum as secondary raw materials</td>
</tr>
<tr>
<td>Toxicity of accessorial elements in the tailings</td>
<td>Backfilling of residues into the mine</td>
</tr>
<tr>
<td>SO₂-emissions</td>
<td>Alternative processes such as heap- and in situ-leaching.</td>
</tr>
</tbody>
</table>

Discussion:
Similar to copper, nickel occurs as sulfidic mineralisations and is mined and processed in similar ways, entailing similar problems. While copper is produced by various leaching processes, this technology has not been applied to nickel to any great extent yet (WATLING, 2008), but is promising (CHADWICK, 2010a). The first mine applying bioleaching for Ni recovery is the Talvivaara Mine in Finland (TALVIVAARA, 2010). The H2020 Project BIOMOre (www.biomore.info/, 2015-2018) addresses among other metals also the enhanced in situ-leaching of nickel. Unwanted side reactions of the leaching solution with the minerals in the gangue are problems to be solved.
6.5. Zinc

<table>
<thead>
<tr>
<th>Hazards:</th>
<th>Countermeasures:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Geotechnical stability of tailings-ponds of beneficiation and flue-gas desulfurification gypsum</td>
<td>• Careful design, construction and maintenance of tailings-ponds</td>
</tr>
<tr>
<td>• Acid tailings drainage,</td>
<td>• Utilisation of residues such as gypsum as secondary raw materials</td>
</tr>
<tr>
<td>• Toxicity of accessorial elements in the tailings</td>
<td>• Backfilling of residues into the mine</td>
</tr>
<tr>
<td>• SO₂-emissions</td>
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</table>

Discussion:
Zinc often occurs in sulfidic ores together with lead and silver, which also partly determines the management routes for zinc milling residues. These ores are mostly mined underground. The ores are crushed and then enriched in a froth-floatation process, resulting in tailings from the gangue that require management in tailings ponds. The ore concentrate is subject to a controlled oxidation process ('roasted'), to convert the sulfide into oxides. These mixed oxides are leached in a two-step process with weak and strong sulfuric acid, converting the zinc oxide into dissolved zinc sulfate. The residue from the leaching process contains silver and lead and is usually sold to other companies for extracting these metals. The zinc sulfate solution still contains cadmium, copper, arsenic, antimony, cobalt, germanium, nickel, and thallium as impurities that have to be removed before the following electrolytic refining process. These impurities are sold as by-products for recovering the metal value.

With decreasing ore grade the zinc sulfide particles become smaller and therefore the ore needs to ground finer in order to separate it from other ore minerals. High-intensity mills also put strains onto the grain boundaries making the minerals more amenable to leaching. The resulting slurry is leached with sulfuric acid and the addition of oxygen to destroy the sulfides (Albion process). If all the sulfides are oxidised, the resulting tailings are less prone to produce acid drainage, but the small and uniform grain-size makes dewatering more difficult and energy consuming.

6.6. Lead
Counter-measures:

- Careful design, construction and maintenance of tailings-ponds
- Utilisation of residues such as gypsum as secondary raw materials
- Backfilling of residues into the mine

Discussion:
Lead is a chalcophilic element and as such occurs often together with sulfidic zinc, copper, and nickel ores. Extraction and processing these poly-metallic ores results in similar waste management issues, including tailings from e.g. flotation, as discussed above for copper, nickel, and zinc. The lead-containing ores are processed in several stages, resulting in the metal, dross/slags (mainly silicates), matte (mixed sulfides), and speiss (mainly arsenides). These residues today are further processed to recover residual lead and other metals of value, such as silver, nickel, zinc, cadmium, or bismuth.

Decreasing average mined ore concentration exacerbate the tailings problem due to larger quantities to be disposed of and smaller grain-sizes to make smaller ore particles accessible.

6.7. Gold

<table>
<thead>
<tr>
<th>Hazards:</th>
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<tbody>
<tr>
<td>- Spills and accidental discharges of cyanide-containing solutions</td>
<td></td>
</tr>
<tr>
<td>- Geotechnical stability of tailings-ponds containing cyanides</td>
<td></td>
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<tr>
<td>- Contaminated tailings drainage</td>
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<tr>
<td>- Hg exposure in artisanal mining</td>
<td></td>
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<tr>
<td>- Hg contamination of the environment from artisanal mining</td>
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<tr>
<th>Counter-measures:</th>
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<tbody>
<tr>
<td>- Careful design, construction and maintenance of tailings-ponds</td>
<td></td>
</tr>
<tr>
<td>- Development of selective complexing agents for Au, improved</td>
<td></td>
</tr>
<tr>
<td>- Process control to minimise cyanide use</td>
<td></td>
</tr>
<tr>
<td>- Replacement of Hg-amalgam process in artisanal mining</td>
<td></td>
</tr>
</tbody>
</table>

Discussion:
Gold occurs as sedimentary, placer deposits ('nuggets') and as ore veins in certain hard-rocks. The latter today are the most important sources. Gold being a noble metal is not easily dissolved and therefore not readily amenable to hydrometallurgical techniques. Most of the relevant ores are also refractory, meaning they are not accessible to pyro-metallurgical processes, such as direct smelting. Most aqueous ions of gold are unstable and gold easily precipitates from solutions. Gold can be dissolved in aqua regia (a mixture of nitric and hydrochloric acid), but its highly corrosive nature makes its use only feasible in the final purification step. Otherwise, the only two known method to dissolve gold is in highly alkaline cyanide solutions and in mercury, both of which are used in the
recovery of gold from its ore, the latter today predominantly only in artisanal gold mining.

In artisanal mining the material from the gold-bearing veins is crushed to a small grain-size and mixed with mercury. The resulting liquid gold-mercury amalgam then is collected and distilled to recover the mercury, or sometimes evaporated over an open fire. This artisanal process leads to considerable exposure to mercury vapours and the mercury losses in the tailings that are often discharged into rivers to environmental contamination.

In industrial gold milling the mined material is crushed to a very fine grain size and mixed with a sodium, potassium or calcium cyanide solution. The gold dissolves as a cyanide complex (Eq. 1) and can be separated from the gangue slurry.

\[
\text{Eq. 1} \quad 4 \text{Au} + 8 \text{NaCN} + \text{O}_2(g) + 2 \text{H}_2\text{O} \rightarrow 4 \text{Na[Au(CN)]}_2 + 4 \text{NaOH}
\]

The pH of the slurry has to be kept high in order to prevent the formation of the highly poisonous cyan gas (HCN). As Eq. 1 indicates, the reaction consumes oxygen and for this reason air or oxygen are blown into the slurry. It may also be necessary to pre-oxidise the slurry to prevent the cyanide being consumed by the oxidation of ferrous iron or the formation of thiocyanates with the sulfide-sulfur in the gangue. Roasting or froth flotation of ores to remove accessory sulfides may be necessary pre-treatment steps. The necessity for such pre-treatments often increase with more intense grinding to access smaller gold particles, as this also improves the access to cyanide-consuming gangue minerals.

The gold in most cases is recovered from the cyanide solution by adsorption onto activated carbon, but also ion exchange resins have been investigated for some time now (e.g. SCHOEMAN et al., 2012).

The cyanide ion halts cellular respiration by inhibiting an enzyme in the mitochondria called cytochrome c oxidase, leading to death. Cyanide ion are rapidly decomposed when exposed to sunlight in surface waters, but remains stable in the tailings slurries. In tailings ponds and heap leach piles, cyanide may be lost by volatilisation of HCN (due to decreasing pH values), degraded by various abiotic and biotic processes, fixed by precipitation and adsorption of metallo-cyanides, and may potentially migrate as seepage to underlying strata and groundwater. While less acutely toxic than the cyanide ion, the breakdown products, such as metal-cyanide complexes, organic-cyanide compounds, cyanogen chloride, cyanates, thiocyanates, chloramines, and ammonia, often remain undetected because they are not part of routine water-quality analyses.
The long-term behaviour of cyanide in tailings and the long-term effects on biota of cyanide and its breakdown products are not well known (MORAN, 2002).

In order to reduce the hazards from these tailings, they are subject to an oxidation treatment that converts the cyanide into the less toxic cyanate ion, which then reacts with water to form hydrogen carbonate and ammonia. A number of commercial processes (some of which are patent protected), for instance the Maelgwn Mineral Services CN-D™ process (http://www.maelgwyn.com/cyanidedestruction.html), INCO, Caro’s acid (H₂SO₅), the alkaline chlorination, or the peroxide process (e.g. USEPA, 1994), are in use and are able to reduce cyanide concentrations below permissible discharge limits (CEU, 2006). Cyanide destruction leads to gold being precipitated out and thus enhanced recovery, which can off-set the cost of cyanide destruction (CHADWICK, 2010a).

The industry now subscribes to a voluntary International Cyanide Management Code (http://www.cyanidecode.org) to limit discharges of cyanide with the tailings. Cyanide-using mining companies and cyanide producers pay a subscription fee in order to be certified. The actual cost for compliance with the code is based on individual conditions. For an operating mine, there may be costs associated with increased reporting, changes in mining practices, fees for external audits, and personnel time. The Code required evidence of compliance, so practices and written procedures become more detailed. Equipment inspections will increase and operational parameters of plants have to ascertained. Specific spill controls will have to be installed along cyanide lines. These measures, however, also represent long-term cost savings related to potential future spills or leakage. Compliance with the Code may be required by investors as financial risk management measure (GARCIA, 2009).

Research is on-going to replace the cyanide with other selective complexing agents that can work in multi-ion solutions. Thiosulfates are being investigated, but do not adsorb onto activated carbon, so that other stripping methods, e.g. based on resin adsorption, have to be developed as well (CHADWICK, 2010b). Organic complexes are other likely candidates (e.g. LIU, 2013), but the process development has not yet achieved a sufficiently high technology readiness level.

Improved physical (gravity) separation processes can result in gold concentrates that are amenable to direct smelting, thus avoiding the cyanide leaching process. However, with smaller the gold particles (i.e. below 50 μm) the recovery rates drop from 99% to 80 to 90% (CHADWICK, 2010b), which is another example for less (potential) environmental impacts being off-set by less efficient use of resources.
6.8. Silver

<table>
<thead>
<tr>
<th>Hazards:</th>
<th>Counter-measures:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Geotechnical stability of tailings-ponds of beneficiation and flue-gas desulfurization gypsum</td>
<td>• Careful design, construction and maintenance of tailings-ponds</td>
</tr>
<tr>
<td>• Acid tailings drainage, toxicity of accessorial elements in the tailings</td>
<td>• Those implemented for the respective main product of the mine</td>
</tr>
<tr>
<td>• SO₂-emissions from roasting</td>
<td>• Utilisation of residues such as gypsum as secondary raw materials</td>
</tr>
<tr>
<td>• Those associated with the mining and milling of the major metal, if Ag is a by-product</td>
<td>• Backfilling of residues into the mine</td>
</tr>
</tbody>
</table>

Discussion:
Silver rarely occurs as the native element, but mostly in poly-metallic ores in association with other chalcophilic elements, such as copper, zinc, or lead as well as gold. A large proportion of the silver today in consequence is mined as a by-product to these base metals or gold (USGS, 2016a). Therefore, no problems specific to silver mining arise, but those associated with the processing of sulfidic ores already discussed above.

6.9. Tin, zirconium, titanium, tantalum, niobium and Rare Earth Elements (REE)

<table>
<thead>
<tr>
<th>Hazards:</th>
<th>Counter-measures:</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Geotechnical stability of tailings-ponds</td>
<td>• Careful design, construction and maintenance of tailings-ponds</td>
</tr>
<tr>
<td>• NORM in tailings</td>
<td>• Separation of NORM for further use or safe disposal</td>
</tr>
</tbody>
</table>

Discussion:
Heavy minerals are defined as those with a density above 2.8 g/cm³, and are minor constituents of a wide range of rocks, and comprise a wide variety of minerals, including oxides, phosphates and silicates. They are typically harder than the other minerals in the rocks from which they originate and, therefore, survive the erosion and transport processes. Hence, economic deposits of heavy minerals occur predominantly concentrated by marine, alluvial and/or wind processes and are called placers deposits. Heavy mineral such as monazite, zircon, xenotime, ilmenite, rutile and others and ores such as cassiterite are the raw materials for certain metals or their compounds. Zirconium, titanium, thorium, tin and the rare earth elements (REE) are the major target elements.
The rare earth elements (REE) consist of the 15 lanthanides lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), promethium (Pm), samarium (Sm), europium (Eu), gadolinium (Gd), terbium (Tb), dysprosium (Dy), holmium (Ho), Erbium (Er), thulium (Tm), ytterbium (Yb), and lutetium (Lu) as well as the elements scandium (Sc) and yttrium (Y), which behave geochemically similar. REE are not actually particularly rare in terms of abundance, but are dispersed in geological matrices due to their chemical properties. Their similarity also makes it difficult to separate them.

Heavy minerals occur in mineral sand placer deposits, and in veins or disseminated predominantly in alkaline intrusion in the hard rock (e.g. China, USA). Well known placer deposits in the Indian Ocean region are the cassiterite sands of Southeast Asia (Malaysia, Thailand and Indonesia), the tin province of Australia along the west Pacific, heavy mineral placers on the coasts of Mozambique, South Africa, Western Australia, Northeast Sri Lanka and western and eastern coasts of India, with other smaller deposits in the USA.

Ilmenite (FeTiO₃), rutile, leucoxene and sphene are the source of titanium and is usually associated with iron. It is also readily mined in one of the purest forms, rutile (TiO₂) from beach sand. The deposits are mainly located in the Americas, Australia, sub-Saharan Africa, Scandinavia, and Malaysia.
Figure 7 Flow-sheet from heavy mineral ore to pigment, zirconia/zirconium, and rare earth, as well as associated major waste streams (IAEA, 2003).

The major REE sources are the minerals bastnaesite ([Ce,La][CO₃]F), monazite ([Ce,La,Y,Th]PO₄), xenotime (YPO₄), and loparite and lateritic ores (including bauxite). Monazite forms in phosphatic pegmatites, but is actually a standard trace constituent in many ordinary igneous, metamorphic and vein filling rocks. Notable occurrences of monazite are widespread and diverse. They include beach and river sand deposits from India, Australia, Brazil, Sri Lanka, Malaysia, Nigeria, and the USA.

Cassiterite (SnO₂) occurs in the form of placers in alluvium, as well as lodes in hard rock and may be associated with minerals such as monazite, zircon (ZrSiO₄), xenotime, ilmenite, struverite (Ta/Nb bearing TiO₂), columbite ([Fe,Mn][Nb,Ta]₂O₆), tourmaline and others.

Due to this variety of minerals in heavy mineral sands, mines often produce a range of metal ore concentrates. Figure 7 illustrates the products and wastes from such a mine.
6.9.1. Titanium

Feed-stocks for titanium metal and technical TiO₂ production are the minerals ilmenite (FeTiO₃) and rutile (TiO₂(c)). Most of the titanium minerals (>95%) are processed into pigment (USGS, 2016c), but the use of titanium metal and its alloys as well as compounds with carbon and nitrogen are steadily increasing. Ilmenite accounts for 92% of the Ti production (USGS, 2016c). Ilmenite is either smelted under a reducing conditions in an electric arc furnace to give molten iron and titania slag (Pistorius, 2008), converted by roasting into a mixture of iron-oxide and rutile (Becher-process, Becher et al. 1965), or is dissolved in sulfuric acid and the iron content is precipitated as ferric sulfate. The sulfuric acid process results in large quantities of waste sulfuric acid for which there was no use and it was discharged by tankers or via pipeline into the sea. This practice has now largely been discontinued and the other routes for titania production are being followed. While the direct smelting results in pig iron, the iron residues from the other processes are converted into iron-oxides that can be sold to steelmakers or cement factories. The resulting 'synthetic' rutile is subject to similar refinement procedures as the natural rutile.

Titanium dioxide production is the subject of three EU directives (http://ec.europa.eu/environment/waste/titanium.htm). The Commission has reviewed these directives in 2007 (Stewart et al., 2007).

6.9.2. Zircon

Zircon is predominantly sold and used as zircon without further processing, other than possibly milling to produce zircon flour. A general flow-sheet from heavy minerals to zircon end products is given in Figure 7.

6.9.3. Tin

At tin smelting plants, tin ores concentrates are used as feed materials to produce metal tin. At the end of the process tin slag is produced as residues. Tin smelting, dating back to pre-historic times e.g. in Britain, has resulted in millions of tons of glass-like slag in various parts of the country, but the hazard from this material is likely to be low. Tin slag typically contains significant amount of tantalum and niobium. It can be used as feed material to tantalum extracting plants. Struverite is also a good raw material for tantalum extraction.

6.9.4. Niobium and Tantalum

Niobium minerals usually contain both niobium and tantalum. Since they are rather similar chemically, it is difficult to separate them. Niobium can be extracted
from the ores by first fusing the ore with alkali, and then extracting the resultant mixture into hydrofluoric acid, HF. Current methodology involves the separation of tantalum from these acid solutions using a liquid-liquid extraction technique (CARDARELLI, p. 357). Electrolysis of molten fluorides is also used (BOWLES, 1968).

6.9.5. Rare Earth Elements

China has been dominating the REE production for the last decade, overtaking the USA and other producers. Bastnaesite deposits in China and the United States constitute the largest percentage of the world's rare-earth economic resources, and monazite placer deposits (heavy mineral sands in India, Malaysia, Sri Lanka, Thailand, and Brazil) constitute the second largest segment (USGS, 2016b). Bastnaesite and monazite mining and processing follows two different routes.

The hard-rock ores of bastnaesite are usually mined in open pits and require crushing, screening, grinding and flotation to arrive at a bastnaesite pre-concentrate. These physical processes produce large quantities of tailings, that are disposed of in ponds. The mineral concentrate is digested in hydrochloric acid and the resulting REE laden liquor is passed through a sequence of solvent extraction with several mixer-settler steps. Final products of this element-selective extraction processes are separated REE oxides that are sold into the market. Most of this processing takes place in China (SCHÜLER et al., 2011)

Monazite sands are usually mined by dredging. The heavy minerals are pre-concentrated by screening and gravity separation. Further mineral separation is effected in magnetic separators (removal of ilmenite and other magnetic minerals), followed by electrostatic separation for electrically conducting and non-conducting heavy minerals are typically separated in electrostatic plate separators followed by magnetic separators that help to distinguish induced magnetic from non-magnetic minerals. The tailings from the pre-concentration and separation steps are pumped back into the pit as the dredger moves forward or are disposed of in tailings ponds. The heavy mineral concentrates are processed into individual REE by digestion in sulfuric acid and selective precipitation.

Heavy REE (HREE) are also produced from lateritic clays in China, the processing of which is simple. The clays are suspended and washed with (NH₄)₂SO₄ in an ion-exchange batch or heap-leaching process. More recently the Chinese government enforced the adoption of in situ-leaching in order to reduce the environmental impacts from surface mining and mine waste management (PAPANGELAKIS & MOLDOVEANU, 2014). The REE are precipitated as carbonates and calcined into mixed oxides to be sold off for further separation. The process results in clay tailings and process residues enriched in uranium and thorium. Their relatively
easy access has led to a large number of informal and unlicensed mines in China with no or little environmental protection activities (e.g. SCHÜLER et al. 2011).

There is limited REE production in Europe. The Norra Kärr zirconium deposit in Sweden was explored for REE, but the exploration license has been withdrawn by the Swedish High Court in early 2016 (https://en.wikipedia.org/wiki/Norra_Kärr_mine_project). Re-working materials from the Sillamäe tailings pond in Estonia for REE is also under consideration. This tailings pond inter alia contains uranium and REE milling residues and is exposed to the Baltic Sea (SIINMAA, 2014).

Dredging of surface deposits has left behind thousands of mined-out ponds worldwide. Typically such ponds have thick layers of slime. The mined-out ponds are very large in size and most of them are quite deep. Remediation is often necessary before the former mining sites can be re-used.

Residues are produced from mining, beneficiation and chemical processing of mineral sands and minerals. They are produced as tailings, fine dust, sludge (oxides, hydroxides, or sulfates), scales, and slag.

Heavy minerals from monazite sands and some laterites contain usually significant amounts of radionuclides (uranium and thorium), i.e. Naturally Occurring Radioactive Materials (NORM) that are sometimes recovered as by-products, but also often discarded with the tailings and other processing residues. Residues from all types of production can cause a disposal problem because of the radioactivity content (IAEA, 2003). The volume and the activity level of radionuclides in residues varies depending on the processing methods applied. In the placer deposits mining, the volume of tailings generated could be very large. The main waste generated during the wet and dry processing of heavy mineral sands is the waste from the dry plant, where contained activity can be enhanced. Slimes and sands tails from wet processing are generally low in radioactivity and can be returned to the mined out sites. The issue of whether mineral processing residues should be recombined, kept separate, and/or covered needs to be assessed on a site by site basis. Some countries have banned the mining and processing of monazite sands due to the high NORM content (SCHÜLER et al., 2011).

The major applications for REE today are electric motors and generators, phosphors (LEDs, fluorescent tubes), electronics, and catalysers. In spite of the several REE figuring on the list of critical raw materials in the EU, their current recycling rates are low mainly due to the longevity of certain products and due to low collection rates at the end of the life of many consumer goods (SCHÜLER et al., 2011). Even if collection rates would significantly increase, separating out the REE
requires significant effort and energy in terms of dismantling and chemical processing akin to the original milling processes. However, SCHÜLER et al. (2011) concluded that there may be still gains in reduced environmental impacts and energy saving over mining.

6.10. Chromium

<table>
<thead>
<tr>
<th>Risk:</th>
<th>Environmental releases of toxic Cr(VI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Risks from ancillary materials production, such as aluminium for the aluminothermic process</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Counter-measures:</th>
<th>Wet grinding of chromite ore to prevent oxidation to Cr(VI)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Acid drainage control to prevent Cr(VI) releases</td>
</tr>
<tr>
<td></td>
<td>Increased recycling of alloyed steel to reduce the need for virgin ores</td>
</tr>
<tr>
<td></td>
<td>Recycling of dust and slags in the smelting process</td>
</tr>
<tr>
<td></td>
<td>Improvements to the processing of ancillary materials.</td>
</tr>
</tbody>
</table>

Chromite (FeCr$_2$O$_4$) or (Fe,Mg)Cr$_2$O$_4$ are the only chromium ores of economic relevance. The world's leading chromite and chromium producer is South Africa with 47% of the world market (USGS, 2016e). The only European country producing chromium is Finland with its Kemi Mine (USGS, 2013). The main intermediary products are ferrochromium alloy and chromium metal, which are particularly used in the steelmaking industry.

Ferrochromium is produced using in an electrical arc furnaces using coal or coke as reducing agent (ICDA, 2011). There are a number technical variants to the process aimed at being able to utilise ore fines and to reduce the electricity consumption that is considerable (UGWUEGBU, 2012). Ferrochromium and chromium metal are also produced using an aluminothermic process with aluminium as reductant. Chrome metal can also be produced in a two-step by roasting and leaching process. There are several aqueous chemical processes to separate Cr from Fe for the production of chromium compounds for use e.g. in tannery. However, as the vast majority of chromium is used in steelmaking, ferrochromium as an intermediate is sufficient.

As for all hard ores, a crushing and concentration process is required that will result in gangue and tailings. These wastes will contain some residual Cr. During the processing and after disposal some of the Cr(III) may become oxidised to Cr(IV). Similarly, dry grinding of chromite ore can induce the formation of Cr(VI) in the waste streams (MININGWATCH CANADA, 2012). While the ferrochromium smelting occurs in a reducing environment, carried-over Cr in dusts and slags can
be oxidised to Cr(VI) during the cooling phase. This may limit the re-use of dusts and slags outside the milling plant.

Recycling of (well classified) steel scrap has the potential to save considerable amounts of virgin chromite. Outokumpu's smelter in Tornio (Finland) uses 85% scrap and 15% ore from the Kemi mine (USGS, 2013).

6.11. Vanadium

Most of the vanadium is recovered from vanadium-bearing magnetite ores. South Africa, China, and Russia cover together 97% of the world production (USGS, 2016f). Iron is the main product and vanadium is recovered from the slags in a two-stage roasting and leaching process (VANITEC, 2014). Crude oils contain considerable quantities of vanadium that are released to the atmosphere upon combustion. In industrial combustion plants the vanadium can be recovered from flue-gases and boiler slags. Petroleum coke from certain refinery processes is another source.

As for chromium, the vanadium production processes lead to comparatively little milling wastes, as dusts and slags are fed back into the smelting process. Also, vanadium is mainly a by-product from iron production or other processes.
7. Industrial minerals

7.1. Phosphate rock

| Risk: | • Geotechnical stability of phosphogypsum stacks  
|       | • NORM and heavy metals in residues  

| Counter-measures: | • Increase of efficiency in phosphorus use along the value chain reduces phosphate rock use  
|                   | • Careful design, construction and maintenance of phosphogypsum stacks  
|                   | • Alternatives to the sulfuric acid process, such as the nitrophosphate process  
|                   | • Separation of NORM and heavy metals for further use or safe disposal  
|                   | • Utilisation of phosphogypsum to replace virgin mined gypsum in cements, plaster-boards, etc.  
|                   | • Vertical integration in resource countries (e.g. Morocco) result in less phosphogypsum production in the EU

Discussion:

Overview
Fertiliser and industrial phosphates are primarily derived from phosphate rock mined as naturally occurring ores. The principal constituent of phosphate rock (or phosphorite) are apatites, namely carbonate-fluorapatite, $\text{Ca}_5(\text{PO}_4,\text{CO}_3)_3\text{F}$ and francolite $(\text{Ca,Me}_2\text{Sr,Na})_{10}(\text{PO}_4,\text{SO}_4,\text{CO}_3)_6\text{F}_2\cdot 3\cdot$. The typical phosphate ($\text{P}_2\text{O}_5$) concentration of the rock is in the order 15-30%, with clay, sand, carbonate and other impurities present in varying quantities.

Phosphate in mineable quantities is concentrated by sedimentary, igneous, weathering and biological processes (e.g. guano). Radionuclides and heavy metals may be incorporated in sedimentary phosphorite ores through ionic substitution into the apatite crystals or by adsorption. Igneous phosphorite contains less uranium, but more thorium. High phosphate contents usually correspond to high uranium contents (50-300 ppm; IAEA, 2003).

Approximately 30 countries produce phosphate rock for use in domestic markets or for exports. The principal suppliers are North African countries, the USA, China and the Former Soviet Union (FSU). Sedimentary rocks are mostly found in North and West Africa, the USA, China and Australia (amounting to approximately 90% of world production); igneous rock - found in the Kola Peninsula, FSU, South
Africa, China, Finland and South America (notably Brazil). Almost all phosphate rock is mined in open pit mines.

Generally, the starting material for the production of phosphoric acid is beneficiated phosphate ore, referred to as marketable phosphate rock. During beneficiation, phosphate particles are separated from the rest of the ore. Beneficiation can be very simple, just screening or sieving the material and the overburden can be piled or returned to the mine; or very elaborate, including washing, flotation steps, producing phosphatic clay tailings (clay slime from washer stages of beneficiation) and sand tailings (from flotation stages of beneficiation). Phosphatic clay tailings are stored in large settling ponds. Sand tailings are either returned to the mine and used as a backfill in mined-out areas, used for construction of clay-tailings retention dams, or are mixed with clay tailings to increase clay-tailings solids content and reduce settling times. In general, the beneficiation does not change the radionuclide and heavy metal concentration in the ore. Figure x provides a flow diagram with example radionuclide balances during beneficiation (BAETTSLÉ, 1991).

There is a wide variety of processes and combination of processes for obtaining mainly phosphoric acid (H₃PO₄) as intermediate for use in the fertiliser, animal feed, and chemical industry. The choice of process is determined by the required phosphoric acid concentration, its purity, and the cost and availability of process chemicals. There are two large groups of processes, namely wet digestion of the phosphate rock with strong acids (sulfuric acids, hydrochloric acid, nitric acid) and thermal treatment.

**Sulfuric Acid Process**

The most common (95%) process is acidulation with sulfuric acid, which leads to the formation of low-solubility gypsum (CaSO₄ × 2H₂O) or hemi-hydrate (CaSO₄ × 1/2H₂O). Solid calcium sulfate crystals precipitate and can be easily separated from the raw phosphoric acid by filtration. A neutralisation step may be included. In terms of rounded figures, the production of 1 tonne of phosphate (P₂O₅) results in the generation of 4-5 tonnes of phosphogypsum. A number of variations on this scheme are in use, mainly to obtain higher yields and cleaner and more concentrated phosphoric acid. The phosphogypsum arises as slurry and is typically either deposited in piles or discharged into rivers or the sea (WORLD BANK, 1998). These disposal areas, which are referred to as phosphogypsum stacks, are generally constructed directly on virgin or mined-out land, with little or no prior preparation of the land surface. Each phosphoric acid production facility may have one or more phosphogypsum stacks. Additional waste streams arise from scale deposited in small quantities in process piping and in filtration receiving tanks and from filter cloths used to filter the solid gypsum from the acid.
liquid that have to be replaced regularly because of wear. Worn out pipes and other parts containing scales are also to be removed from the plant. Even though these wastes do not add much compared to the volume of phosphogypsum produced they involve radionuclide concentrations up to 1000 times higher than in the phosphogypsum (SCHMIDT et al., 1995). Wastes of this kind are presently disposed of on the phosphogypsum stocks, or in normal landfills in cases where the gypsum is discharged into the sea or rivers.

The sulfuric acid can be produced on site from raw materials such as pyrite or elemental sulfur, which is a by-product from oil and gas production and pyrometallurgical processes for sulfidic ores, and generates little waste, if any. Alternatively, by-product sulfuric acid can be used, which improves the economy of the sulfuric acid process.

**Hydrochloric Acid Process**

The hydrochloric acid process was developed by the Israel Mining Institute (IMI) from the 1950s onwards (IMI, 1956; P&P, 1983). It is rarely used in the EU. At Tessenderlo Chemie in Belgium (the phosphate business is now part of EcoPhos, http://www.business-standard.com/content/b2b-chemicals/tessenderlo-to-sell-feed-phosphate-business-to-ecophos-113112000697_1.html), the hydrochloric acid process is used for the production of dicalciumphosphate, which is predominantly used as an additive in animal feed (TESSENDERLO, 2004).

In this process the ore is treated with hydrochloric acid bringing both phosphoric acid and the calcium chloride (CaCl₂) into solution. The CaF₂ solids formed are disposed off. About 0.5 t of CaF₂ are formed per ton treated P₂O₅. The CaCl₂ solution (the filtrate) is always discharged into surface waters or the sea because dried calcium chloride is highly hygroscopic and cannot be stacked. Underground injection is also a possibility, where saline aquifers are available. In a second phase of the process the monocalciumphosphate is precipitated as dicalciumphosphate and filtered off.

The discharged CaCl₂ solution is treated with calcium carbonate in order to precipitate out heavy metals and radionuclides. The resulting slurries have to be managed as toxic waste.

**Nitric acid process**

Phosphate rock can also be digested using nitric acid, a process that was first invented around 1927 in Norway and subsequently licensed to Norsk Hydro (STEEN et al., 1986), BASF, Hoechst and others. The intention was to produce a combined phosphate-nitrogen fertiliser. The process does not result in phosphogypsum waste. Due to the relative lower cost of sulfuric acid, the
nitrophosphate is used only by a small number of fertiliser producers, namely in Norway and Germany.

**Market developments**
It may be noted that there is a growing trend in phosphate mining countries rather than to export the raw ore to process it into phosphoric acid or to even fertiliser etc., i.e. a trend towards vertical integration. This means that the amount of phosphogypsum produced in Europe will be reduced over time (Tessenderlo, 2006; RIDDER et al., 2012). While this reduces a waste management problem in the EU, it raises at the same time concern over adequate management in the producer countries that typically have less stringent environmental standards or are more lax enforcement of the latter. This may thus lead to risk displacement into these countries.

Measures to increase the efficiency of phosphorus use and to ban it in the EU from certain uses, such as in detergents, are motivated by environmental concerns (e.g. eutrophication) and in order to protect resources (Ridder et al., 2012). Environmental protection and risk reduction by reducing the amount of phosphogypsum produced does not appear to be a motivation. Improvements of phosphate recovery in all steps of the phosphate rock process would reduce the amount of raw material required.

The cost of process chemicals and the possibility to integrate various industrial processes in order to e.g. save energy appear to be the dominating criteria for the choice of processing technology, even though alternatives that produce less process waste would be available.

Phosphogypsum can be used to replace natural, mined gypsum in a wide variety of applications, such in cement or plaster-board production. Here it competes locally with other sources of secondary gypsum, such as from flue-gas desulfurization in thermal power-stations or sulfide ore mills.

### 7.2. Potash

<table>
<thead>
<tr>
<th>Hazard:</th>
<th>Tailings pond failure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Brine seepage and discharges</td>
</tr>
<tr>
<td>Mitigation:</td>
<td>Dry separation of salt components</td>
</tr>
<tr>
<td></td>
<td>Back-filling of tailings</td>
</tr>
<tr>
<td></td>
<td>Reduced and targeted use of fertiliser reduces potassium needs</td>
</tr>
</tbody>
</table>

**Discussion:**
Potash is the main source for potassium in fertilisers and other uses. Potash is the common name for potassium chloride (KCl, sylvine) a salt that occurs pure (rare) or in combination with sodium chloride (NaCl, halite) and other potassium, sodium, or magnesium (bitter) salts, such as potassium sulfate (K$_2$SO$_4$) or carnallite (KMgCl$_6$$\times$6H$_2$O). The major producers are Canada, Russia, Belorussia, and Germany.

Potash is mainly mined from deep mines using conventional mining techniques. The raw salt that contains a mixture of salts as well as clay and carbonate (dolomite) accessories is brought to the surface, crushed and ground to loosen the various constituents, suspended in water. Separation of the salts and other solids can be effected in various ways: dissolution followed by floatation to separate insoluble solids, electrostatic separation, thermal dissolution-re-crystallisation, or heavy liquid separation. Dry electrostatic separation has the advantage of not producing any brine as waste.

Depending on the mined material a number of waste streams arise from these processes (UNEP, 2001):
- Stacks of impure salt (NaCl) tailings on the surface;
- Retention of the fines (clays) and brines (MgCl$_2$) in surface ponds for solar evaporation;
- Deep well injection of brines into confined permeable geological strata;
- Backfilling of mined underground openings with salt tailings, fines and brines;
- Release of wastes to water bodies such as rivers or seas.

During actual operation, relatively small amounts of spoils are being produced, as the mine follows the stratified layers of salts. However, only around a quarter of the extracted volume may be potash, while the remainder will be waste.

Mine safety concerns arise from the placement of unconsolidated tailings into underground workings that experience rapid convergence, as it is the case in many salt mines. If not restrained by a bulkhead of suitable strength, they will be squeezed into the adjacent open workings, endangering the work force. Alternatives such as converting the salt tailings to paste fill are being explored e.g. in Germany (UNEP, 2001). However, back-filling is ten-times more expensive than surface disposal.

In Saskatchewan (Canada), where provincial regulations prohibit surface disposal, a cut-and-fill mining technique is used, whereby mining progress upwards, back-filling the mined-out voids underneath. Slurries are cycloned to separate out clay particles, so that no settling ponds are needed. Process water is re-circulated in the
mine and process plant with additional recovery of potash. The higher waste management costs are off-set by higher recovery rates and less future remediation costs (UNEP, 2001).

In Germany, brines are released into surface water courses. While in the past this resulted in detrimental effects to some tributaries of the Elbe river, today monitoring and controlled release rates keep salt loads to acceptable concentrations.

Salt stacks on the surface have to have collection systems for surface run-off and recirculation of any brine formed due to atmospheric precipitation.

Subsidence over salt mines that have often left large mine voids has been a concern in the past, but mine planning proceeds now more carefully. Back-filling will reduce such convergence.

7.3. Cement, lime, and magnesium oxide

<table>
<thead>
<tr>
<th>Risk:</th>
<th>Generally low for mining waste</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counter-measures:</td>
<td>Feeding processing waste back into the process</td>
</tr>
<tr>
<td></td>
<td>Utilisation of processing wastes</td>
</tr>
</tbody>
</table>

Discussion:
The European Commission issued a report on best practices in the 'Cement, Lime and Magnesium Oxide Manufacturing Industries' (EC, 2010b) with respect to the stipulations of Directive 2008/1/EC (CEU, 2008). This Directive focuses on air emissions. The major issues with production of these materials are indeed the air emissions and the CO$_2$-footprint. The raw materials, mainly limestone and clay, are extracted from nearby (if possible) quarries. Extractive waste generated would be largely limited to overburden. Not-to-standard products, dust, and similar wastes are recycled in the process or sold for different applications.

Various indirect extractive wastes arise in these industries. For instance, iron oxides are used in cement clinker production and for the respective wastes generated see under 'iron'. All processes are highly endothermic and as a result require large quantities of fuel. Extractive wastes resulting from e.g. coal mining are discussed in the respective sections below. The industries increasingly use waste carbon ranging from plastics, sewage sludge to animal meal in order to reduce their primary energy requirements. However, this requires careful feedstock and process control to reduce emissions (CEU, 2010b).
7.4. China clay

**Risk:**  
- Risks associated with tailings ponds  
- Discharge waters from hydraulic mining

**Counter-measures:**  
- Improved control on tailings ponds  
- Closed circuits of process waters to reduce water use  
- Dry mining, when possible

**Discussion:**
Very few clays used in the manufacture of ceramics can be used directly, but require disaggregation and the removal of coarser fractions. These sand and silt fractions can amount to 90% of the excavated material (DCC, n.d.). Some of these 'tailings' are backfilled or stacked in ponds, while others form a secondary resource as aggregates in the building industry (SCOTT *et al.*, 2005). Some of the clays are extracted by hydraulic mining with water jets, which facilitates the following classification steps, but can lead to significant waste water discharges into surface waters (UKEA, 2014). Recirculation of process water reduces the flow of water through the mine system. Dry mining is also practiced, but requires also large quantities of process waters to suspend the clays after crushing for size classification.

China clays are derived from the weathering of granites and may be enriched in the more resilient heavy minerals, such as zircon and monazite. These minerals in turn can be the source of heavy metals, REE, and uranium. The mica in china-clay tailings can also be a commercially viable source of lithium (SIAME & PASCOE, 2011). Other radionuclides (NORM), such as polonium can also be bound to the clays. These NORMs can become concentrated in scale and soot (in flue-stacks) during the various processing steps (READ *et al.*, 2004).

7.5. Refractory materials

**Risk:**  
- Risks associated with tailings ponds from bauxite mining

**Counter-measures:**  
- For alumina see 'aluminium'

**Discussion:**
The term refractory materials refers to a group of various materials that are capable to withstand temperatures above 540°C without physical or chemical degradation. The oxides of aluminium (alumina), silicon (silica), magnesium (magnesia) and calcium (lime) are the most important materials refractory materials. Fire clays, which are clays rich in hydrous aluminium silicates, are also widely used in the manufacture of refractory bricks.
Owing to the variation of source materials a generic assessment of the risks and wastes associated with their extraction process cannot be given. Alumina-based refractory materials are based on bauxite mining, which is discussed under 'aluminium'. Fire clays are mined from suitable resources, which in the past were e.g. associated with coal mines.

### 7.6. Asbestos including chrysotile

| Risk | • Atmospheric release of asbestos fibres from disposed of mine waste  
      | • Migration of fibres from disposed of mine wastes into groundwaters |
|------|------------------------------------------------------------------|
| Counter-measures | • Mining and (new) use ban in the European Union in force. |

**Discussion:**
The term 'asbestos' designates a group of naturally occurring fibrous serpentine or amphibole minerals with current or historical commercial usefulness due to their extraordinary tensile strength, poor heat conduction and relative resistance to chemical attack. The principal varieties of asbestos are chrysotile, a serpentine material, and crocidolite, amosite, anthophyllite, tremolite and actinolite, which are amphiboles. Exposure to asbestos, including chrysotile, causes cancer of the lung, larynx and ovary, mesothelioma (a cancer of the pleural and peritoneal linings) and asbestosis (fibrosis of the lungs). In consequence, its mining and use has been banned in many countries around the world, including the European Union (WHO, 2014).

Asbestos, particularly chrysotile, continues to be used and mined around the world at a level of around 2 million tonnes annually (USGS, 2016d).

### 7.7. Aggregates, sand and gravel

<table>
<thead>
<tr>
<th>Risk</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Counter-measures</td>
<td>Recycling of construction materials</td>
</tr>
</tbody>
</table>

**Discussion:**
The amount of waste generated by the extraction of sand and gravel for aggregates is minimal. Usually deposits close to the surface are worked and almost all the materials extracted can be turned into a marketable commodity. Fines from washing and sieving processes are returned to the pits.
The main issue may be competition between the use of sand and gravel layers as aquifers for drinking water and as a source of aggregates.

Recycled construction material replaces already a considerable amount of virgin sand and gravel in road construction and building.
8. Coal

8.1. Hard coal

<table>
<thead>
<tr>
<th>Risks:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Acid drainage from spoil heaps</td>
<td>• Heavy metal, arsenic, and radionuclide dispersal from acid</td>
</tr>
<tr>
<td>• Heavy metal, arsenic, and radionuclide dispersal from acid</td>
<td>(mine) drainage</td>
</tr>
<tr>
<td>• Structural failure of impoundments for mine residues, fly-ash</td>
<td>• Structural failure of impoundments for mine residues, fly-ash</td>
</tr>
<tr>
<td>and flue-gas desulfurication gypsum</td>
<td>and flue-gas desulfurication gypsum</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Counter-measures:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>• Selective mining, avoiding sulfide-rich strata and those with</td>
<td>• Engineering measures and regulatory control of impoundments</td>
</tr>
<tr>
<td>high ash content</td>
<td>• Engineering measures and regulatory control of impoundments</td>
</tr>
<tr>
<td>• Engineering measures and regulatory control of impoundments</td>
<td>• Engineering measures and regulatory control of impoundments</td>
</tr>
<tr>
<td>• Utilisation of fly-ashes and desulfurication gypsum as secondary</td>
<td>• Utilisation of fly-ashes and desulfurication gypsum as mine</td>
</tr>
<tr>
<td>raw materials</td>
<td>backfill</td>
</tr>
<tr>
<td>• Utilisation of fly-ashes and desulfurication gypsum as mine backfill</td>
<td></td>
</tr>
</tbody>
</table>

Discussion:
Hard coal continues to be a main source of energy particularly in thermal power stations world-wide. Hard coal production and consumption in Europe have steadily declined since the 1990s (EUROSTAT, 2015). However, domestic EU production only covers around 30% of EU consumption. Hard coal is mainly used for electricity generation and district heating while its use for individual domestic heating only plays a minor role today. Hard coal is also used for the production of coke (see below) required in the steel industry.

With many of the coal mines being closed in Europe, issues related to coal mine wastes are being increasingly externalised. However, hard coal burning produces considerable quantities of residues such as fly-ash from flue-gas scrubbing and gypsum slurries from flue-gas desulfurization. Most of these residues are disposed of in impoundments. Depending on the composition of the coal, the burning and the scrubbing process, certain fly-ashes exhibit pozzolanic (i.e. cement-like) behaviour and can be used as active ingredients in mortars and concretes e.g. for civil engineering applications. Fly-ash as additive improves the properties of concretes for many applications (c.f. EN450; ScotAsh, 2014). To this end a separation into several constituents may be needed. The glassy spheres of relatively uniform sizes that can be classed makes processed fly-ashes interesting as fillers etc. in various industries. Desulfurication gypsum can replace virgin, mined gypsum in many application (e.g. plaster-board production). For this reason this material is not considered a waste, but rather a product.
However, both fly-ash and desulfurization gypsum can contain radionuclides, heavy metals, and any other non-burnable toxic constituent from the original coal that become more concentrated in the residue compared to the coal. This may preclude their use (e.g. in dry-wall products) or restrict it to such uses, where exposures cannot occur (e.g. road bases).

Where coal is burned in power-stations close by the mines, both materials can also be used as backfill in the mine. This has the advantage of stabilising the mine against subsidence and convergence and, depending on the type of coal-seam and mining method, may increase the percentage of recovery: in classical room-and-pillar mining a certain amount of coal has to be left behind in order to support the roof of the mined out areas; by backfilling these mine voids, the remaining coal can be mined, once the backfill has solidified.

8.2. Coke

Coke is not actually a mined mineral resource, but a processed form of coal that is traded as a commodity. Its major application is in the steel-making industry, while domestic use for heating has virtually died out. It once was the major by-product from urban gas production. Its main waste product are tars and phenol-containing waste waters. While historically many of the wastes were actually utilised for a number of applications (disinfectants, biocides, fungicides, paints), their potentially carcinogenic nature has led to a gradual replacement.

Europe's coke production has significantly declined in line with the reduction of coal production (EUROSTAT, 2015), but there are still 47 coking plants in operation (http://www.crugroup.com/market-analysis/products/metallurgicalcokemarketoutlook?TabId=59963, accessed 23.03.16). Coke needs in the steel industry are now fulfilled to a large degree by imports from overseas, where Asia has the largest producers (http://www.statista.com/statistics/267892/coke-production-by-continent/, accessed 23.03.16). This also means that the respective risks are displaced to the coal-mining countries.

8.3. Lignite

<table>
<thead>
<tr>
<th>Risk:</th>
<th>Counter-</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Acid drainage from spoil heaps</td>
<td>• Selective mining, avoiding sulfide-rich strata and those with</td>
</tr>
<tr>
<td>• Heavy metal, arsenic, and radionuclide dispersal from acid (mine) drainage</td>
<td></td>
</tr>
<tr>
<td>• Water balance challenges</td>
<td></td>
</tr>
<tr>
<td>• Structural failure of impoundments for mine residues, fly-ash and flue-gas desulfurization gypsum</td>
<td></td>
</tr>
</tbody>
</table>


**measures:**

- high ash content
- Engineering measures and regulatory control of impoundments
- Utilisation of fly-ashes and desulfurication gypsum as secondary raw materials

**Discussion:**

Lignite (‘brown coal’) is mainly mined from relatively shallow deposits overlain by unconsolidated sediments. This means that they are usually mined in open-cast, so-called ‘strip mines’. Today the majority of the lignite in Europe is burned in commercial electrical power-stations. Domestic use has considerably declined since the early 1990s (EUROSTAT, 2015).

Mining produces two types of waste, the overburden and below-grade coal, that require separate management solutions. In strip mining using large excavators separation is effected by selective excavation and deposition. Mine operations are designed in a way that allows immediate backfilling of the excavated material. Top-soil is removed separately and stored for later re-use in re-vegetating the backfilled areas.

Mine waste management and mining legacy management are closely related and address the same range of problems. There are three major problems associated with most lignite mines: generation of so-called Acid Mine Drainage (AMD), slope stability in the mined-out pits, and the management of drainage waters.

Acid mine drainage is generated, when sulfide-bearing minerals in the overburden or the lignite itself are oxidised upon exposure to the air during the mining operation. Before mining, these minerals would have been below the water table with no or limited access of oxygen only.

AMD can normally not be avoided during operations and the respective drainage waters from the pit would be collected and treated by liming before discharge into surface water courses. Water treatment slurries are disposed of in the mined-out pit. Once an open-pit is being flooded the amount of AMD generation is reduced, but the water management to avoid AMD is a complex problem due to the seasonal instability of the water column in temperate climates.

The deposited overburden is of somewhat lower density than in its natural situation, consisting largely of loose sand. Any grading of slopes has to follow the natural angle in order to avoid collapsing slopes. Similarly, slopes in the mined-out pit are steeper than the natural angle and may require re-grading to attain stability. Slope stability will also change during any flooding of residual open-pits.
Too fast flooding can lead to unstable slopes. Collapsing slopes can result in landslides affecting significant areas around the open-pit mine.

Operating an open pit requires the pumping of large quantities of water and their discharge in surface water courses. This perturbs natural regional water balances over a time-scale of decades to centuries. During mining a metastable situation determined by the pumping rate will be attained. After the end of mining the flooding of residual pits requires careful management in order to avoid slope instabilities due to too fast flooding and the perturbation of river flows that may have been augmented by mine drainage waters for decades.

Most of the lignite is burned in power-stations close to the mines. Residues arising are bottom ash, fly-ash, flue-gas desulfurisation residues, as well as volatile organic carbons (VOCs) and CO$_2$, which are released to the atmosphere. The amount of both, bottom and fly-ash depends on the quality of the lignite and modern mining targets lignite seams with low ash content. As for hard coal, the fly-ashes can have beneficial and commercially attractive uses. However, lignite fly-ashes are more heterogeneous and may contain higher amounts of unwanted constituents (heavy metals, radionuclides, arsenic). This may limit their use to civil engineering applications, e.g. road construction. Therefore, large quantities are backfilled into the mined-out pits. Flue-gas desulfurisation residues arise as gypsum sludges and suffering from the same problem with undesirable constituents are also commonly deposited in mined-out areas. All of these residues may contain heavy metals, radionuclides, and arsenic that were originally incorporated in the accessory minerals to the lignite, such as pyrites. Due to the glassy matrix, there are only moderate environmental risks when these residues are backfilled. Both, heavy metals and radionuclides could pose certain health risks, when the residues are re-utilised, e.g. in dry-walls/plaster-boards.
9. Waste management costs

9.1. Data availability

Although operational and associated costs of mining and milling are of interest to several groups of stakeholders, such data are difficult to obtain. The main reason certainly is the commercial sensitivity of such data in an economically competitive environment. The situation is further complicated by the fact that within the EU there may be only one or a very small number of mines for some commodities. Some of the mines are also (still) state-owned, which makes (historic) operating cost assessments very difficult. This situation has hampered reliable and full life-cycle cost assessments in many related industries and there is no easy solution to this problem. The British consultancy Symonds Group Ltd. was tasked by the European Commission in 2001 to assess the cost of mine waste management and any improvements on it (Symonds, 2001). They identified a small number of commercial data sources that mainly serve potential investors into the raw materials market. It was beyond the scope of the present study to obtain data from commercial sources such as S&P Global Market Intelligence (http://www.snl.com/Sectors/metalsmining/).

9.2. Cost as a function of mine-type

The cost of mining is closely related to the cost of loosening and moving any rock masses. The deeper the mine and the harder the rock, the more costly a mine operation will be. For this reason, deep mines produce less waste by minimising mined volumes and targeting extraction. Deep mines also back-fill as much waste as possible into mined-out voids so as to avoid lifting mass to the surface, which is a slow process and constitutes a production bottle-neck.

Comparatively shallow strip mines - a technique mainly used in lignite mining, progress in the horizontal direction and are usually able to backfill most of the stripped overburden immediately into mined-out parts of the pit. 'Strip mines' usually do not require land for waste residue disposal outside the pit.

To the contrary, open-pit mines for ores and similar progress mainly in the vertical direction and have often not sufficient space inside the pit to dispose of removed overburden. Such mines tend to be associated with significant mining residue heaps.

Solution mining only generates small amounts of drill chippings from the construction of the necessary boreholes. These may be, however, contaminated with drilling fluids and oils and need to be disposed of in licensed facilities, which can be costly.
Quarries usually progress horizontally into hillsides, but sometimes also vertically. In more recent years underground quarrying comes into favour due to lower visibility and the deeper material being less weathered. Quarries generate waste from breakages during operation of cut stone and removal of unsuitable material. However, these wastes typically are either sold for aggregate or ballast, or are disposed of within the quarry. The cost of waste management does not appear to be an issue in quarrying.

A J. Rutquist (Boliden) is quoted in EU (2007) stating that the cost of mining for open pits is around 2€/ton, while that in deep underground-mines exceeds 15€/t. It is not known, whether these figures include the cost of waste management.

9.3. Cost elements

For many mining and milling operations the major cost factor in waste management is the management of tailings. As the ore-grades generally decline, the amount of ore processed for a given amount of product increases and in consequence the amount of tailings. As noted above, lower ore-grades require more intensive comminution, resulting in more difficult to dispose of tailings. This further increases the cost of management due to higher energy requirements for dewatering. As already noted, bringing tailings back into a (deep) mine in many cases may not be an economically feasible option due to the very unfavourable cost relations between placing tailings into tailings ponds, steeply inclined and sub-horizontal mine workings, with the latter being almost one order of magnitude higher in some instances (Symonds, 2001).

Depending on their respective properties and the mine's needs, mining and milling residues may also find beneficial uses within the operation as civil construction materials, aggregates, and similar, thus avoiding the cost of buying-in such materials. Back-filling serves several purposes, as it is not only a way to dispose of wastes, but also stabilises the mine voids, and reduces the volume requiring dewatering or ventilation. It also allows to mine areas between back-filled volumina, thus increasing the recovery rate for instance in coal and salt mines. Though additives, such as cements, may be required to stabilise the back-fill mass, back-filling in such instances is a productive activity and not only a cost-factor.

Selling off wastes for re-use, e.g. as aggregates may entail a variety of regulatory (for clearance) or standardisation (for market acceptance) costs. The cost of preparation including these costs together have to allow competitive pricing.
9.4. Life-cycle considerations

Life-cycle cost assessment should also be considered, when designing a waste management facility. Operating costs during the active mining and milling is only one aspect. An inexpensive and convenient method during the operational phase may entail higher closing and steward-ship (see above) costs. For instance, over-the-end tipping of spoils results in long, steep and uninterrupted slopes that will have to be re-graded during decommissioning, which involves significant amounts of earth-moving. Life-cycle planning would avoid such situations.

Symonds (2001) noted that moving from good practices in waste management to 'best practices' may entail only marginal costs, but that complete processes changes will entail substantial capital investment. Thus changing, for instance, treatment processes and feed-stocks in alumina production in order to reduce 'red mud' production, would require a complete rebuild of a mill at substantial capital outlay.
10. Research Initiatives

10.1. Context

The environmentally friendly and sustained supply of (mineral) raw materials has been figuring prominently on the research agenda of the European Commission for the past years. It has been driven largely by the expected supply shortages due to diminishing resources, but also by concerns over supply security due to the concentration of some 'critical' raw materials in certain countries, such as China. Also the environmental impacts from certain mining operations have been in the focus. There is a concern now, however, that these aspects may drop from the attention of politicians and policy-makers due to price drops resulting from oversupply in the wake of economic recessions in some parts of the world. There is a risk that mining and milling companies reduce their R&D activities. Many of the research and technological developments require a multi-year sustained effort in order to achieve a sufficiently high technology readiness level (TRL). Good practice in the supply of raw material will still require a sustained effort in order to achieve it (CSES, 2014).

The European Union's raw materials strategy is built on three pillars, namely the 'Raw Materials Initiative', the 'European Innovation Partnership', and the 'Horizon 2020' funding programme. The Raw Materials Initiative (RMI) itself rests on three pillars that aim to secure access for Europe to adequate supplies of raw materials, to secure a sustainable production, and to boost resource efficiency and a circular economy. Developing and promoting good practices in all aspects of mining, including waste management, is a key element to secure sustainable production. Regulatory instruments, such as legislation on wastes, will help to ensure resource efficiency and guide the way to a more circular economy. The Strategic Implementation Plan (SIP) for the European Innovation Partnership (EIP) again rests on three pillars, focusing technological, non-technological, and international co-operation factors. Providing the context for efficient and effective waste management, including the utilisation and re-reprocessing of mining wastes is a key aspect in securing a sustained and sustainable supply of raw materials to the European Union. The necessary research is funded under the umbrella of the Horizon 2020 framework.

The European Technology Platform on Sustainable Mineral Resources' (ETP SMR, http://www.etpsmr.org/) mission is to develop long-term research and innovation agendas for the European minerals industry and roadmaps for action at EU and national level. The ETP SMR Members act as a think-thank to EU affairs concerning the mineral resources Industries. The Members are all stakeholders across the raw-material value chain, overcoming the traditional fragmentation of
the mineral resources sector. The ETP SMR Vision is to modernise and reshape the European minerals industries, a fundamental pillar of the European economy. These include coal, metal ores, industrial minerals, ornamental stones, aggregates, smelters as well as technology suppliers and engineering companies. The ETP SMR aims at achieving societal, environmental and economic benefits, as well as strengthening the European research and technical (or technological) development. The ETP SMR vision is, *inter alia*, to ensure the supply of the mineral resources needed by the EU economy, while minimising the related environmental footprint (decoupling).

In order to support sustained roads to innovation in raw materials, the European Institute for Innovation and Technology (EIT, [http://eit.europa.eu/](http://eit.europa.eu/)) created in 2015 a Knowledge and Information Community (KIC) on raw materials ([http://eitrawmaterials.eu/](http://eitrawmaterials.eu/)). The partners in this KIC represent a large proportion of European mining and mining technology interests. An important aspect of its mission is to co-ordinate R&D efforts and to create synergies with a view to improve the sustainable and sustained supply of (mineral) raw materials for the EU. While a considerable amount of RTD is undertaken by the major, internationally operating mining companies, it is important that the EU remains at the leading edge of these developments in order to ensure an environmentally friendly supply. It is also expected that the KIC and the research actions discussed below will serve to focus the RTD activities in the European Union.

In the following sections an overview over current and likely future research on mineral resources and their exploitation is given. There is also a considerable body of industry research, but due to its 'commercial-in-confidence' nature, it is difficult to obtain information on it. Based on what is being published in research and professional journals, one can assume that the majority of it is process-related. In general, industry is averse to make step-changes and prefers evolutionary developments to minimise business risks.

In addition, there is a large body of (on-going) industrial and academic research on dam stability and related geo-engineering issues, but this has not been reviewed as belonging largely into the realm of civil engineering and is not necessarily mining-specific.

### 10.2. Current relevant research projects

**Project BIOMOre**

The aims of BIOMore (2015-2018) are three-fold:

*Economics:* The increasing shortage of technology metals (Cu, Zn, Ni, Pb, Co, Mo, Re, REE or precious metals) in the EU requires new and innovative yet environmentally sustainable mining technologies. BIOMOre could be a cost-
efficient and economical answer to this problem. Expanding pre-feasibility studies and related CAPEX and OPEX cost figures will be part of the project.

Technology: The BIOMOre objective is to develop an optimized technological concept for in-situ recovering of metals from the surface without the need of establishing an underground infrastructure. This technology, if successful, will make commodities accessible at depths greater than 1,500 m (Temperatures: 50 - 60 ºC) which are not exploitable using traditional underground methods.

Environment: The BIOMOre concept will reduce the environmental impacts of mining exploitation as a whole and improve chances for better public acceptance. The application of this new technology will of course be based on permits according to mining laws as well as environmental and water protection regulations.
Web-site: www.biomore.info/

Project CHROMIC
CHROMIC (effiCient mineral processing and Hydrometallurgical RecOvery of by-product Metals from low-grade metal containing seCondary raw materials, 2016-2020) aims to develop such new recovery processes for critical (Cr, Nb) and economically valuable (Mo, V) by-product metals from secondary resources, based on the smart integration of enhanced pre-treatment, selective alkaline leaching and highly selective metal recovery across the value chain. An overarching assessment of the related economic, environmental and health and safety aspects will be carried out in an interactive way to ensure that the developed technologies meet the requirements of the circular economy, whilst being in line with current market demand. The technology will be developed for two models streams (stainless steel slags and ferrochrome slags) with the potential of replication to numerous industrial residues across Europe. Involvement of society from early on will smooth the path towards implementation, so that the CHROMIC processes can contribute to securing Europe's supply of critical raw materials.

Project ENVIREE Among the secondary materials to be studied by ENVIREE (2015-2017) are those from mining activities that have been used for their original mineral content but are now considered as waste. This kind of waste is by far the most abundant weight-wise in Europe. Essentially there are some options for these materials. They can be simply left where they are hoping that there will be no leaching of any possible contaminants, or they can be used with improved methods to recover other elements than those originally sought. The ENVIREE project aims at complete extraction process proposal for these secondary sources of REE. It will investigate innovative leaching followed by
selective and effective separation of the metals. The selected processes will be developed to pilot scale processing using e.g. the existing hydrochemical test bed at Chalmers. In order to have a complete holistic view of the process, a life cycle assessment (LCA), strategic environmental impact assessment (SEA), energy efficiency and economic feasibility for the processes developed as well as finding optimal remediation procedure will be included. The project results will be brought to the end user represented by different industries from different parts of Europe and also third countries via dissemination, networking and market uptake efforts.

Web-site: [http://www.enviree.eu](http://www.enviree.eu)

**Project EURARE**

The main goal of the EURARE (2013-2018) project is to set the basis for the development of a European Rare Earth Element (REE) industry. It will safeguard the uninterrupted supply of REE raw materials and products crucial for sectors of the EU economy (including automotive, electronics, machinery and chemicals) in a sustainable, economically viable and environmentally friendly way. EURARE scientific and technical objectives are:

- Definition and assessment of exploitable REE mineral resources and REE demand in Europe;
- Development of sustainable and efficient REE ore beneficiation technologies, that will lead to the production of high grade REE concentrates and minimization of tailings produced;
- Development of sustainable REE extraction and refining technologies, to produce pure REE oxides, REE metals and REE alloys suitable for use in downstream industries;
- Development of a strategy for safe REE mining and processing;
- Yield demonstration of the novel EURARE REE exploitation technologies;
- Identification of novel sustainable exploitation schemes for Europe's REE deposits. A by-product from some of the processes being looked into is also the valorisation/reworking of bauxite processing residues ('red mud').

Web-site: [http://www.eurare.eu](http://www.eurare.eu)

**Project FAME**

FAME (Flexible and Mobile Economic Processing Technologies, 2015-2018) focuses on addressing a number of economic and environmental challenges to improve processing technologies and to recover valuable materials from low grade and / or complex feedstock’s ore by increasing the range of yields of recovered raw materials with lower energy consumption and minimising mine waste. In turn, this will reduce the environmental fingerprint whilst increasing the utilisation of residues.

Web-site: [http://fame-project.eu](http://fame-project.eu)
**Project FORAM**
The project Towards a World Forum on Raw Materials (FORAM, 2016-2018) will develop and set up an EU-based platform of international experts and stakeholders that will advance the idea of a World Forum on Raw Materials (WFRM) to enhance the international cooperation on raw material policies and investments. The global use of mineral resources has drastically increased and supply chains have become ever more complex. A number of global initiatives and organizations have been contributing to knowledge and information transfer, including the EC, UNEP International Resource Panel, the World Resources Forum, the World Material Forum, the OECD and others. It is widely felt that improved international resource transparency and governance would be beneficial for all, since it would lead to stability, predictability, resource-efficiency and hence a better foundation for competitiveness on a sustainable basis. The FORAM project will contribute to consolidate the efforts towards a more joint and coherent approach towards raw materials policies and investments worldwide. The project will in particular seek to engage the participation of G20 Member countries and other countries active in the mining and other raw materials sectors. FORAM will be the largest collaborative effort for raw materials strategy cooperation on a global level so far.

**Project I²Mine**
The recently completed FP7 project I²Mine (2011-2015) was aimed at developing the innovative methods, technologies, machines and equipment necessary for the efficient exploitation of minerals and disposal of waste, all of which will be carried out underground. The objective was to dramatically reduce the volume of surface transportation of both minerals and waste, to minimise the above ground installations and to reduce the environmental impact. The overall objective was to move towards a low visibility mine with near to zero environmental and societal impacts.

In the context of I²Mine the French National competence center for Industrial Safety and Environmental Protection, INERIS ([www.ineris.fr](http://www.ineris.fr)) also developed a decision support system ('GreenMining', [http://green-mining.ineris.fr](http://green-mining.ineris.fr)) for helping to identify best practices in mining.
Web-site: [http://www.i2mine.eu](http://www.i2mine.eu)

**Project IMPaCT**
The current mining paradigm calls for large 'world-class' deposits that require innovations in mining techniques to deal with low grades and large infra-structure to deal with high throughputs. High investment is not available in the current economic climate and many small companies have ceased to trade. The problem is
most extreme for critical raw materials that are produced in small quantities. The IMPaCT project (2016-2020) aims to develop a new 'switch on-switch off' (SOSO) mining paradigm to improve the viability of critical metal and other small complex deposits. SOSO centres around technological innovations in mining equipment design and mine planning to reduce the throughput of extracted material, infrastructure needs, land use, resource consumption, and waste. Successful SOSO projects require that mining and processing technologies can be adapted to multiple deposits and commodities. Risks associated with the approach are geological uncertainty, metallurgical variability and social acceptance. The project aims to develop the proof-of-concept of sustainable mining and processing solutions using case studies in the West Balkans, and subsequently to examine the step-changes that would be required for the technology to be applied globally. Dissemination activities include feedback to European and national policy-makers, and the mining industry in general.


Project INTMET

The INTMET (2016-2019) approach represents a unique technological breakthrough to overcome the limitations related to difficult low grade and complex ores to achieve high efficient recovery of valuable metals (Cu, Zn, Pb, Ag) and CRM (Co, In, Sb). Main objective of INTMET is applying on-site mine-to-metal hydro-processing of the produced concentrates enhancing substantially raw materials efficiency thanks to increased Cu+Zn+Pb recovery over 60%. Three innovative hydrometallurgical processes and novel extraction techniques will be developed and tested, aiming to maximise metal recovery yield and minimising energy consumption and environmental footprint. Additionally, secondary materials, such as tailings and metallurgical wastes will be tested as well for metals recovery and sulfur valorisation.

Web-site: not yet available

Project INTRAW

Certain countries around the world have been very successful in developing their own raw materials industry or to secure sufficient supply. The H2020 project INTRAW (2015-2018) was set up with the aim to develop co-operations between Australia, Canada, Japan, South Africa, and the USA with a view to exchange experiences and to develop strategies for Europe. INTRAW will also develop an International Raw Materials Observatory.

Web-site: http://intraw.eu

Project METGROW+

METGROW+ (2016-2020) will address and solve bottlenecks in the European raw materials supply by developing innovative metallurgical technologies for unlocking the use of potential domestic raw materials. The value chain and
Mining Waste Directive 2006/21/EC

Business models for metal recovery from low grade ores and wastes are studied. Within this project, both primary and secondary materials are studied as potential metal resources. Economically important nickel-cobalt deposits and low grade poly-metallic wastes, iron containing sludges (goethite, jarosite etc.) that are currently not yet being exploited due to technical bottlenecks, are in the focus. METGROW+ targets innovative hydrometallurgical processes to extract important metals, including Ni, Cu, Zn, Co, In, Ga, Ge from low grade ores in a cost-effective way. In addition, a toolbox for metallurgical systems is to be created, using new methods and combinations thereof. The unused potential of metal containing fine grained industrial residues are evaluated, and flexible hydrometallurgical processes are to be developed for both materials.

Web-site: http://metgrowplus.eu

Project MICA
The H2020 Project MICA (2015-2017) aims to provide the instruments for developing a quantitative knowledge base on mineral raw materials from an European perspective. The process will be stakeholder need-driven. To this end, the various stakeholders and their respective needs will be analysed. The available data sources will be mapped together with methods for demand and supply forecasts. The policy and regulatory framework that will be needed to ensure adequate supply will be assessed. The final product will be the outline of an expert system that can be interrogated by all stakeholders, including policy-makers.

Web-site: http://www.mica-project.eu

Project MIN-GUIDE
MIN-GUIDE (2016-2019) addresses the need for a secure and sustainable supply of minerals in Europe by developing a 'Minerals Policy Guide'. The key objectives of the project are to:

- Provide guidance for EU and Member States’ minerals policy making;
- Facilitate minerals policy decision making through knowledge co-production for transferability of best practice minerals policy, and
- Foster community and network building for the co-management of an innovation catalysing minerals policy framework.

This will be achieved through a systematic profiling and policy benchmarking of relevant policy and legislation in Europe, which includes the identification of innovation friendly best practices through quantitative indicators and a qualitative analysis country-specific framework conditions, as well as through the compilation of minerals statistics and reporting systems. These insights will form the basis for developing an interactive, tailor-made online 'Minerals Policy Guide'.

Another key feature of the MIN-GUIDE project will be knowledge co-production for minerals policy decision makers through Policy Laboratories exploring these
best practice examples along the whole mineral production value chain (exploration and extraction, processing, recycling and mine closure).

Web-site: not yet available

**Project MINATURA2020**

Extraction of natural mineral resources requires access to the land on or under which these resources are found. This land-use may compete with other land- and resources uses or may face certain land-use restrictions. Such competing uses may include protection of aquifers for drinking water, nature reserves, heritage sites, infrastructure and settlements, other mineral resources, forestry or agriculture. The H2020 project MINATURA2020 (2015-2018) is developing methods to assess such potential conflicts as a basis for developing policies to secure adequate access to mineral raw materials of 'public importance' in the European Union.


**Project MinFuture**

Global demand for minerals is growing rapidly. Global material supply chains linking the extraction, transport and processing stages of raw materials have become increasingly complex and today involve multiple players and product components. An interactive platform that provides transparency about existing approaches and information gaps concerning global material flows is needed to understand these global supply chains; developing this capability is critical for maintaining competitiveness in the European economy. Against this backdrop, MinFuture (2016-2018, kick-off 01/2017) aims to identify, integrate, and develop expertise for global material flow analysis and scenario modelling. Specific activities include the:

- Analysis of barriers and gateways for delivering more transparent and interoperable materials information;
- Assessment of existing model approaches for global material flow analysis, including the 'demand-supply' forecasting methods;
- Delivery of a 'common methodology' which integrates mineral data, information and knowledge across national boundaries and between governmental and non-governmental organisations;
- Development of recommendations for a roadmap to implement the 'common methodology' at international level;
- Creation of a web-portal as central access point for material flow information, including links to existing data sources, models, tools and analysis.


**Project MIN-Lex**

This study aims at summarising the mining and raw materials relevant laws and regulations around Europe.
Project PROSUM
The Objective of PROSUM (2015-2017) is to deliver the first Urban Mine Knowledge Data Platform. A centralised database of all available data and information on arisings, stocks, flows and treatment of waste electrical and electronic equipment (WEEE), end-of-life vehicles (ELVs), batteries and mining wastes will be developed. It will provide the foundation for improving Europe's position on raw material supply, with the ability to accommodate more wastes and resources in future. It will provide user friendly, seamless access to data and intelligence on mineral resources from extraction to end of life products with the ability to reference all spatial and non-spatial data. It will also provide screened interoperable data on products and mining waste in stock, waste flows, the nature of the waste and the materials and elements which they contain.
Web-site: http://www.prosumproject.eu/

Project Real-Time-Mining
The overall aim of Real-Time-Mining (2015-2019) is to develop a real-time framework to decrease environmental impact and increase resource efficiency in the European raw materials extraction industry. The key concept promotes a change in paradigm from discontinuous intermittent process monitoring to a continuous process and quality management system in highly selective mining operations. Real-Time-Mining will develop a real-time process-feedback control loop linking on-line data acquired during extraction at the mining face rapidly with an sequentially up datable resource model associated with real-time optimisation of long-term planning, short-term sequencing and production control decisions. The project will integrate automated sensor-based materials characterisation, on-line machine performance measurements, underground navigation and positioning, underground mining system simulation and optimisation of planning decisions, with state-of-the art updating techniques for resource/reserve models. The impact of the project is expected through a reduction in CO2-emissions, increased energy efficiency, and production of near-zero waste by maximising process efficiency and resource utilization. Hence, economically marginal or difficult to access deposits will become viable. This will result in a sustained increase in the competitiveness of the European raw material extraction through a reduced dependency on raw materials from non-EU sources.
Web-site: https://www.realtime-mining.eu/

Project RESLAG
The main objective of RESLAG is to valorise the steel slag that is currently not being recycled (right now it is partially landfilled and partially stored in the steel factories) and reuse it as a raw material for four innovative applications that contribute to a circular economy in the steel sector with an additional cross-
sectorial approach. These applications will be demonstrated at pilot level and led by end-user industries. Altogether open enormously the range of possibilities of taking profit from slag not only for the steel sector but also for many other sectors. Specific targets include a 25% reduction of landfilled and self-stored steel slag, a 10%-20% reduction of energy consumption by Thermal Energy Storage applied to off-gas from electrical arc furnaces, a 40-71 kg of CO₂ reduction per ton of produced steel, and a 20% reduction of primary raw materials.

Web-site: http://www.reslag.eu/

Project SCRREEN
SCRREEN (Solutions for CRitical Raw materials - a European Expert Network) was launched in December 2016. Since the publication of the first list of Critical Raw Materials (CRM) in 2010 by the Ad-hoc Working Group on CRM, numerous European projects have addressed (part of) the CRM value chain and several initiatives have contributed to gather (part of) the related community into clusters and associations. This led to the production of important, but unfortunately dispersed knowledge. Thus SCRREEN aims at gathering European initiatives, associations, clusters, and projects working on CRMs into a long lasting Expert Network on CRMs that includes relevant stakeholders, public authorities, and civil society representatives. SCRREEN will contribute to improve the CRM strategy in Europe by:

- Mapping primary and secondary resources as well as substitutes of CRMs,
- Estimating the expected demand of various CRMs in the future and identifying major trends,
- Providing policy and technology recommendations for actions improving the production and the potential substitution of CRM,
- Addressing specifically WEEE and other end-of-life products issues related to their mapping and treatment standardisation and
- Identifying the knowledge gained over the last years and easing the access to these data beyond the project.

The project consortium also acknowledges the challenges posed by the disruptions required to develop new CRM strategies, which is why stakeholder dialogue is at the core of SCRREEN: policy, society, R&D, and industrial decision-makers are involved to facilitate strategic knowledge-based decisions making to be carried out by these groups. A specific attention will also be given to informing the general public on modern societies’ strong dependence on imported raw materials, on the need to replace rare materials with substitutes and on the need to set up innovative and clean actions for exploration, extraction, processing and recycling.

**Project SLIM**
The project SLIM “Sustainable Low Impact Mining solution for the exploitation of small mineral deposits based on advanced rock blasting and environmental technologies” has been launched in December 2016. This initiative involves 13 European partners from Austria, Denmark, Sweden, France and Spain and will include the validation of technologies developed in mines located in Toledo and Granada (Spain) and in Eisenerz (Austria).

The objective of the project is to develop a cost-effective and sustainable selective low impact mining solution based on non-linear rock mass fragmentation supported by blasting models, mitigation actions for airborne particulate matter, vibration impacts, and nitrate leaching as applicable to small mineral deposits (including those with chemically complex ore-forming phases). This will be achieved through a new generation of explosives and an advanced automatic blast design software based on improved rock mass characterisation with a view to minimise rock-damage and far-field vibration impacts.


**Project SMART GROUND**
SMART GROUND (2015-2018) aims at improving the availability and accessibility of data and information on SRM (Secondary Raw Materials) in the EU, while creating collaborations and synergies among the different stakeholders involved in the SRM value chain. In order to do so, the consortium will carry out a set of activities to integrate all the data from existing sources and new information retrieved as time progresses, into a single EU database. Such database will also enable the exchange of contacts and information among the relevant stakeholders, which are interested in providing or obtaining SRM. The objectives are to:

- Collect quantitative and structured knowledge from existing SRM resources and to identify critical points and bottlenecks that hinder the effective use of SRM from landfills and dumps;
- Take stock of existing standards for raw materials and waste inventory and develop new ones for SRM, with the aim of validation at selected pilot sites;
- Integrate and harmonise the data and information collected by gathering them in a single EU database;
- Identify the most promising markets for the SRM;
- Evaluate and to analyse the environmental, economic and social impacts triggered by different processes;
- Analyse the existing legislation at EU and national level on waste management and diffusion of best practices;
- Facilitate the access to information on available SRM for end-users;
• Raise awareness among policy-makers and public opinion to support the social recognisability of the positive impact of dumps exploitation to obtain SRM.

Web-site: http://www.smart-ground.eu/

Project STRADE
STRADE (2015-2018) addresses the long-term security and sustainability of the European raw material supply from European and non-European countries. It will develop dialogue-based, innovative policy recommendations for a European strategy on future raw-material supplies. STRADE will initially concentrate on the industry perspective. Based on an analysis of the European mineral raw-material mining sector's competitiveness, the objective is to provide a strategy on how the EU can work to promote mining investment into and within the EU.

Areas in which there is a need to revisit and improve present policies and conditions to advance European competitiveness for inward investments will be identified. STRADE also addresses equipment and service suppliers, exploration companies and investors. EU-level dialogues should be initiated with mineral-producing countries to support European businesses in these sectors within non-EU countries. These activities will also serve as a gateway to future cooperation between the EU and other raw material-producing countries and will often address environmental challenges in the mining sector. Subsequently, STRADE will focus on government level and the EU's relation to mineral-producing countries.

Web-site: not yet available

Project VERAM
VERAM (2015-2018) aims to provide an umbrella and coordination function for the raw materials related research and innovation activities across the relevant European Technology Platforms (ETPs) and their national technology platforms, as well as related other stakeholders across the raw materials value chain in order to increase synergies and facilitate uptake of research results and innovation across the sectors and their value chains. The project will encourage capacity building as well as transfer of knowledge and innovation capability. It will coordinate the network of people involved in the different Horizon 2020 and other projects and initiatives and will provide a platform for identifying gaps and complementarities and bridge these. VERAM will also advise the European Commission and national governments of future research needs and tools to stimulate innovation and assist in overcoming the fragmentation in the implementation of the EIP on RM SIP. VERAM will look for mutually beneficial information exchange, encourage cross-fertilization between actions undertaken by different raw material industries and will speed-up exploitation of breakthrough innovations. The final result of the
activities will be a common long-term 2050 vision and roadmap for the relevant raw materials, including metals, industrial minerals and aggregates and wood.

Web-site: http://www.etpsmr.org/?post_projects=veram

Project ¡VAMOS!
¡VAMOS! (2015-2019) will enable access to high grade EU reserves of deeper seated minerals by providing a new Safe, Clean and Low Visibility Mining Technique and will prove the Environmental and Economic Viability of extracting currently unreachable mineral deposits, thus encouraging investment and helping to safeguard the EU access to strategically important minerals. The ¡VAMOS! mining technique will enable: re-opening of abandoned mines; extensions of open cut mines that are limited by stripping ratio, hydrological or geotechnical problems; and opening of new mines with limited environmental impacts in the EU. The specific objectives of ¡VAMOS! include to:

- Develop a prototype underwater, remotely controlled, mining system with associated launch and recovery equipment;
- Conduct field trials with the prototype equipment in abandoned and inactive mine sites with a range of rock types and at a range of submerged depths;
- Evaluate the environmental performance, the economic feasibility, productivity and cost of operation;
- Maximize positive social and economic impacts and enable the market uptake of ¡VAMOS! solutions by defining and overcoming the practicalities of the concept, proving the operational feasibility and the economic viability of the proposed technique;
- Contribute to social acceptance of the new extraction technique via public demonstrations in different EU regions, combined with public outreach and dissemination on new mining alternatives.

Web-site: http://vamos-project.eu

It may be noted that there are also industry-led initiatives, such as PROMETIA (www.prometia.fr) that aim at improving mining and processing techniques with a view of enhanced recovery and minimisation of waste generation.

There are also a variety of projects under the European Innovation Partnership on Raw Materials (EIP RM, https://ec.europa.eu/growth/tools-databases/eip-raw-materials/en/content/european-innovation-partnership-eip-raw-materials) that address directly or indirectly mining waste issues.

EIP BRAVO - Bauxite Residue and Aluminium Valorisation Operations
BRAVO followed from a 'Commitment' (see below) in the raw materials area and has the objective to:
- Boost the innovation capacity of the aluminium value chain with respect to secondary raw materials recovery;
- Foster international co-operation among 30 key players, their 54 members across the aluminium value chain from extraction to recycling;
- Create new value chains for the recovered raw materials from by-products of the manufacturing process by collaboration and integration of downstream industries;
- Test the viability of solutions and holistic processing concepts for secondary raw materials processing via pilot actions;
- Mobilise a significant part of the aluminium value chain to increase the impact of research, innovations and achieve technology transfer both along the aluminium value chain and from parallel industries such as recycling;
- Enhance the conditions of the raw materials value chain in order to optimise raw materials flows through improved cooperation of actors;
- Promote socially acceptable, environmentally responsible and economically viable technologies;
- Recognise waste as a resource: generation of a more valuable waste that can be processed to recover critical raw materials.

Web-site: [http://bravoeip.eu](http://bravoeip.eu)

All these initiatives address the issue of resources efficiency by comprehensive extraction of (metal) value from the materials mined and by utilisation of mining residues, thus minimising the amount of residues to be managed as waste. Under the heading 'urban mining' some of these projects also address the paradigm of circular economy by identifying dormant stocks that can be brought back into the active cycle of materials use. It is also notable, that the majority of these projects not only address the technical issues themselves, but also their socio-economic context.

### 10.3. Future research activities

The 'Horizon 2020 Work Programme 2016-2017 in the area of Climate action, environment, resource efficiency and raw materials' (EU, 2016) outlines a number of calls on ensuring the sustainable supply of raw materials to the EU. The call proceeds in two stages with deadlines in March 2016 (projects awarded under this round of calls have been listed above) and March 2017. Below are listed a number of calls that will implicitly address mining and milling waste issues through improved or alternative processes in mining and milling.


- **a) Sustainable selective low impact mining (2016)**
For instance project SLIM above

b) *New technologies for the enhanced recovery of by-products (2016)*
- For instance project ENVIREE above

c) *New sensitive exploration technologies (2017)*
- Achieving the objectives of the EIP on Raw Materials, particularly in terms of ensuring the sustainable supply of raw materials to the EU and improving supply conditions within the EU;
- Pushing the EU to the forefront in the area of sustainable exploration technologies and solutions through generated know how (planned patents, publications in high impact journals and joint public-private publications etc.);
- Increasing the reserves of various primary raw materials within the EU;
- Reducing the exploration costs for the industry through new cost-effective exploration technologies, while safe-guarding environmental stability;
- In longer term improving the competitiveness of and creating added value and new jobs in raw materials producing, equipment manufacturing, information and communication technologies and/or downstream industries;
- Improving the awareness, acceptance and trust of society in a sustainable raw materials production in the EU.

**SC5-14-2016-2017: Raw materials innovation actions**

*a) Intelligent mining on land (2016)*
- For instance project Real-Time-Mining above

*b) Processing of lower grade and/or complex primary and/or secondary raw materials in the most sustainable ways (2017)*
- Contribute to achieving the targets of the EIP on Raw Materials, particularly in terms of innovative pilot actions on processing and/or recycling for innovative production of raw materials;
- Improve economic viability and market potential that will be gained through the pilot, leading to expanding the business across the EU after the project is finished;
- Create added value and new jobs in raw materials producing, equipment manufacturing and/or downstream industries;
- Optimise raw materials recovery (increased yield and selectivity) from low grade and/or complex and variable primary and/or secondary resources;
- Push the EU to the forefront in the area of raw materials processing technologies and solutions through generated know how (planned patents, publications in high impact journals and joint public-private publications etc.);
- Lead to unlocking substantial reserves by giving economic viability to new or today unexploited resources within the EU;
• Improve the environmental performance, including reduction in waste generation and a better recovery of resources from generated waste;
• Improve the health and safety performance of the operations; improve the awareness, acceptance and trust of society in a sustainable raw materials production in the EU.

c) Sustainable metallurgical processes (2017)
• Contribute to achieving the targets of the EIP on Raw Materials, particularly in terms of innovative pilot actions for innovative production of raw materials;
• Improve economic viability and market potential that will be gained through the pilot, leading to expanding the business across the EU after the project is finished;
• Optimise metal production (increased yield and selectivity) from primary and/or secondary resources, while keeping competitive process performance in terms of resource and energy efficiency;
• Push the EU to the forefront in the area of metals processing and refining technologies and solutions through generated know how (planned patents, publications in high impact journals and joint public-private publications etc.);
• Create added value and new jobs in metallurgy, equipment manufacturing and/or downstream industries;
• Improve the environmental (control of emissions, residues, effluents), health and safety performance of the operations;
• Improve the awareness, acceptance and trust of society in a sustainable raw materials production in the EU.

SC5-15-2016-2017: Raw materials policy support actions
• c.f. project SCRREEN above

b) Good practice in waste collection systems (2017)
• Of relevance in a circular economy context in order to reduce virgin resource use

c) Optimising collection of raw materials data in Member States (2017)
• Probably will be a follow-on and complementary to the MICA project.

d) Linking land use planning policies to national mineral policies (2017)
• Probably will be a follow-on to the MINATURA2020 project.

e) EU network of mining and metallurgy regions (2017)
• Achieving the objectives of the EIP on Raw Materials in terms of improving conditions for sustainable access and supply of raw materials in the EU;
• Creating a longer term sustainable network;
• Establishing operational synergies between R&I investments and ESIF to improve R&I infrastructure and capacity and to foster market uptake and replication of innovative solutions in the relevant fields;
• Improved framework conditions at regional level leading to a more transparent and secure environment for investment in new mining and metallurgy projects in the EU and economic growth in the regions;
• Improving awareness of the importance of raw materials for our society and about new ways of mining taking into account environmental, health and safety considerations;
• Helping stakeholders to make informed decisions about new mining and metallurgy projects in the EU through engagement of local communities, facilitating social agreements, improving the awareness, gaining citizens' acceptance and trust in a sustainable raw materials production in the EU;
• Effective implementation and widespread use of the Social Licence to Operate (SLO) guidelines and toolbox in practice.

Recently, two 'Commitments' have been submitted by relevant consortia.

f) EU network of regions on sustainable wood mobilisation (wood supply) (2017)

• Not relevant here

**SC5-21-2016-2017: Cultural heritage as a driver for sustainable growth**

European cities and rural areas are unique cultural landscapes full of character at the core of Europe's identity. They are examples of our living heritage which is continually evolving and being added to. However, some of them are facing economic, social and environmental problems, resulting in unemployment, disengagement, depopulation, marginalisation or loss of cultural and biological diversity. These challenges create demand for testing and experimenting with innovative pathways for regeneration. Cultural heritage (both tangible and intangible) can be used as a driver for the sustainable growth of urban and rural areas, as a factor of production and competitiveness and a means for introducing socially and environmentally innovative solutions. The overall challenge is to go far beyond simple conservation, restoration, physical rehabilitation or repurposing of a site and to demonstrate heritage potential as a powerful economic, social and environmental catalyst for regeneration, sustainable development, economic growth and improvement of people's well-being and living environments.

Many of the former mining areas around Europe face these problems and much of the culture heritage associated with it is under threat. Dealing with the mine legacies, including mine wastes, would open up opportunities for revival together with the interest of re-opening some of the mining in order to increase the supply security for Europe.
SC5-17-2016: ERA-NET Co-fund on Raw materials
The European Commission also fosters the co-ordination of nationally and internationally funded research activities in the raw materials sector through the ERA-NET (http://ec.europa.eu/research/era/era-net-in-horizon-2020_en.html) co-funding mechanism. This mechanism has been extended by the launch of the ERA-MIN 2 programme on 2 December 2016 (http://www.era-min.eu.org/news/134-era-min-2-officially-launched). ERA-MIN 2 is a pan-European network of the main R&I funding organisations, consisting of 21 public funding organisations from 18 countries/regions: 13 EU Member States countries/regions (Belgium-Flanders, Finland, France, Germany, Ireland, Italy, Poland, Portugal, Romania, Slovenia, Spain, Spain-Castilla y Léon, Sweden), one EU Associated Country (Turkey) and four third countries (Argentina, Brazil, Chile and South Africa). Participation in ERA-MIN2 depends on the Member States pledging contributions to the fund supporting the programme.

Apart from the above more technical research programmes, the EU also addresses also the context of raw materials supply:

SC5-25-2016: Macro-economic and societal benefits from creating new markets in a circular economy
This action is aimed at
- Facilitating a better understanding and operational use of the current evidence base, including reliable datasets and projections;
- Identification of market and societal impacts of resource and waste flows – from extraction to end of life;
- Identification of innovative approaches based on the circular economy concept in Member States;
- Assessment of their economic, societal and resource-efficiency impact on existing or new markets;
- Estimation of such impacts in the short, medium and long term; and
- Estimation and assessment of the macro-economic, societal and environmental costs and benefits of mainstreaming such approaches.

The European Commission also established the instrument of 'Commitments' to promote particular areas of research. With these 'Commitments' groups of stakeholders set out particular areas of research that they recognise as important and that they wish cover in future EU-funded projects. These 'Commitments' typically will result in a proposal under the funding instruments discussed above, but will also be used in the formulation of future calls under H2020 or beyond. Relevant 'Commitments' submitted by March 2016 include:
Safe & Productive Mining Waste Facilities
This Commitment recognises that classification of secondary resources and slope stability are key to making existing and future mining waste disposal sites safe and productive. The first aim of this commitment is to develop the methodology for classifying the mineral content and exploitation potential of mining waste disposal sites, and - in connection with this - develop a toolbox for classifying these sites to facilitate environmental and societal impact as well as economic value assessment. This will help identify recovery or other compound-based uses from this waste and drive market uptake. The second aim of this commitment is to develop novel approaches to the design of new waste disposal sites and the maintenance of existing sites so as to prevent and/or mitigate slope stability problems which can lead to disaster. By accomplishing these R&D actions, EU businesses will be in a much better position to design safer, sustainable waste disposal facilities which can be maintained and exploited.


CUMiHR - Continuous Underground Mining of Hard Rock Minerals
The main economic, technological and environmental challenges of mining include reducing high investment costs, reducing generation of waste and large tailings, identifying and addressing environmental impacts on the marine ecosystems, and improving flexibility, automation and safety of operations.

The underground mining industry mining minerals in hard rock, defined as typically >150 MPa compressive strength, use methods and processes that in many cases initially was developed in the early 19th century. These methods have safety, environmental and efficiency issues that need to be solved to increase productivity and reduce cost in mining, i.e. for a resource efficient, selective and sustainable production of raw materials in the future.

This project will address the need of improving underground rock excavation by replacing the traditional Drill and Blast (D&B) method in mining for hard rock with a technology using Mechanical Rock Excavation (MRE). The project intends to demonstrate MRE technology in a pilot action/plant.


EHI - Creation of a European Hydrometallurgical Institute
The objectives of this commitment are to:

- Create an independent service provider for up-scaling and integrating hydrometallurgical processes: up-scaling facilities in ore-processing and pyro-metallurgy already exist in Europe. Their expertise enables
innovation in primary and secondary raw materials' production in Europe. To propose a full technological offer, an open hydrometallurgical pilot facility is required;

- Enable access to low grade, poly-metallic resources in Europe: primary and secondary resources in Europe are often complex and difficult to valorise. There is a need to foster innovation in extractive metallurgy to access these resources;

- Develop eco-conceived extractive processes: in a context of increased awareness to environmental issues, innovative hydrometallurgical processes need to maximize resource efficiency, to minimize their carbon and water foot-print, to produce safe effluents and solid wastes.


EUROPEM - Creation of a European research network on ore processing and extractive metallurgy

The objectives of the commitment are to:

- Develop innovative technical solutions to optimize raw materials and waste treatment: accessing strategic materials is critical; so it is of paramount importance to extend the knowledge base in processing and extractive metallurgy to optimize the transformation of ore or waste stream into valuable materials;

- Enhance EU skills in mineral processing and extractive metallurgy of ores and industrial residues: industrial companies cannot afford employing all the specialists required to support their activities, but they need these specialists to exist in Europe and they need to know where to find them; EUROPEM will provide access to these specialists;

- In the longer term, boost the innovation capacity of the EU raw materials related sectors by training a new generation of skilled engineers and metallurgists, the network will contribute to expand the future European innovation potential.


REMIND - EU Responsible mining demonstrations: best practice and capacity building

The objectives of the commitment are to:

- Enhance the social acceptance of non-energy mineral raw materials extractive activities is a key to the sustainable supply of these raw materials from European sources, one of the three pillars of the EU Raw Materials Initiative;
• Develop and implement an EU 'Responsible Mining' concept, based on existing experience at EU and international levels;
• Develop multi-stakeholder dialogue in support of sustainable non-energy extractive industries;
• Develop and promote a 'EU Responsible Mining Charter' and related sustainable performance reporting, building on existing sustainability indicators frameworks and reporting guidelines, with suggestions on possible needs for additional or improved indicators;
• Foster the development of institutional and corporate capacities to implement the concept.


ENTRIE - Euromines Network for implementation and exchange on Non-Technological Raw-Materials Innovation in the EU
Euromines, as the recognized representative of the European metals and minerals mining industry to the European Institutions and a service provider to its members in the Member States, wishes to engage its network of membership for the effective implementation of the SIP. Therefore EU originating actions need to be taken to national, regional or local level. Member States have the sovereign right to exploit their own resources pursuant to their own economic, social, environmental and developmental policies. The natural endowment with primary resources depends very much on geology and the availability of secondary resources, the historical development of the country and its economy and the national economic policies. Euromines provides a suitable network for this implementation, cooperation and for the exchange of information throughout the sector within Europe and links to the mining community throughout the world.


EURELCO - European Enhanced Landfill Mining Consortium
The objectives of EURELCO is to be a an open, quadruple helix (multi-stakeholder) network that supports the required technological, legal, social, economic, environmental and organisational innovation with respect to Enhanced Landfill Mining within the context of a transition to a circular, low carbon economy. Enhanced Landfill Mining is defined here as the safe exploration, conditioning, excavation and integrated valorisation of (historic, present and/or future) landfilled waste streams as both materials (Waste-to-Material, WtM) and energy (Waste-to-Energy, WtE), using innovative transformation technologies and respecting the most stringent social and ecological criteria.

EURELCO Web-site: http://www.eurelco.org/

MetNet - European Pilot Plant Network for Extractive Metallurgy and Mineral Processing
The objectives of MetNet are to:

- Create an independent and collaborative network to provide services and facilities for up-scaling of metallurgical and mineral processes in Europe. Pooling expertise of existing up-scaling facilities in Europe to create an easy-access holistic pilot-plant facility network for mineral processing and metallurgical treatment that will enable ideas and research to come into industrial use faster;
- Secure competence for European industry in metallurgy and mineral processing, strengthening competences by providing access to industrial environment for graduates, post-graduates, other academics and technical staff from industry for practical training to convert theoretical knowledge into practice;
- Boost innovation and job creation. Initiating joint cross-sectorial projects for innovative metallurgy and mineral processing and acting as an independent technological 'think-tank'. The combination of knowledge and processes at the facilities will lead to the development of new techniques and offers, securing future supply of raw materials and metals in Europe and supporting the development of new activities and companies, e.g. technology providers.

METNET Web-site: http://metnet.eu/

I²Mine-pilot - Fully automated mineral winning process/system including near-to-face processing and backfilling for deep metal mines
The objective of the project is to establish a pilot installation of an integrated minerals extraction/processing process for deep metal mines that will be based on developments of innovative methods, technologies, machines and equipment for mining at great depths. The development work is envisaged to be carried out mainly in the frame of I²Mine (www.i2mine.eu) and I²Mine-2 as well as in the frame of the Swedish 'Smart Mine of the Future' study. The installation should comprise (among other things):

- Systems for characterising resources in terms of geo-metallurgy and rock mechanics linked and fully utilised in production planning, mining and processing;
- Autonomous, highly selective mineral extraction processes and machinery continuously exploiting deposits in greater depths;
• New near-to-face pre-concentration and processing methods including fully automated backfilling based on very low content ore.


OPTIMIN 2020 - Optimizing the Minerals Policy Framework at EU and National Levels by 2020

Developing EU mineral resources is challenging due to reduced access to resources, public opposition, problematic permitting processes, inconsistent minerals policies, heterogeneous legislative frameworks, and a scarcity of reliable data. The objective of this commitment is to contribute to ensuring a stable and competitive supply of raw materials from EU sources to promote good governance and facilitate public acceptance. Sub-objectives are to enhance EU efforts to harmonize national mineral policies and plans, as well as permitting and reporting on primary and secondary minerals, based on best practice, so as to ease the access to primary and secondary resources, improve transnational permitting procedures, contribute to the definition of transnational standards for exchange of data and knowledge, and offer a more transparent and participative exchange of ideas with stakeholders.


While the call mentioned above concerns immediately mining and the extraction of raw materials, in the context of the move towards a circular economy calls concerning industrial production processes would also be relevant, as they address the demand for virgin raw materials, e.g. CIRC-01-2016-2017 (Systemic, eco-innovative approaches for the circular economy: large-scale demonstration projects) and CIRC-04-2016 (New models and economic incentives for circular economy business). Also the calls under SPIRE have the objective of resources efficiency (SPIRE PPP – Sustainable Process Industry through Resource and Energy Efficiency Public-Private Partnership).

The Commission has opened discussions in April 2016 with a wide variety of stakeholders on the scope and content of the final round of calls under H2020 for the period of 2018-2020. This allowed to lobby for maintaining the interest in an environmentally friendly and sustained supply of mineral raw materials for the European Union. The ‘presidency event’ in Bratislava in the context of the Slovak presidency of the Council of the European Union, gave also the opportunity to influence the raw materials-related research agenda for H2020.
RARE³
RARE³ represents the Katholieke Universiteit (KU) Leuven Research Platform focusing on the Advanced Recycling and Reuse of Rare Earths and other Critical Metals (indium, germanium, tantalum, cobalt, etc.). As part of the comprehensive zero-waste approach, RARE³ performs fundamental, strategic and applied science in order to develop recycling processes for complex end-of-life products (e.g. permanent magnets, lamp phosphors) and newly produced and historically landfilled industrial residues containing critical metals. These residues include bauxite residue (red mud), goethite, phosphogypsum, metallurgical slags, flotation tailings etc. Research activities within RARE³ are:

- The use of ionic liquid technology (‘ionometallurgy’) for the recovery, separation and purification of critical metals;
- The application of methods of process intensification to improve the recovery methods; and
- The development of novel electrometallurgical processes. To corroborate the environmental benefits of the RARE³ recycling processes, novel Life Cycle Assessment (LCA) methodologies are developed and implemented.

Web-site: http://www.kuleuven.rare3.eu
11. Conclusions

The majority of the processes discussed in the preceding chapters are mature and safe when implemented following best-practice recommendations. For existing operations there may be, however, discrepancies between the implementation as designed and as built. The reasons for this include economic pressures that may lead to 'cutting corners' and an inadequate regulatory oversight that redresses such situations. Another reason is that many facilities have existed for years or even decades and were not constructed according to what is considered today as best-practice. These may constitute legacy situations that are technically difficult and costly to resolve. In some cases ownership issues may arise, particularly in the Eastern European countries, where operation paradigms have changed dramatically in the early 1990s. The multitude of environmental remediation programmes financed *inter alia* by the European Union have shown that addressing these legacy sites is costly.

Tailings ponds often constitute an inherent safety risk, as they have to retain large quantities of (semi-)liquid tailings with earth-dams. In most cases generation of tailings as part of the ore processing cannot be avoided. However, more targeted extraction can help to reduce the amount of tailings produced. Current research projects aim to develop strategies and techniques for such more targeted extraction. There are also techniques available to thicken tailings before disposal, so that they constitute a lower inherent risk should dams fail. This simplifies also their long-term management. Regulatory oversight in form of periodic inspections during construction and operation may have to be strengthened in various jurisdictions.

*In situ*-leaching can reduce significantly the environmental impact from surface and deep mining and will reduce the amount of mining and milling waste, in particular tailings, to be managed to a minimum. However, the leaching systems have to be carefully controlled hydraulically in order to prevent the contamination of surrounding aquifers. Remediation may take years. On the other hand, many mineral bearing strata would not be suitable for drinking water production in any case.

In some cases it would be possible, in principle, to change feed-stocks and/or milling processes. For instance, alternative processes to those currently used for alumina production would significantly reduce the amount of 'red mud' being produced. These changes would, however, incur significant costs in rebuilding plants etc. and have not reached yet a sufficiently high technology readiness level. Sponsored research could advance this. However, the processes will have to be competitive at a global scale.
However, while many new processes to avoid or valorise process residues are being developed and tested at pilot-scale, the key question are the cost and the marketability of the products. When there is no market that can absorb these new products and that ensures a commercial profit or at least gives a significant cost reduction for the producer, these new value chains will not be taken up.

When changing processes to avoid hazards or reduce environmental impacts, one needs to do this on the basis of a comprehensive life-cycle impact and cost assessment. Focusing unilaterally on particular technological aspects may otherwise overlook important impacts and cost arising at other stages of the life-cycle. Alternative processes that may result in less on-site hazards may actually be more environmentally costly due to increased energy expenditure resulting in larger CO₂-footprints.

In many instances the industry has already optimised their processes over a wide range of parameters within the given economic, regulatory, and organisational setting. Moving to less well-established processes in order to achieve incremental improvements in environmental safety may not entail sufficient economic benefits to take the risk of investment. If these environmental benefits can be proven over the life-cycle, it may be worthwhile to investigate providing e.g. tax incentives to cover the investment risks.

It should be noted that a significant part of the processes discussed in this report actually do take place outside the European Union territory. While mining and processing companies registered in the EU will have to adhere to EU legislation for operations outside the EU, there is no obligation to do so for foreign companies selling mining products to the EU.

The review of current and anticipated research programmes and projects at EU-level (which can be considered to reflect similar activities at national level) show a strong focus on resource efficiency together with the avoidance of mining residues that need to be managed as waste.

Policies and regulations implicitly interfere with a free market economy, being either restrictive or subsidising. Providing for the possible needs of future generations may be a sufficient justification for interference in order to minimise resources uses and foster re-use/recycling.

A number of policy options have been identified that can be formulated as objectives, to be achieved considering the prevailing global economic context. Namely, 'comprehensive' extraction could be made the leading principle,
considering, however, technical and market constraints, as well as potential indirect costs, such as the CO₂ footprint.

It could be also made mandatory to analyse and segregate for disposal wastes from mining and milling in order to facilitate their later recovery. Recording their exact location and depositing this information with relevant government or EU bodies would help to create an EU-wide map of such resources for future use. It has been shown that for thermodynamic reasons a 100% efficiency in recycling/re-use can never be achieved and that all materials uses are associated with some dispersive losses. For this reason, and also as long as we expect economic growth, a 'circular economy' will not obviate the need for mining.
12. References


INTERNATIONAL CYANIDE MANAGEMENT INSTITUTE (n.y.): Cyanide Management Code.- http://www.cyanidecode.org (accessed 17.05.16)


13. Abbreviations and glossary

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
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<tbody>
<tr>
<td>Ag</td>
<td>Silver</td>
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<tr>
<td>Al</td>
<td>Aluminium</td>
</tr>
<tr>
<td>AMD</td>
<td>Acid Mine Drainage</td>
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<tr>
<td>Au</td>
<td>Gold</td>
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<tr>
<td>Beneficiation</td>
<td>The process of concentrating ores for further processing</td>
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<tr>
<td>CAPEX</td>
<td>Capital expenditure</td>
</tr>
<tr>
<td>Comminution</td>
<td>The reduction in grain-size of ores to such a size that ore-minerals and gangue minerals can be separated</td>
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<tr>
<td>CRM</td>
<td>Critical Raw Materials (as per lists issued e.g. by the EU)</td>
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<tr>
<td>Cu</td>
<td>Copper</td>
</tr>
<tr>
<td>ETP</td>
<td>European Technology Platform</td>
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<tr>
<td>EIP</td>
<td>European Innovation Partnership</td>
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<tr>
<td>ETP SMR</td>
<td>European Technology Platform on Sustainable Mineral Resources</td>
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<tr>
<td>Fe</td>
<td>Iron</td>
</tr>
<tr>
<td>Gangue</td>
<td>Minerals of no commercial value associated with ore minerals</td>
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<tr>
<td>Hazard</td>
<td>A hazard is a situation that poses a level of threat to life, health, property, or the environment</td>
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<tr>
<td>Hg</td>
<td>Mercury</td>
</tr>
<tr>
<td>MPa</td>
<td>(Mega)pascal; 1 MPa = 1 000 000 Pa</td>
</tr>
<tr>
<td>Nb</td>
<td>Niobium</td>
</tr>
<tr>
<td>NORM</td>
<td>Naturally Occurring Radioactive Materials</td>
</tr>
<tr>
<td>OPEX</td>
<td>Operating expenses</td>
</tr>
<tr>
<td>Overburden</td>
<td>Geological materials that overlie ores and other materials of commercial interest and which must be removed to provide access to the latter</td>
</tr>
<tr>
<td>REE</td>
<td>Rare Earth Elements</td>
</tr>
<tr>
<td>RM</td>
<td>Raw materials</td>
</tr>
<tr>
<td>RTD</td>
<td>Research and Technological Development</td>
</tr>
<tr>
<td>Risk</td>
<td>= probability of event occurring x impact of event occurring</td>
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<tr>
<td>SIP</td>
<td>Strategic Implementation Plan</td>
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<tr>
<td>Sn</td>
<td>Tin</td>
</tr>
<tr>
<td>Term</td>
<td>Definition</td>
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<tr>
<td>-------</td>
<td>------------------------------------------------</td>
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<tr>
<td>Tailings</td>
<td>Process residues from the beneficiation of ores etc., particular from grinding and washing processes</td>
</tr>
<tr>
<td>Ti</td>
<td>Titanium</td>
</tr>
<tr>
<td>TRL</td>
<td>Technology Readiness Level</td>
</tr>
<tr>
<td>VOC</td>
<td>Volatile Organic Carbon</td>
</tr>
<tr>
<td>WEEE</td>
<td>Waste Electrical and Electronic Equipment</td>
</tr>
<tr>
<td>Zn</td>
<td>Zinc</td>
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In the aftermath of two major accidents involving the spill of hazardous extractive waste, the Mining Waste Directive 2006/21/EC was adopted at EU level with the aim to prevent, or reduce as far as possible, the adverse effects from extractive waste management on health and the environment.

The deadline for transposition of the directive by the Member States expired on 1 May 2008. Research indicates that all Member States (EU-27) have experienced transposition problems in terms of ‘timing’ or ‘quality’ or both.

It appears that the majority of Member States have adopted the measures needed to implement the provisions of the directive, but the practical implementation of some aspects remains problematic.

The quality of available data does not allow for the complete picture of practical implementation of the directive to be fully outlined and assessed. While EU legislation on the management of extractive waste is still relevant to real needs, the levels of effectiveness and efficiency across the EU may vary from one Member State to another.

This European Implementation Assessment, which is intended to support the Implementation Report being prepared by European Parliament’s Committee on the Environment, Public Health and Food Safety, makes recommendations for action aimed at improving the identified shortcomings.

The study also sheds light on the prospects for extractive waste management in the context of the ‘circular economy’ concept.