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Near-zero-waste recycling of low-grade sulphidic mining waste for critical-metal, mineral and construction raw-material production in a circular economy (NEMO)

D4.1

Report on legislative/regulative requirements for transport and processing of mining residues in the EU and construction product standards and certification procedures

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Executive Summary

This deliverable report aims to 1) facilitate the exchange of materials for testing amongst partners in the NEMO project, and 2) define the regulative framework for processing of mine tailings into construction materials and products. To this double purpose, the relevant legislative and regulative documents on the European and national level were reviewed. In addition material property specifications for the targeted construction product applications were derived from European and national product standards and prescriptions.

Regarding material logistics, it can be concluded that materials which are already classified as waste have to be shipped accordingly. Regarding the mine tailings, this in general applies to all dumped materials which are not part of an ongoing production process. On the contrary, all material samples which are directly taken from an ongoing ore refining process are not considered as waste materials and therefore do not fall under the waste shipment directive. These material samples can therefore be shipped like other ordinary mineral products.

As regards to technical construction product specifications, the considered product types were 1) constituent of common cement, and 2) construction aggregates.

1. When used as constituent of common cement or supplementary cementitious material (SCM), calcined mining tailings could classify under constituent type Q, i.e. natural calcined pozzolana, if the material property requirements can be complied to, and if suitability for use in terms of concrete performance and durability can be proven. The material property requirements for use in common cement or as direct addition to concrete were summarized.
2. When used as construction aggregate, the material property requirements depend largely on the targeted end use. Different requirements apply for different applications. A distinction is made between unbound and bound applications and typical material requirements for use in civil works or concrete were described.

In case technical product requirements can be met, then permission to use the processed residues in construction materials is pending on compliance to environmental legislation. A review was made of the EU waste directive and its implementation in several member states to define limits in total concentrations and leaching of pollutants from construction products.

The results reported in this deliverable will act as a guideline to follow up activities in Work Package 4 by facilitating the exchange of materials in the pilot and demonstration activities, and by setting targets for material or product properties for construction applications in Tasks 4.3 and 4.4.

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1 Introduction

Within the NEMO project, different types of ores, tailings and/or waste materials will be treated in order to recover residual metals, collect possible hazardous components and to convert the mineral fraction into a suitable building material.

The different steps of material processing (i. e. material characterization, leaching, calcining, concrete manufacturing) will take place at different locations, therefore, the materials need to be shipped a couple of times. During the project, larger amounts shall be shipped for pilot trials at different sites.

To allow a fluent and seamless exchange of larger samples between the partners and their later utilization as building materials, the relevant legislative regulations need to be assessed in advance. This applies to the regulations regarding the transport and processing of such materials as well as the regulations regarding the quality of building materials made of the processed mineral fraction.

2 Planned Criteria

Subtask 4.1.1: Material logistics and product standards (VITO, TK)

This subtask entails the:

- Listing of requirements for shipping of waste in/among partner countries and in the EU in general. (Support in) acquisition of permits for shipping (VITO, TK);
- Establishment of end-product requirements for the targeted construction materials in terms of CEN standardisation and certification (VITO).

Deliverable D 4.1 Report on legislative/regulative requirements for (1) transport and processing of mining residues in the EU and (2) construction product standards and certification procedures (VITO, M12)

3 Materials and methods

This report has been compiled based on a literature review and expert interviews.

4 NEMO Materials Logistics and Processing

4.1 Material classification

In order to set-up a proper transport and treatment regime, it is important to define whether the material is considered as a waste material or not. However, the definition of the so-called waste characteristic is based on the relationship between the material and its owner rather than a physical or chemical specification. According to 2008/98/EC, waste is defined as “any substance or object which the holder discards or intends or is required to discard”.

The EC directive on waste also defines a class ‘by-product’ for materials which are not deliberately produced in a production process but can be utilized in a certain manner afterwards. However, the classification of a ‘by-product’ has a couple of prerequisites. Unless all of them are met, the material is still considered as waste.

Furthermore, the directive describes an 'end-of-waste' concept. Thus, waste materials can achieve a non-waste-status after undergoing a recycling or recovery process. However, this concept also relies on specific regulations at the community or national level.

With respect to samples for the NEMO project, only the non-waste and waste status are considered to be relevant. The classification of 'by-products' and the utilisation of the 'end-of-waste' concept will be clearly advantageous for the future commercial treatment of mine tailings. However, the application of such concepts relies on the successful demonstration of possible utilisation methods which is actually part of the NEMO project.

Consequently, during the project all materials which are already classified as waste have to be treated accordingly. Regarding the mine tailings, this in general applies to all dumped materials which are not part of an ongoing production process. On the contrary, all material samples which are directly taken from an ongoing ore refining process are not considered as waste materials and therefore do not fall under the waste shipment directive. These material samples can therefore be shipped like other ordinary mineral products.

4.1.1 Transport of secondary ore and mining residues

In general, all samples shall be shipped in proper packaging and accompanied by the relevant documentation:

- Sending party
- Receiving party
- NEMO project sample code
- Material safety data sheet (MSDS)

4.1.2 Special regulations regarding waste materials

Regulations for the shipment of waste materials between countries inside the European Community are given in the 2006/1013/EC regulation. The directive requires a so-called notification process for the shipment of waste. For laboratory analyses, samples up to 25 kg can be shipped without the notification process but require a documentation as defined in article 18 of 2006/1013/EC.

4.1.3 Sample logistics summary

A summary for the sample shipping requirements is given in Table 1.

Table 1: Conditions for sample shipping within the NEMO project

Classification	(Raw) material from the production process	Waste material (not classified as hazardous waste)
Examples	Primary ore Secondary ore Concentrated ore	Dumped tailings Tailing pond sediments
Sample shipping < 25 kg	No special requirements	Documentation (Art. 18 2006/1013/EC)
Sample shipping > 25 kg		Notification (Art. 4 2006/1013/EC)

4.2 Processing of mining residues

4.2.1 Special regulations regarding waste materials

In order to treat waste materials, permits are required on national level. All partners involved in the treatment of possible waste materials are holding the necessary permits. This has been documented in the NEMO deliverable D10.3.

5 Construction Product Specifications

If a material is to be used in construction applications it is required to meet a set of material properties. Such material properties are laid down in technical specifications and codes. In the construction sector, technical specifications apply to products (e. g. concrete pavers) and commodities (e. g. cements) that are used to build a structure. The construction design code offers guidelines on how these construction materials should be assembled, i. e. it describes guidelines for the design of the structure and the construction practice itself. Both sets of documents are highly integrated, building codes will refer to technical specification documents, also called standards, when listing materials to be used for a civil works. On the other hand, standards will refer to a range of other specifications, e. g. when referring to methods to measure a specified property such as compressive strength.

In addition to technical product specifications that stipulate material performance, end-products will also need to comply to environmental quality legislation and its implementation in national regulations. Regulations on environmental quality aim to preserve the natural environment and avoid human and environmental exposure to harmful substances. In most EU member states such regulations combine requirements or limits on total concentrations and/or emissions (e. g. leaching) of harmful components such as persistent organic pollutants (POPs) or heavy metals.

In the following subchapters an overview will be given of technical product standards and environmental quality requirements for the target applications in the NEMO project, i. e. constituent of common cement and concrete and artificial aggregate for use in bound (e. g. concrete or roadbase) and unbound (e. g. embankment or backfill) applications. Finally a note will be made on alternative routes to market access and certification procedures for product quality assurance.

5.1 Technical product standards

Rapid access to product markets for secondary resources such as processed, cleaned mine tailings will require compliance to product standards. Technical product specifications therefore constitute an all-important set of boundary conditions in the development of application routes for mine tailings. This chapter introduces the standardisation system for construction materials and provides detail on product requirements for artificial aggregates and cement constituents in the European Union. Depending on the end-product, e. g. common cement, or ready-mix concrete the specifications for constituents vary. Generic property or performance requirements are given first, followed by more detailed descriptions of the targeted applications in the NEMO project.

5.1.1 Introduction to the standardization system

The standardisation system is a coordination system set up to deliver mutual gains for users and producers. On the one hand it defines product quality to protect user interests, such as safety and quality. On the other hand, it provides producers a "universal" basis of product requirements that enables interchangeability, mass production, and (inter)national trade. In this respect, harmonisation or mutual acceptance of existing standards is usually at the core of market integration and (free) trade agreements. The integration of the European market required adoption of a common standardization system, coordinated by the CEN (Comité Européen de Normalisation) for European standards (a large body of EN standards harmonized in the European Union including, DIN, BS, NF,…).

For construction, a distinction can be made between two types of standards. The first type of standard provides product and property definitions. The second type sets out methods for testing or measuring a specified property. In principle, standards should define and specify a product based on its performance, i. e. the properties of final interest to the end-user. However, for a number of reasons, many product standards include clauses that specify the origin and composition of subcomponents. Such material prescriptive standards offer advantages to producers such as enhanced control on supply chains and reduced number of parameters to be tested for quality control. On the other hand, material prescriptive standards exclude alternative materials or resources from market access and as such may block innovation or waste-to-resource industrial synergies. Moreover, material prescriptive standards are generally not in line with the Construction Product Regulation (CPR, EU regulation No 305/2011) that lays down harmonized rules to assess the performance of construction products in the EU common market. As part of EU legislation, the adherent body of EN standards is required to comply with the CPR and can be expected to gradually release material prescriptive specifications and shift to performance based requirements in the coming years. In the following the current situation in terms of product specifications is given, where relevant note is made of what the impact of a shift towards performance based standards would imply for the materials studied in the NEMO project.

5.1.2 Requirements for common cement constituents – use of calcined mine tailings as supplementary cementitious materials

Supplementary cementitious materials or mineral admixtures are inorganic materials that, in combination with Portland cement, contribute to the properties of the hardened concrete through a chemical reaction. This chemical reaction can be of hydraulic or pozzolanic nature. Hydraulic materials set and harden submerged in water by forming cementitious products in a hydration reaction. A pozzolanic material is a siliceous or siliceous and aluminous material which, in itself, possesses little or no cementitious value but which will, in finely divided form and in the presence of water, react chemically with calcium hydroxide at ambient temperature to form compounds possessing cementitious properties. It should be noted that this definition of a pozzolan imparts no bearing on the origin of the material, only on its capability of reacting with lime and water.

An estimated 800 million tonnes of SCMs are being used each year. These are mostly by-products from other industries such as fly ash from coal combustion or blast furnace slags from iron smelting. SCMs can be added in two different stages in the production chain leading to concrete. In a first route, SCMs are blended with Portland clinker and other constituents to make so-called composite cements, this practice is most common in Europe. In a second route SCMs are added in directly at the concrete-making stage together with Portland cement, aggregates and other constituents, this practice is more common in North America, but also in Europe in pre-cast concrete production companies.

5.1.2.1 Standards and specifications for use in cement (EN 197-1)

In Europe, the EN 197–1 standard specifies the composition and properties of common cements. The 2011 version of the standard (EN 197–1:2011) contains 27 types of cements containing SCMs, the cement designation depends on the type and proportions of its components. Future versions of the EN 197–1 standard will see further extension of the list of cements by inclusion of new SCMs, new combinations of SCMs and higher proportions of SCMs allowed. In the prEN 197–1 shown in Table 2, 37 cement types are listed. Calcined mining tailings could classify under **type Q** constituent, i.e. Natural calcined pozzolana, provided the material complies to the following requirements:

- Natural calcined pozzolana are usually materials of volcanic or sedimentary origin.
- Natural calcined pozzolana consists essentially of reactive silicon dioxide (SiO_2) and aluminum oxide (Al_2O_3). The remainder contains iron oxide and other oxides.
- The **reactive silicon dioxide content shall not be less than 25.0 % by mass**. The reactive silicon dioxide content is the fraction of silicon dioxide soluble after treatment with hydrochloric acid and with boiling potassium hydroxide (KOH) solution according to EN 196–2.
- The material contains siliceous or silico-aluminous compounds that react, in the presence of water, with calcium hydroxide to form strength developing calcium silicate and calcium aluminate hydrates.

Natural calcined pozzolana can be used in several cement types, i.e. in so-called composite cements consisting of binary combinations with clinker in cement types CEM II/A-Q (6–20 % Q), CEM II/B-Q (21–35 % Q) or CEM IV/A (11–35 % Q) and CEM IV/B (35–55 % Q), or in ternary cements in combination with clinker and another main constituent, e.g. CEM II/B-M, or in combination with clinker and blastfurnace slag in CEM V cement types. Composite cements are predominant in the European market nowadays. They are most commonly used for production of ready-mix concrete, or in the production of non-structural pre-cast elements such as pavers, blocks and the like. Because of their improved resistance in harsh environments as opposed to CEM I – pure Portland cement, their use is in many places prescribed for exposed structures, e.g. road decks exposed to de-icing salts, marine structures, etc.

Blending SCMs into cement products can offer significant advantages to both producers and end-users. For producers this enables to extend cement production without investments in quarry or clinkering facilities, it enables to make use of internal residues such as quarry dust, off-spec materials and may also raise profit margins. From both producer and end-user point of view the resource and CO_2 footprint of cement-based products are reduced, while finally, from an end-user point of view concrete properties such as strength and durability may be improved.

Table 2. Composition of cement types in the pr-EN 197-1 standard on common cements harmonized for the EU market.

Main types	Notation of the 39 products (types of common cement)		Composition (percentage by mass[a])										
			Main constituents										Minor additional constituents
			Clinker	Blast-furnace slag	Silica fume	Pozzolana		Fly ash		Burnt shale	Limestone		
						natural	natural calcined	siliceous	calca-reous				
	Type name	Type notation	K	S	D[b]	P	Q	V	W	T	L	LL	
CEM I	Portland cement	CEM I	95-100	–	–	–	–	–	–	–	–	–	0-5
CEM II	Portland-slag cement	CEM II/A-S	80-94	6-20	–	–	–	–	–	–	–	–	0-5
		CEM II/B-S	65-79	21-35	–	–	–	–	–	–	–	–	0-5
	Portland-silica fume cement	CEM II/A-D	90-94	–	6-10	–	–	–	–	–	–	–	0-5
	Portland-pozzolana cement	CEM II/A-P	80-94	–	–	6-20	–	–	–	–	–	–	0-5
		CEM II/B-P	65-79	–	–	21-35	–	–	–	–	–	–	0-5
		CEM II/A-Q	80-94	–	–	–	6-20	–	–	–	–	–	0-5
		CEM II/B-Q	65-79	–	–	–	21-35	–	–	–	–	–	0-5
	Portland-fly ash cement	CEM II/A-V	80-94	–	–	–	–	6-20	–	–	–	–	0-5
		CEM II/B-V	65-79	–	–	–	–	21-35	–	–	–	–	0-5
		CEM II/A-W	80-94	–	–	–	–	–	6-20	–	–	–	0-5
		CEM II/B-W	65-79	–	–	–	–	–	21-35	–	–	–	0-5
	Portland-burnt shale cement	CEM II/A-T	80-94	–	–	–	–	–	–	6-20	–	–	0-5
		CEM II/B-T	65-79	–	–	–	–	–	–	21-35	–	–	0-5
	Portland-limestone cement	CEM II/A-L	80-94	–	–	–	–	–	–	–	6-20	–	0-5
		CEM II/B-L	65-79	–	–	–	–	–	–	–	21-35	–	0-5
		CEM II/A-LL	80-94	–	–	–	–	–	–	–	–	6-20	0-5
		CEM II/B-LL	65-79	–	–	–	–	–	–	–	–	21-35	0-5
	Portland-composite cement[c]	CEM II/A-M	80-88	<------------ 12-20 ------------>									0-5
		CEM II/B-M	65-79	<------------ 21-35 ------------>									0-5
		CEM II/C-M (S-L)	50-64	16-44	–	–	–	–	–	–	6-20	–	0-5
		CEM II/C-M (S-LL)	50-64	16-44	–	–	–	–	–	–	–	6-20	0-5
		CEM II/C-M (P-L)	50-64	–	–	16-44	–	–	–	–	6-20	–	0-5
		CEM II/C-M (P-LL)	50-64	–	–	16-44	–	–	–	–	–	6-20	0-5
		CEM II/C-M (V-L)	50-64	–	–	–	–	16-44	–	–	6-20	–	0-5
		CEM II/C-M (V-LL)	50-64	–	–	–	–	16-44	–	–	–	6-20	0-5
		CEM II/C-M (S-P)	50-64	16-44	–	6-20	–	–	–	–	–	–	0-5
		CEM II/C-M (S-V)	50-64	16-44	–	–	–	6-20	–	–	–	–	0-5
CEM III	Blast furnace cement	CEM III/A	35-64	36-65	–	–	–	–	–	–	–	–	0-5
		CEM III/B	20-34	66-80	–	–	–	–	–	–	–	–	0-5
		CEM III/C	5-19	81-95	–	–	–	–	–	–	–	–	0-5
CEM IV	Pozzolanic cement[c]	CEM IV/A	65-89	–	<------- 11-35 ------->					–	–	–	0-5
		CEM IV/B	45-64	–	<------- 36-55 ------->					–	–	–	0-5
CEM V	Slag-pozzolanic cement[c]	CEM V/A	40-64	18-30	–	<----- 18-30 ----->			–	–	–	–	0-5
		CEM V/B	20-38	31-49	–	<----- 31-49 ----->			–	–	–	–	0-5
CEM VI	Composite cement[c]	CEM VI (S-P)	35-49	31-59	–	6-20	–	–	–	–	–	–	0-5
		CEM VI (S-V)	35-49	31-59	–	–	–	6-20	–	–	–	–	0-5
		CEM VI (S-L)	35-49	31-59	–	–	–	–	–	–	6-20	–	0-5
		CEM VI (S-LL)	35-49	31-59	–	–	–	–	–	–	–	6-20	0-5

a The values in the table refer to the sum of the main and minor additional constituents.
b The proportion of silica fume is limited to 6-10 %.
c In Portland-composite cements CEM II/A-M, CEM II/B-M and CEM II/C-M, in Pozzolanic cements CEM IV/A and CEM IV/B, in Slag-pozzolanic cements CEM V/A and CEM V/B and in Composite cements CEM VI the main constituents other than clinker shall be declared by designation of the cement (for examples, see Clause 8).

5.1.2.2 *Standards and specifications for use as mineral additions to concrete (EN 206-1)*

In Europe there is no separate harmonized standard for use of natural calcined pozzolana in concrete. EN 206–1 distinguishes two types of mineral additions to concrete. Type I additions are filler aggregates that need to conform to either EN 12620 or EN 13055 to qualify for general suitability for use. EN 12620 and EN 13055 are described in more detail in the section on "Requirements for construction aggregates". Type II additions for concrete comprise SCMs such as coal combustion fly ash (conforming to EN 450–1), ground granulated blastfurnace slag (conforming to EN 15167–1) and silica fume (conforming to EN 13263–1). General suitability for other mineral additions (such as calcined mining tailings) are not regulated by specific European standards, instead establishment of suitability can be obtained based on a European Technical Assessment or provisions valid in the place of use of the concrete.

As a reference the compositional requirements for coal combustion fly ashes for use in concrete is given in Table 3. It is likely that compliance to the specified limits will bring more trust and confidence to concrete producers and end-users.

Table 3- Summary of the main limits provided by the EN 450-1:2012 on the use of Fly ash in concrete.

Property	EN 450–1:2012 Limit
SiO_2+ Al_2O_3+Fe_2O_3	Min 70 m%
Reactive silica	–
Sulfate (SO_3)	Max 3.0 m%
Loss on Ignition (LOI)	Category A: max 5.0 m% Category B: max 7.0 m% Category C: max 9.0 m%
Chloride (Cl^-) %	Max 0.1 m%
Calcium Oxide (CaO)	Max 10.0 m%
Free Lime	*
Alkalis (Na_2O eq)	Max 5.0 m%
Magnesium Oxide (MgO)	Max. 4.0 m%**
Soluble phosphate	Max. 100 mg/kg
Total phosphate	Max 5.0 m%
Fineness (45 µm residue)	Type N: Max 40 % ; Type S: 12 %
Water requirement	< 95 % of cement for type S
Pozzolanic activity index	after 28 days ≥ 75 %, after 90 days ≥ 85 %

** If the free lime content is higher than 1.5 m%, than the fly ash should comply to the expansion test requirements as detailed above for use of siliceous fly ash in cement.*
*** Only for fly ash from co-combustion in initial type testing.*

The quantities of mineral additions to be used in the concrete are to be determined based on initial tests for both type I and type II additions. For type II additions to be taken into account as a part of the cement binder (provisions on cement content and water/cement ratio) the suitability of the *k*-value concept or the principles of the equivalent concrete performance concept (ECPC) and the equivalent performance of combinations concept (EPCC) should be established. The *k*-value concept is based on the comparison of the durability performance (or strength as proxy criterion for durability where appropriate) of a reference concrete against a test concrete in which the cement is partially substituted by a type II addition. To comply to the ECPC and EPCC, an equivalent performance in terms of durability needs to be demonstrated when compared to a reference concrete that is conforming to the requirements of the exposure class. It should be noted that this concept can only be used for cements conforming to EN 197–1 plus one or more additions.

5.1.3 Requirements for construction aggregates

Aggregates are used in the construction of infrastructure and buildings in two main ways, i. e. 1) in **unbound applications**, and 2) in **bound applications** where the aggregate is bound by a cementitious or bituminous binder. In this section technical specifications for the application areas of most practical potential for granulated mine tailings, i. e.:

1. Unbound application where the granulated mine tailings are used as part of backfill or foundations or as part of landscape elements such as embankments;
2. Bound application where the granulated mine tailings are used as aggregate substitute in concrete-like applications

In specifying aggregates a distinction is often made between coarse and fine aggregates. Coarse aggregate is aggregate predominantly retained on a 4 mm aperture sieve. Conversely, fine aggregate is aggregate predominantly passing a 4 mm aperture sieve.

In addition, standards make a distinction between dense aggregates and lightweight aggregates. Dense aggregates have an oven dried particle density greater than 2 t/m^3 and are covered by EN 12620 and EN 13242, lightweight aggregates have particle densities lighter than 2 t/m^3 and are covered by EN 13055. The standard documents define the properties, and refer to the appropriate test methods for measurement. Prescribers (e. g. public authorities on a national level) or clients define material property requirements for the eventual application or product.

Thus, requirements for aggregate properties largely depend on the eventual application. The regulated properties range from geometrical requirements such as size grading, particle shape (flakiness and shape index) over physical requirements such as resistance to fragmentation, resistance to wear, particle density, water absorption, bulk density, etc. to chemical requirements such as total sulfur content, water soluble sulfate content, chlorides. In terms of durability, properties such as magnesium sulfate soundness, resistance to freezing and thawing or alkali silica reactivity may be specified. In addition the content and release of hazardous substances is required to comply to national regulations (cf, section on Environmental legislation on reuse of residues as construction material). Since material requirements vary by application and, to some extent, by region, as an illustration a comparison of aggregate requirements for different applications in the Belgian standard specifications for road construction (SB 250) is given in Table 4, the standard specification also includes requirements for buildings and other infrastructure (bridges etc.) and is often adopted in the private sector.

Table 4. Material requirements for fine and coarse aggregates for unbound and bound construction applications (excerpt from Belgian standard specifications)

	Fine aggregate (sand)							
Property	Drainage	Filler in coarse subbase	Subbase	Base – lean concrete	Lean concrete	Screed	Concrete - road	Concrete - buildings
Geometrical requirements								
Max. size (D)		D ≤ 4 mm: ≤ 85 m%	D ≤ 2 mm: ≤ 30 m%	D ≤ 4 mm: ≤ 85 m%	D ≤ 4 mm: ≤ 85 m%	D ≤ 6.3 mm: ≤ 90 m%	D ≤ 4 mm: ≤ 85 m%	D ≤ 4 mm: ≤ 85 m%
< 1 mm	65-100 m%				65-100 m%		65-95 m%	65-100 m%
< 0.5 mm	35-100 m%				35-100 m%		35-80 m%	35-100 m%
< 0.25 mm	10-63 m%				10-70 m%		10-45 m%	10-60 m%
< 0.125 mm	0-10 m%				0-15 m%		0-25 m%	0-20 m%
< 63 µm	≤ 7 m%	≤ 16 m%	≤ 16 m%	≤ 10 m%	≤ 10 m%		≤ 3 m%	≤ 3 m%
Chemical requirements								
Methylene Blue Value	≤ 10	≤ 10	≤ 10	≤ 10	≤ 10	≤ 8	≤ 10	≤ 10
Soluble chlorides					≤ 0.10 m%		≤ 0.06 m%	

	Coarse aggregate				
Property	Subbase	Base	Lean concrete	Concrete - Road	Concrete - buildings
Geometrical requirements					
Max. size (D)	D ≤ 80 mm: 100 m%			D ≤ 31.5 mm: ≤ 85 m%	
< 63 µm	≤ 4 m%	≤ 4 m%	≤ 2 m%	≤ 1.5 m%	≤ 1.5 m%
Flakiness Index		≤ 35		≤ 20-30	≤ 20
Broken and rounded stones		C50/10		C95/1 or C50/30	≤ 30 m%
Resistance to fragmentation		LA 35-50	LA 35-40	LA 15-30	
Resistance to wear				MDe15-25	

5.1.4 Certification Procedures

Products sold on the common European market are subject to certification. Certification involves controlling that the product properties meet the producer declaration. Depending on the product this can involve regular checking of the compliance to product standards. For construction materials certification control is obligatory and needs to be carried out by independent accredited organisations. The European Commission proposed that the list of accredited organisations (certification bodies) with the right to issue the "EC certificate of conformity" will be determined on the basis of proposals from the Member States, and that such certification (EC certificate of conformity) is particularly important for products derived from waste.

5.2 Environmental legislation on reuse of residues as construction material

Environmental protection is of primary concern in modern day society. In response to the increasing impact of human activities, environmental legislation is implemented by governments worldwide to regulate land use, resource usage and waste management. Environmental legislation therefore represents an important set of boundary conditions within which economic activities should take place. In developing new industrial processes and products such boundaries, and their anticipated future evolution, should be clearly identified and respected.

In line with the NEMO objectives, the EU policy on waste management and its implementation into member state regulations and environmental quality criteria is reviewed with respect to reuse as construction material. A comparison of national environmental quality criteria (total concentrations and emission limits) is used as a benchmark for processed mining tailings.

The Waste Framework Directive and its amendments (2008/98/EC) set the basic concepts and definitions related to waste management, such as definitions of waste, recycling, recovery. It explains when waste ceases to be waste and becomes a **secondary raw material** (so called **end-of-waste** criteria), and how to distinguish between **waste** and **by-products**. The Directive lays down some basic waste management principles: it requires that waste be managed without endangering human health and harming the environment, and in particular without risk to water, air, soil, plants or animals, without causing a nuisance through noise or odours, and without adversely affecting the natural environment or places of special interest.

The Waste Framework Directive also contains a list of **wastes** and hazardous wastes (marked with an asterisk). The inclusion of a substance or an object in this list shall not mean that it is a waste in all circumstances (Art. 7.1 of 2008/98/EC). The subject or object is only a waste in case the holder discards or intends or is required to discard (Art. 3.1 of 2008/98/EC). Table 5 below gives an overview of the European waste codes for wastes from physical and chemical processing of metalliferous minerals.

Table 5. Overview of the European waste codes for the wastes from physical and chemical processing of metalliferous minerals

European waste code	Description
01 03	wastes from physical and chemical processing of metalliferous minerals
01 03 04*	acid-generating tailings from processing of sulphide ore
01 03 05*	other tailings containing dangerous substances
01 03 06	tailings other than those mentioned in 01 03 04 and 01 03 05
01 03 07*	other wastes containing dangerous substances from physical and chemical processing of metalliferous minerals
01 03 99	wastes not otherwise specified

End-of-waste criteria specify when certain waste ceases to be waste and obtains a status of a product (or a secondary raw material). According to Article 6 (1) and (2) of the Waste Framework Directive (2008/98/EC), certain specified waste shall cease to be waste when it has undergone a recovery (including recycling) operation and complies with specific criteria to be developed in line with certain legal conditions, in particular:

- the substance or object is commonly used for specific purposes;
- there is an existing market or demand for the substance or object;
- the use is lawful (substance or object **fulfills the technical requirements** for the specific purposes and meets the existing legislation and standards applicable to products);
- the use will **not lead to overall adverse environmental or human health impacts**.

Some European Member States (e. g. Austria, France[1], the Netherlands and UK) have developed specific end-of-waste criteria for use as construction aggregate with restrictions or conditions on the use. These end-of-waste criteria contain an exhaustive list of streams, referring to the European waste codes, that can be used as input material for aggregates. They also contain restrictions on the use (application) and conditions on the quality (expressed as product quality standards). Depending on the country, quality has to be assured by specific sampling and testing. Other Member states have only national regulation (Belgium, Czech Republic, Denmark, Finland, Germany, Italy, Portugal, Spain and Sweden).

None of these end-of-waste criteria include streams from physical and chemical processing of metalliferous minerals. When processed mining tailings would meet the chemical characteristics of the end-of-waste criteria and it would be applied under the same restrictions, it is likely that the tailings (or products made of it) could be accepted as a secondary resource.

In the following paragraphs focus is on the maximum allowed heavy metals and organic compounds of the material (total concentration) and of the leached solution, as this will be important to take into account for the valorization of the processed tailings (or products containing them). The following sections give an overview of the end-of-waste criteria for:

- unbound applications, in case the material is not bound;
- bound applications, in case the mixture contains a binding agent, such as cement or bitumen.

5.2.1 End-of-waste criteria - unbound application as aggregate

Table 6 and Table 7 give an overview of allowed total concentrations and allowed leaching of material used in unbound applications. In the tables we have added the criteria for Belgium (Flanders) too, although these are not classified as end-of-waste criteria according to the EU legislation[2].

[1] Regulation in draft.

[2] In Flanders the users of waste need an authorization for each application (so meeting the standards is not sufficient to use the materials)

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Table 6. End-of-Waste total concentration criteria for heavy metals (expressed as mg/kg dm) for Austria and Belgium for unbound applications. The most stringent limit values are marked green and bold.

Country	Austria	Austria	Belgium[1]
Class	U-A [2]	U-B [2]	
As			**250**
Cd			**10**
Cr	**90**	**90**	1250
Cu	**90**	**90**	375
Hg	**0.7**	**0.7**	5
Pb	**100**	**100**	1250
Ni	**60**	**60**	250
Zn	**450**	**450**	1250

1: Flemish values from the local regulation (no official end-of-waste criteria).

2: Aggregates for unbound and hydraulically or bituminous bound use

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Table 7. End-of-Waste leaching criteria (expressed as mg/kg dm - l/s 10) for the Netherlands, France, Austria and Belgium for unbound applications. The most stringent limit values are marked green and bold.

Country	The Netherlands	France	France	France	Austria	Austria	Belgium[1]
Class		Type 1 road	Type 2 road	Type 2 road	U-A [2]	U-B [3]	
Test	CEN/TS 14405 (L/S=10 L/kg)	EN12457-2 and 4 (L/S=10 L/kg)			EN12457-4 (L/S=10 L/kg)		CEN/TS 14405 (LS=10 L/kg)
Sb	0.32	0.6	0.3	**0.08**			
As	0.9	**0.6**	**0.6**	**0.6**			0.8
Ba	**22**	36	25	25			
Cd	0.04	0.05	0.05	0.05			**0.03**
Cr	0.63	4	2	0.6	**0.3**	1	0.5
Cr - VI		1.2	**0.6**				
Co	**0.54**				0.6	2	
Cu	0.9	10	5	3			**0.5**
Hg	0.02	**0.01**	**0.01**	**0.01**			0.02
Pb	2.3	**0.6**	**0.6**	**0.6**			1.3
Mo	1	5.5	2.8	0.6	**0.5**	**0.5**	
Ni	**0.11**	0.5	0.5	0.5	0.4	0.6	0.75
Se	0.15	0.5	0.4	**0.1**			
Sn	**0.4**						
V	1.8				**0.5**	**0.5**	
Zn	4.5	5	5	5			**2.8**
Br	**20**						
Cl	**616**	10000	5000	1000	800	800	
F	55	60	30	13	**10**	**10**	
SO_4	1730	10000	5000	**1300**	2500	4000	
NH_4-N					**4**	8	
NO_3-N					**100**	130	
NO_2-N					**1**	2	
TOC					**100**	200	

1: Flemish values from the local regulation (no official end-of-waste criteria).
2: Aggregates for unbound and hydraulically or bituminous bound use
3: Aggregates for unbound and hydraulically or bituminous bound use

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5.2.2 End-of-waste criteria - bound application as aggregate

Table 8 and Table 9 give an overview of allowed total concentration and allowed leaching of material used in bound applications as aggregate. Leaching is carried out on crushed materials according to the indicated test methods (i.e. upflow percolation column leaching or batch leaching). In some countries a diffusion/tank leaching test on the uncrushed bound material is prescribed. Leaching of crushed material has been shown to be higher than from unbroken specimens. Moreover, leaching tests on crushed materials are considered to be more representative for a second life use of the bound material as e.g. road base.

Table 8. End-of-Waste total concentration criteria for heavy metals (expressed as mg/kg dm) for Austria for bound applications. The most stringent limit values are marked green and bold.

	Austria
Class	H-B [1]
Cr	**90**
Cu	**90**
Hg	**0.7**
Pb	**100**
Ni	**60**
Zn	**450**

1: Aggregates exclusively for the manufacture of concrete strength class C12/15

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Table 9. End-of-Waste leaching criteria (expressed as mg/kg - dm l/s 10) for the Netherlands, France and Austria for bound applications. The most stringent limit values are marked green and bold.

	The Netherlands	**France**	**Austria**
Class		Concrete	H-B [1]
Test	CEN/TS 14405 (L/S=10 L/kg)	EN12457-2 and 4 (L/S=10 L/kg)	EN12457-4 (L/S=10 L/kg)
Sb	0.7	**0.08**	
As	2	**0.6**	
Ba	100	**25**	
Cd	0.06	**0.05**	
Cr	7	**0.6**	1
Co	**2.4**		
Cu	10	3	**2**
Hg	0.08	**0.01**	
Pb	8.3	**0.6**	
Mo	15	0.6	**0.5**
Ni	2.1	**0.5**	0.6
Se	2	**0.1**	
Sn	**2.3**		
V	20		**0.5**
Zn	14	**5**	
Br	**34**		
Cl	8800	1000	**800**
F	1500	12	**10**
SO4	20000	**1300**	
NH4-N			**8**
TOC			**200**

1: Aggregates exclusively for the manufacture of concrete strength class C12/15

5.2.3 Cr(VI) limit for cement

Cr in cement can be present in various oxidation states. Cr(0) metal and Cr(III) are sparingly soluble and not considered as harmful. However, Cr(VI) occurs as soluble chromates and is recognized toxic and carcinogenic compound. Therefore in Europe a **2 ppm total concentration limit for Cr(VI)** is imposed for cements. Cement producers commonly add reducing agents such as ferrous sulphate to cement to reduce Cr(VI) to harmless and non-regulated Cr(III).

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6 Conclusions

This deliverable report aims to 1) facilitate the exchange of materials for testing amongst partners in the NEMO project, and 2) define the regulative framework for processing of mine tailings into construction materials and products. To this double purpose, the relevant legislative and regulative documents on the European and national level were reviewed. In addition material property specifications for the targeted construction product applications were derived from European and national product standards and prescriptions.

Regarding material logistics, it can be concluded that materials which are already classified as waste have to be shipped accordingly. Regarding the mine tailings, this in general applies to all dumped materials which are not part of an ongoing production process. On the contrary, all material samples which are directly taken from an ongoing ore refining process are not considered as waste materials and therefore do not fall under the waste shipment directive. These material samples can therefore be shipped like other ordinary mineral products. This is summarized in the table below:

Classification	(Raw) material from the production process	Waste material (not classified as hazardous waste)
Examples	Primary ore Secondary ore Concentrated ore	Dumped tailings Tailing pond sediments
Sample shipping < 25 kg	No special requirements	Documentation (Art. 18 2006/1013/EC)
Sample shipping > 25 kg	No special requirements	Notification (Art. 4 2006/1013/EC)

As regards to technical construction product specifications, the considered product types were 1) constituent of common cement, and 2) construction aggregates.

1. When used as constituent of common cement or supplementary cementitious material (SCM), calcined mining tailings could classify under constituent type Q, i. e. natural calcined pozzolana in EN 197–1, if the material property requirements can be complied to, and if suitability for use in terms of concrete performance and durability can be proven. The material property requirements for use in common cement or as direct addition to concrete were summarized.
2. When used as construction aggregate, the material property requirements depend largely on the targeted end use. Different requirements apply for different applications. A distinction is made between unbound and bound applications and typical material requirements for use in civil works or concrete were described.

In case technical product requirements can be met, then permission to use the processed residues in construction materials is pending on compliance to environmental legislation. A review was made of the EU waste directive and its implementation in several member states to define limits in total concentrations and leaching of pollutants from construction products.

The results reported in this deliverable will act as a guideline to follow up activities in Work Package 4 by facilitating the exchange of materials in the pilot and demonstration activities, and by setting targets for material or product properties for construction applications in Tasks 4.3 and 4.4.

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7 References

Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste

Directive 2003/53/EC of the European Parliament and of the Council of 18 June 2003 amending for the 26th time Council Directive 76/769/EEC relating to restrictions on the marketing and use of certain dangerous substances and preparations (nonylphenol, nonylphenol ethoxylate and cement)

Guidelines on the interpretation of key provisions of Directive 2008/98/EC on waste

Regulation (EC) No 1013/2006 of the European Parliament and of the Council of 14 June 2006 on shipments of waste

EN 197-1:2011 - Cement - Part 1: Composition, specifications and conformity criteria for common cements

prEN 197-1 - Cement - Part 1: Composition, specifications and conformity criteria for common cements

EN 206-1:2013 - Concrete. Specification, performance, production and conformity

EN 450-1:2012 - Fly ash for concrete. Definition, specifications and conformity criteria

EN 12620:2013 - Aggregates for concrete

EN 13055:2016 - Lightweight aggregates

EN 13242:2015 - Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction

EN 13263-1:2005 – Silica fume for concrete- Part 1: Definitions, requirements and conformity

EN 15167-1:2006 – Ground granulated blast furnace slag for use in concrete, mortar and grout. Definitions, specifications and conformity

Agentschap Wegen en Verkeer, 2014, “Standaardbestek 250 voor de wegenbouw – versie 3.1” 232 pp

Velzeboer, I., and van Zomeren, A., 2017. “End of Waste criteria for inert aggregates ins Member States”, ECN-E—17-010.

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