LEGAL AND ENVIRONMENTAL BOTTLENECKS AND OPPORTUNITIES FOR SLAG-BASED PRODUCTS VALORISATION

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Introduction

The 6th International Slag Valorisation Symposium in Mechelen, Belgium on 1-5 April 2019 is an opportunity to present this introductory overview of valorisation of slags from the steel industry and its contribution to industrial symbiosis between this sector and the construction materials industry. With characteristics depending on their process of generation, significant quantities of slags are already available for recovery as secondary construction aggregates and raw materials for cement. However, slags are residues from industrial processes and therefore their valorisation faces technical, environmental, economic and legal challenges related to the legal status given to the material.

Are the current national and European regulatory frameworks bottlenecks for slag-based products valorisation? Would environmental drivers such as carbon footprints, end-of-waste criteria, by-products status and standardisation of secondary materials be opportunities for greater development of steel slags recovery according to the European Union's policy of circular economy?

Steel slags, a significant stream of industrial waste presenting a real potential for valorisation

Slag is a generic name for a non-metallic rock-like material produced together with the metallic products, which is an important secondary raw material flow.

Slags occur both in ferrous and non-ferrous metal production. Slags are non-metallic mineral materials resulting from metallurgical thermal processes such as the extraction of iron from iron ore, the conversion of pig iron into steel, and the refinement of crude steel into basic products of various steel grades. Blast furnace slags and steel slags are well-known residues classified as waste, by-products or secondary materials generated by steel industries. In the smelting process, slags, in

their liquid state, have a different density to the melted metal and are therefore separable.

The iron and steel industry use two main production routes: blast furnaces (BF) and electric arc furnaces (EAFs). The former uses iron ore as an input to produce pig iron, which is then converted into steel *via* the converter process (*i.e.* using pure oxygen to remove excess carbon). The latter uses mostly scrap and may add iron-bearing sources like direct reduced iron or pig iron, as required. The characteristics of slag from blast furnaces, steel converters and from electric arc furnaces are different, showing thus different properties and fields of applications.

Steel slag has particular properties such as high strength, high density, and good polish stone values. This makes it very suitable for use as aggregates for asphalt mixtures and as a reinforcement and stabilisation base for shores and rivers. However, the swelling potential of some kinds of steel slags may be an important barrier for reuse as a secondary construction material.

EUROSLAG indicates that each year the EU generates 48 million tonnes of ferrous slags, whereas EUROFER indicated that, in 2013, EU28 produced 166 million tonnes of crude steel.

According to EUROSLAG, 87% of the ferrous slags are used in construction applications (cement, concrete, engineering works…). Other valuable applications include agriculture, where silicate contents are used as fertiliser.

Table 1: Annual ferrous slag generation in the EU

Figures from EuroSlag (in mill tonnes)	2010	2008	2006	2004	2002	2000
Total slag	**45.30**	**45.70**	**45.60**	**39.80**	**35.00**	**41.80**
+ from storage (estimated by DTI)	*2.60*	*1.80*	*8.00*	*12.60*	*7.40*	*4.40*
Total output	47.90	47.50	53.60	52.40	42.40	46.20
Production						
Production of blast furnace slag	**23.50**	**28, 10**	**28.80**	**24.60**	**17.80**	**25.00**
Granulated blast furnace slag	19.27	23.60	22.18	18.45	11.93	17.25
Air-cooled blast furnace slag	4.23	4.22	6.05	5.66	5.16	7.25
Pelletised blast furnace slag		0.28	0.58	0.49	0.36	0.50
+ from storage (estimated by DTI)	*2.10*	*2.20*	*3.40*			

Production of steelslag	**21.80**	**17.60**	**16.80**	**15.20**	**17.20**	**16.80**
Basic oxygen furnace slag	10.46	9.50	9.69	9.42	8.77	9.91
Electrical Arc Furnace Slag / High Alloy Steel	1.74	0.70	0.91	1.37	2.41	2.18
Electrical Arc Furnace Slag / Carbon Steel	6.76	5.63	4.35	4.41	6.02	4.70
Steelmaking	2.83	1.76	1.86			
+ from storage (estimated by DTI)	*0.50*	*-0.40*	*4.60*	*10.00*	*-0.20*	-
Disposal, recycling and storage						
Total	**47.90**	**47.50**	**53.60**	**52.40**	**42.40**	**46.20**
Blast furnace slag	**25.60**	**30.30**	**32.20**	**27.20**	**25.40**	**29.40**
Cement production	16.90	21.82	21.25	17.41	14.20	16.43
Road construction	5.89	8.18	10.63	8.98	10.03	11.61
Interim storage	2.56	-	-	0.54	-	0.79
Others	0.26	0.30	0.32	0.27	0.51	0.59
Steel slag	**22.30**	**17.20**	**21.40**	**25.20**	**17.00**	**16.80**
Cement production	1.34	0.17	0.26	0.25	1.36	1.34
Road construction	10.70	10.66	11.86	11.34	6.80	6.55
Hydraulic engeering	0.67	0.17	0.64	0.76	0.34	0.67
Fertilzer	0.67	0.69	0.64	0.76	0.68	0.67
Internal use for metallurgical proces	2.23	1.38	2.46	0.25	2.38	2.35
Interim storage	2.45	2.58	3.38	4.28	1.19	1.18
Final disposal	2.90	1.03	1.58	2.77	4.08	4.03
Others	1.34	0.52	0.62	1.51		
Summary						
Dispoal	6%	2%	3%	5%	10%	9%
S1 symbiosis	5%	3%	5%	0%	6%	5%
Interim storage	10%	5%	6%	9%	3%	4%
Recycled to other uses	79%	89%	86%	85%	82%	82%
Specific uses						
Total use for road construction	35%	40%	42%	39%	40%	39%
Total use in cement production	38%	46%	40%	34%	37%	38%

Source: Euroslag - bi-annualy surveys (http://www.euroslag.com/products/statistics/2010/) / calculations by DTI

Data from largest producers in 2010, see Euroslag for years before

Production of blast furnace slag	A, B, FIN, F, D, I, L, PL, E, SK, S, NL, UK
Production of steel slag	A, B, DK, FIN, F, D, GR, I, L, PL, RO, E, SK, SLO, S, NL, UK
Use of blast furnace slag	A, B, FIN, F, D, I, L, PL, E, SK, S, NL, UK
Use of steel slag	A, B, DK, FIN, F, D, GR, I, L, PL, RO, E, SK, SLO, S, NL, UK

Slag valorisation, a recovery process covered by environmental regulations and product standards of the European Union and its member states

The EU has a mature legislation. EU regulations that co-determine the use of slag are in the first place the EU Waste Framework Directive and the EU Water Framework Directive. Other important regulations are the EU Waste Catalogue, the EU Council Decision on the Landfill of Waste, the EU Waste Shipment Regulation, REACH and the EU Construction Product Regulation.

Generated not purposely and simultaneously with iron and steel products, slags are industrial waste or by-products.

The Framework Directive on Waste (2008/98/EC)

An important element in the Framework Directive on Waste (2008/98/EC, Article 4) is the waste hierarchy which gives priority in the decreasing order to waste prevention, reuse, preparation for reuse, recycling, other recovery and disposal.

The Waste Framework Directive sets the basic concepts and definitions related to waste management, such as definition of waste, recycling, recovery. Its Article 6 defines the end-of-waste (EoW) criteria, which specify when waste ceases to be waste and obtains the status of a product (secondary raw material). This is important to facilitate and promote the recycling of waste and reducing the amount of wastes sent for disposal and energy recovery. The end-of-waste criteria are also of key importance for companies to be able to engage in industrial symbiosis.

The Waste Framework Directive also opens the possibility (in Article 5) to classify substances or objects resulting from a production process as a by-product which will exempt it from the waste legislation. Figure 1 shows the conditions and procedure for the waste versus by-product decision. If a material is deemed to be a by-product, it can be considered as a product, and an EoW assessment is no longer relevant. Article 5, 1 (d) sets the condition that “further use is lawful”, *i.e.* the substance or object fulfils all relevant product, environmental and health protection requirements for the specific use and will not lead to overall adverse environmental or human health impacts”. This is the same requirement on environmental and health protection as that in Article 6,1 (d) which defines EoW criteria, but it does not call for limit values for pollutants (which might possibly be relevant, if the by-product is used as an aggregate and not covered by other environmental legislation). (Source: A possible methodology for setting pollutant limit values for aggregates in the EoW framework JRC-IPTS)

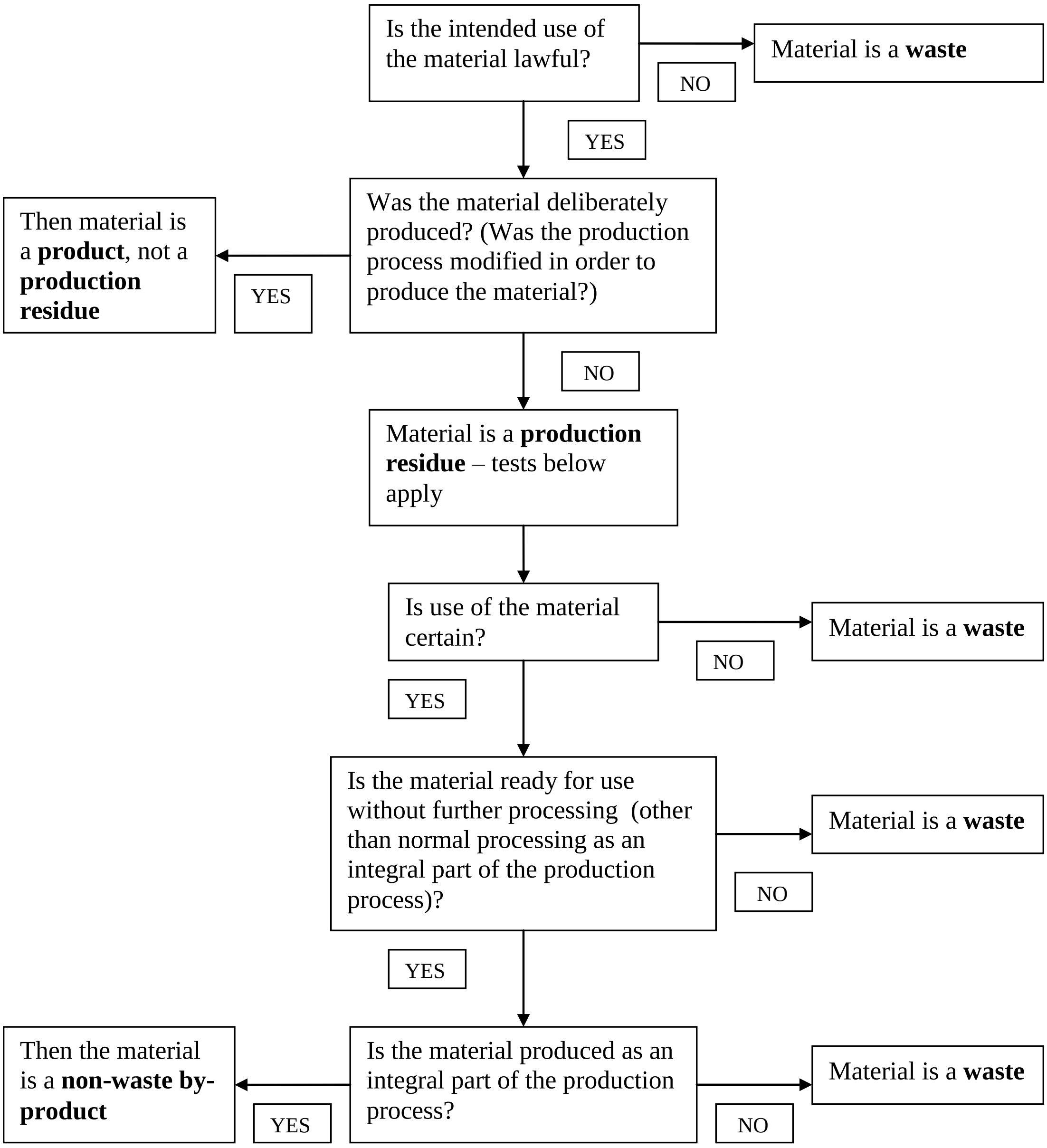

Figure 1: A decision tree for waste versus by-product decisions

The industry advocates classifying the material not as "waste", but rather as "by-products" in line with Article 5 of the Waste Framework Directive, or as "end-of-waste products" in line with Article 6. This is because the EU Waste Framework Directive does not apply to by-products or end-of-waste products and this strengthens their position and their value in the market. The same reasoning holds from the EU Waste Shipments Legislation, which applies to all shipments of waste either between EU Member States, or between the EU and third countries.

The REACH regulation ((EC) No 1907/2006)

The REACH regulation ((EC) No 1907/2006 of the European Parliament and the Council) lays down specific duties and obligations on manufacturers, importers and downstream users of substances on their own, in preparations and in articles. The objective is to ensure a high level of protection of human health and the environment as well as the free movement of substances, on their own, in preparations and in articles, while enhancing competitiveness and innovation. Any manufacturer or importer of a substance, either on its own or in one or more preparations in quantities of one tonne or more per year shall submit a registration to the European Chemicals Agency (ECHA). REACH focuses on substances. The main principle of the legislation is that if no data are provided, the product cannot be placed on the market.

In its guidance document, ECHA (2010) has stated that for the sake of consistency and enforceability, all forms of recovery, including mechanical processing, are considered as a manufacturing process whenever, after having undergone on or several recovery steps, they result in the generation of one or several substances as such or in a mixture or in an article that has ceased to be waste.

EUROSLAG in agreement with EUROFER, in 2009, initiated the registration of the ferrous slags – grouped in five types - as substances. Thus, ferrous slags produced by the steel industry are registered as UVCB[a]. When slags are used in applications such as the production of cement and concrete products, the hydraulic properties of the slag are important for these applications. Thus, the chemical composition of the slag is clearly more important. As a result, ferrous slag has to be considered as a substance. When slags are used in applications such as aggregates in construction, the shape, the surface or its performance as a product are more important than the chemical composition. In such cases, slag-based aggregates should be considered as articles as other natural, recovered or recycled aggregates.

The Water Framework Directive (2000/60/EC) and the Groundwater Directive (2006/118/EC)

The Water Framework Directive (2000/60/EC) obliges EU member states to improve the quality of natural water bodies, in particular groundwater. Both this general requirement and the national requirements arising from the implementation of the

[a] Substances of Unknown or Variable Composition, Complex reaction or Biological materials, substances that cannot be sufficiently identified by their chemical composition, because (ECHA, 2010). The number of constituents is relatively large and/or the composition is, to a significant part, unknown and/or the variability of the composition is relatively large or poorly predictable. For such substances, further identifiers have to be considered such as sources of origin or type of production processes.

Water Framework Directive and its daughter directive, the Groundwater Directive (2006/118/EC) must be taken into account when setting the primary water quality criteria. Based on substantial experience, several European member states thus seem to have concluded that testing and associated limit values or risk assessments will be required to provide adequate environmental and human health protection in association with beneficial use of waste-derived aggregates in general including slag-based aggregates. For example, France has recently developed a methodology for the environmental and sanitary acceptance before the use of non-hazardous waste derived aggregates in order to prevent risks of pollution of groundwater and damage to human health. Risk-based limit values for utilisation of waste and product aggregates have been set in several EU Member States, including Belgium, Denmark, France, Germany, The Netherlands and Sweden. These values should be relevant for slag aggregates.

The Construction Products Regulation (CPR, 305/2011/EU)

The Construction Products Regulation (CPR, 305/2011/EU) has replaced the CPD in 2013. Although the CPR extends the considerations of environment and health from concerning only the service life in the CPD to the entire lifecycle, the associated product standards will still only prescribe the harmonised test methods to be used in environmental and health assessments. The actual criteria to be met by construction products will still be a matter for individual Member States. Several Member States such as The Netherlands and to some extent also Germany have set leaching limit values for construction products to be used for different applications.

Differences in standards across EU member states

The view of the industry is that the national waste regulations (implemented along the lines of the EU WFD) and the EU REACH regulation operate as two parallel and separate trajectories. The experience has been that even in a single region authorities operate separately from each other, with their own interpretations and administrative requirements, tests and procedures.

One of the main barriers towards increasing the valorisation potential of ferrous slag is the differences in regulations and standards mostly concerning environmental requirements (laws) at Member State level. This makes border transport difficult and costly. For instance, Member States do not always translate the EU Waste Framework Directive and the EU Water Framework Directive in mutually consistent ways. The industry indicated that, in certain cases, Germany, France and the Netherlands use different specifications and tests for the use of slag and requirements for slag transport. This means that the slag industry sometimes needs to perform three tests when the slag is intended for parallel use in Germany, The Netherlands and in France. The test in one country is not valid in the other, which implies that there is no mutual

recognition on member state level. Additionally, the procedure of the tests can be different. For leaching aspects, the Waste and Water Framework Directives specifies a minimum of 10 elements to be tested. Yet Germany, for instance, requires a test involving 25 elements. These additional tests lead to higher costs, which in turn decreases the profitability and scope of using slags across borders.

Technical, environmental and economic challenge and potential benefits of slag valorisation for the European environment and economy

Technical challenges and Research and Development

The properties of ferrous slags vary according to their origin point along the steel production route. In particular, not all slags can be used in any type of application. For instance, different types of ferrous slags are profitably used in road construction or concrete production as an aggregate due to the high mechanical resistance of the slag grains, which exceeds that of many natural aggregates. Ferrous slags generated by (blast furnace) primary steel production are used for replacing natural material in cement production. Ferrous slag from converters can be used as liming materials in agriculture.

A substantial amount of research has been done to increase the valorisation of final slags, in particular to deal with the swelling properties of certain types of slags in the context of using it as a secondary construction material. While the problem does not occur with clean blast furnace slag, the problem appears to be more intense in specific Basic Oxygen Furnace steel slag. New production control methods have been invented and applied to increase valorisation.

Research and development, and innovation play a crucial role in the valorisation of slags through industrial symbiosis. Technological advances increase the value capturing capacity of the slag producers and subsequently promote the creation of new products, jobs and growth. Without going into detail on the latest technological developments, promising R&D avenues for slags valorisation are amongst others:

- the development and use of inorganic geo-polymers;
- the use of slags in blended cement, and
- the production of building blocks that can be used in buildings.

Environmental benefits and issues

It is important to facilitate the transformation of slag-based materials into valuable products and avoid these streams, already recognised as by-products in certain Member States, to become waste.

The use of ferrous slag saves energy and disruption of biodiversity and landscapes needed to mine natural aggregates. After being used as building material the slag enters the material cycle for construction materials as aggregates.

However, the valorisation of ferrous slag-based products is also challenged by the presence of hazardous elements in metal streams such as lead and chromium. Research into the environmental aspects of slag will continue to be an important topic for reuse, recycling and remediation. Demonstration projects and activities are a practical tool for promoting the uptake of new resource efficiency technologies and for introducing and adapting the technology to specific use conditions with sufficient mitigation of environmental risks. In particular, there is still a lack of available data with regard to long-term release of pollutants. In order to secure the recyclability of slag-based construction materials, there is a need to understand the long-term behaviour of slag-based materials.

The regulatory frameworks should encompass practical methods or protocols for the management of presence of hazardous substances in slag-based products.

The industry is very much in favour of a fine-tuning and balancing between environmental protection, competitiveness and efficiency, through integrated risk-based approach. In particular the fine-tuning of the interactions between the Waste Framework Directive and REACH regulation is felt as an urgent need. This would significantly reduce the administrative burden and, consequently, the costs associated to the establishment of industrial symbiosis practices across industrial sectors. For instance, a wider use of by-products legal status for valorising slag-based products might more effectively support industrial synergies.

Marketability and competitiveness of slag-based products

Slags mainly substitute natural aggregates. Every year *ca.* 48 million tonnes of ferrous slags are produced and used which avoids the excavation of a similar amount of natural aggregates.

In the slag industry, competition is not so much between slag processing companies but rather with industries that provide the materials, which are substituted by the slag, such as construction and demolition waste and virgin aggregates.

The opportunities for ferrous slag depend on the local market situations and also the presence of steel plants. Regions with iron & steel plants have a relatively better access to slag, which in turn results in a relatively lower price. It is estimated that within a range of 150 km of a steel plant slag can be cost-efficiently used. Above that

range transport costs start to weigh heavier with an estimated maximum range of 200 km to reach the break-even point.

Most of slags are traded intra-EU. The extra EU28 trade for slags is relatively small. Import of ferrous slags represents less than 1% of the total amount produced in the EU28. Exports are slightly bigger but still less than 1%. The main reason for this is the bulk nature of slags and the transport costs in relation to the price of slags.

The EU single market could also take benefit of the development of EU level accepted standards for slag-based construction materials.

The industry has formulated a number of regulatory challenges, which hinder further upscaling at the EU-level or further valorising existing potential. Among others, differences in standards across EU Member States and lack of a single EU market for slag products are mentioned first.

European Union's policies and Slag valorisation

An epitome of industrial symbiosis within a circular economy

Industrial symbiosis is increasingly being seen as a strategic tool for economic development, green growth, innovation and resource efficiency at all policymaking levels in Europe – local, regional, national and international. At the European level, industrial symbiosis was recognised for its potential contribution to sustainable production and EU industry competitiveness under the 'Resource Efficient Europe' flagship initiative.

Unlike scrap metal that is recycled directly into the metal production, slag is used in other productions such as cement production, road construction, hydraulic engineering, and fertiliser production. Thus, the material continues in a circular economy after being cascaded to, which means extracting the highest value compound first and subsequently the other less valuable fractions in a stepwise manner, for instance, the construction sector and the cement producers, which are the major users of slag.

The valorisation of slags is gaining momentum with interesting opportunities. Both industry and academia invest in R&D for valorising this important material stream which can be considered as a promising source of secondary raw materials. The potential is not only determined by the sheer size of the non-scrap metal waste flow, but also by the availability and proximity of the so-called urban mine.

Promoting the set-up of regional industrial symbiosis networks in areas where companies in the metal industry operate on a company scale that is too small to handle the slag-based products valorisation efficiently is beneficial as well.

In line with the definition of Erkman and Ramaswamy (2001) the principal objective of industrial ecology is to restructure the industrial system by optimising resource use, closing material loops and minimising emissions, promoting de-materialisation and reducing and eliminating the dependence on non-renewable energy sources.

Demand promotion for industrial symbiosis products may be an important instrument for increasing circularity, especially when it substitutes virgin raw materials. Green Public Procurement is a valuable instrument in this respect, for instance in the case of using particular types of ferrous slag for public infrastructure works.

Thus, slag-based products valorisation responds fully to the objective of the EU Circular Economy policy as written in its Communication “Closing the loop – An EU action plan for the circular economy” (COM(201) 614 final), the “industrial symbiosis allows waste or by-products of one industry to become inputs for another”.

A powerful opportunity for CO_2 emissions reductions in construction

The use of slag-based materials gives an environmental advantage in terms of carbon footprint compared to the running of the same industrial process using virgin raw materials.

For instance, the use of granulated blast furnace slag reduces CO_2 emissions in the cement production *via* the replacement of clinker. The latter is obtained after an energy intensive process with substantial CO_2 production. In CEM-II and CEM-III types of cement, granulated slag may substitute up to 80% of the clinker. Consequently, this lowers the CO_2 emissions of the cement industry substantially.

The German Institute for Building Materials (FEhS) (M. Schneider, 2011) has calculated that in 2008 the emissions were reduced by 22 million tonnes CO_2 because of the use of 24 million tonnes of granulated blast furnace slag.

Slag valorisation in cement production is a low carbon technology, which serves the European strategic long-term vision for a competitive and climate neutral economy.

Conclusion

The valorisation of slag-based products is an objective that fully corresponds to EU policies with regard to the circular economy through resource efficiency and the European strategic long-term vision for a competitive and climate-neutral economy. However, some challenges still need to be tackled and solved: to secure a proper legal status to slag-based products, in recognising their market values and their performance/characteristics in targeted applications; to improve the technical and legislative framework in order to ensure a balanced outcome in which slag-based products and more in general secondary raw materials are not put at disadvantage compared to virgin raw materials and the risks for human health and environment are under full control.

To achieve this ambition, the industrial sectors concerned have still to deepen their cooperation aiming at establishing a larger industrial symbiosis basis. In such condition, business and technical relations among industrial sectors will be streamlined, together with their common practical protocols and relevant standards.

Industrial actors, Member States and relevant European stakeholders and authorities should work together to clarify common approaches and interpretations, to harmonise relevant regulations, criteria and standards for the valorisation of slags and to unleash its full potential for the benefit of EU environment and economy and the European industrial sectors.

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