SLAGS VALORISATION IN THE EU: TAPPING THE FULL POTENTIAL

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Introduction

ArcelorMittal is the world's leading steel and mining company, with around 209 000 employees in more than 60 countries. It leads in all major global steel markets, including automotive, construction, household appliances and packaging, with state-of-the-art R&D and technology. With an industrial presence in 18 countries, the company is exposed to all major markets, from emerging to mature.

With a combined production of 95.2 million tons of crude steel in 2018, it is the largest producer of steel in the EU, North and South America and Africa, a significant steel producer in the CIS region, and has a growing presence in Asia, including investments in China and India.

Steel products obviously dominating the ArcelorMittal sales portfolio, the various by-products generated by the steel making process add up to 4% of the total sales in 2018 (Figure 1).

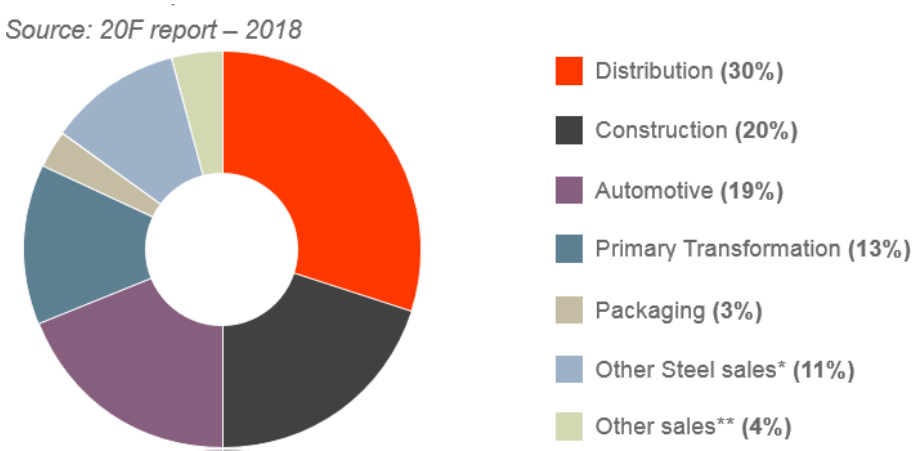

Figure 1: ArcelorMittal sales by market

The current drive for consuming resources more efficiently by a transition to a circular economy, creates expectations for further increasing the valorisation of the by-

products and wastes generated in the steel making process. It requires a coherent policy framework supporting existing routes for valorisation of by-products while providing the incentives for bringing the untapped potential of today in the economy.

This study aims at providing an overview of the current state of production and valorisation of the slags at the ArcelorMittal's EU carbon steel production plants and forwarding proposals for a policy framework to improve their exploitation potential.

Mapping - ArcelorMittal valorisation of slags

The different slags produced in the carbon steel making process are shown in Figure 2.

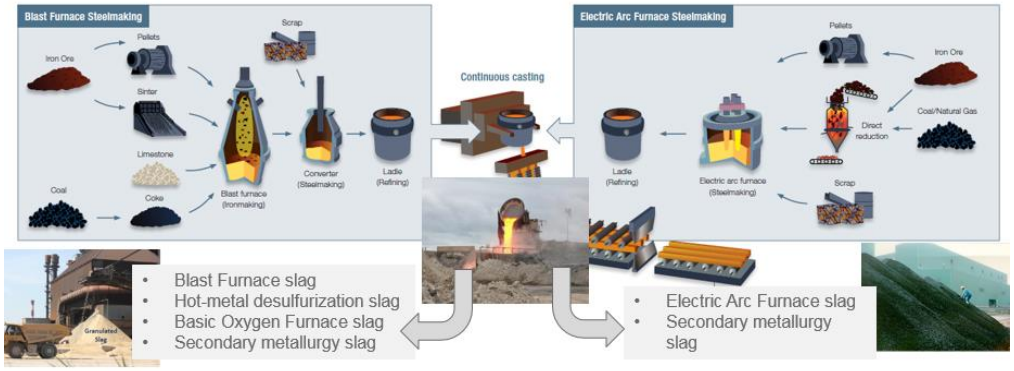

Figure 2: Slags produced by carbon steel making processes

Based on the differences in chemical composition and associated properties, these slags have been registered under Reach registration as in Table 1.

Table 1: Slag families and corresponding EINECS- and CAS-numbers

No.	Substance	EINECS Name	Common name	EINECS No. CAS No.
1	GBS	Slag, ferrous metal, blast furnace (granulated)	**G**ranulated **B**last furnace **S**lag	266-002-0 65996-69-2
	ABS	Slag, ferrous metal, blast furnace (air-cooled)	**A**ir-cooled **B**last furnace **S**lag	266-002-0 65996-69-2
2	BOS	Slag, steelmaking, converter	**B**asic **O**xygen furnace **S**lag (converter slag)	294-409-3 91722-09-7
3	EAF C	Slag, steelmaking, elec. furnace (carbon steel production)	**E**lectric **A**rc **F**urnace slag (from **C**arbon steel production)	932-275-6
4	EAF S	Slag, steelmaking, elec. furnace (stainless/high alloy steel production)	**E**lectric **A**rc **F**urnace slag (from **S**tainless/high alloy steel production)	932-476-9
5	SMS	Slag, steelmaking	**S**teel**m**aking **S**lag	266-004-1 65996-71-6

The associated properties of each type of slag have given rise to the typical uses in the market listed in Table 2.

Table 2: Typical applications per type of slag

	GBS	ABS	Hot metal de-S	BOS	SMS from BOF	EAF	SMS from EAF
Int. recycling			✓	✓	✓		
Cement	✓ additive			✓ raw mat.			
Glass	✓						
Roads building		✓		✓ uncovered		✓	
Stone wool		✓					
Fertiliser				✓			✓
Water works				✓			
Backfill				✓			
Soil stabilisation							✓
Water treatment		✓					
Landfilling			✓				

Figure 3 provides an overview of the 2018 production of slags by European ArcelorMittal carbon steel plants. The ore fed integrated production routes generate the dominant part of all by-products. About 2/3 of this can be attributed to blast furnace slag, a quarter to basic oxygen slag, while desulphurisation and secondary metallurgy slag make up the remaining 5%. At the other hand, the electric steel making facilities are majority fed by ferrous scrap recycled from end-of-life steel products, thus omitting the hot metal production and associated slags.

The ArcelorMittal Europe blast furnace slags are 100% valorised in the market either as **granulated blast furnace slag (GBS)** or **air-cooled blast furnace slag (ABS)** as indicated in Figure 4.

GBS is a by-product with attractive technical properties and environmental profile. To develop its full market potential as additive in cement and concrete, ArcelorMittal has set-up a joint-venture with ECOCEM. The JV has in France two facilities, each with a yearly 500 kton capacity. GBS has its strengths in serving the market for applications requiring corrosion resistance as in marine environments *e.g.* the Netherland's "Delta works" or requiring exceptional durability as in underground constructions in the "Grand Paris" project. R&D resources – under the "ActiSlag" RFCS project – are invested in understanding the reaction mechanisms of GBS setting and developping solutions to raise its early reactivity.

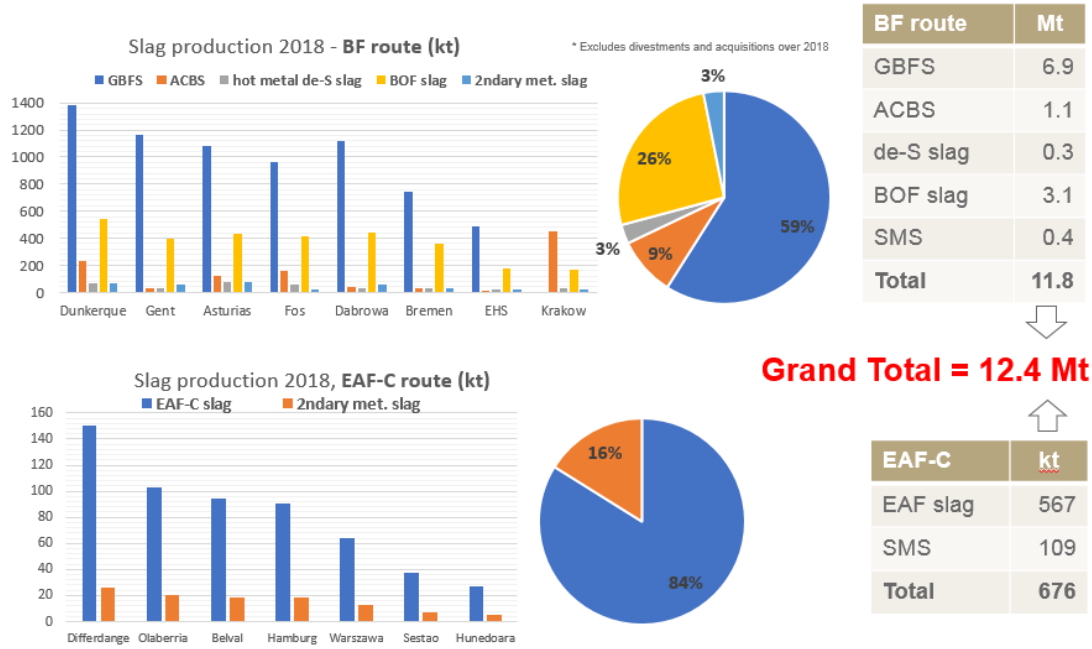

Figure 3: ArcelorMittal Europe carbon steel 2018 slag production

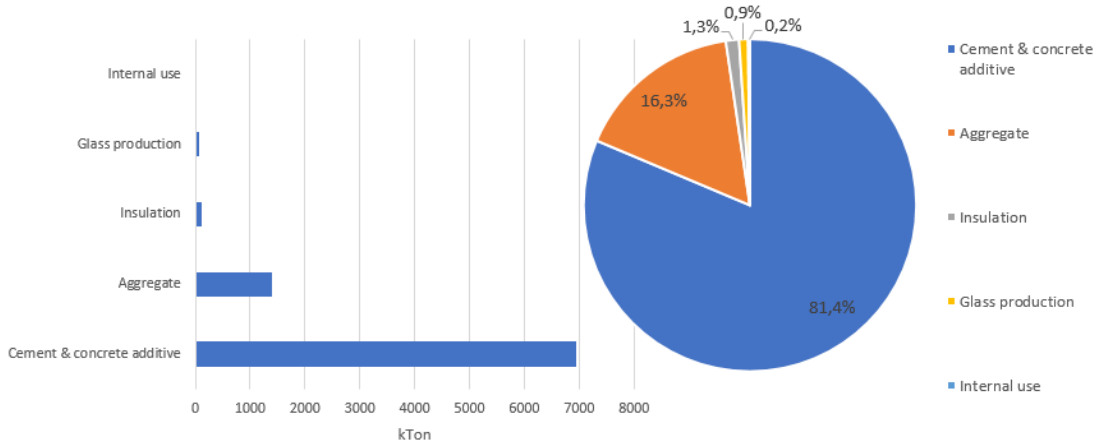

Figure 4: Blast Furnace slag usages (GBS+ABS)

The attraction of GBS is equally situated in its environmental profile as its most likely substitute in concrete or cement mixture is clinker, an 'energy product'. Thus, one can estimate the CO_2 saving potential of valorising the ArcelorMittal Europe blast furnace slags to be equivalent to 6.4 Mt CO_2 annually, assuming full granulation of blast furnace slag and 800 kg CO_2eq for avoided clinker production. Under the EU emission trading scheme (ETS), this 'carbon value' greatly adds to the attractiveness of the GBS product in Europe.

In life-cycle assessment of products, the up-stream of GBS production must be additionally considered. The energy efficiency of the blast furnace reactor makes that

marginal ton of slag[a] is produced at 550 kg of CO_2, significantly lower than the clinker footprint.

The **basic oxygen slag (BOS)** valorisation proves more precarious as - unlike GBS - it is not substituting an 'energy product'. This results in a valorisation ratio of 83% of the BOS production of ArcelorMittal Europe over the applications listed in Figure 5.

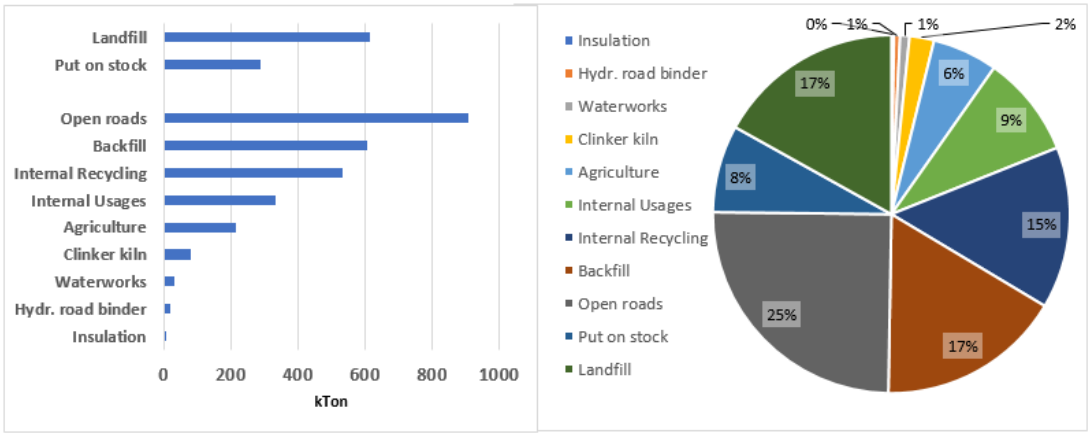

Figure 5: ArcelorMittal 2018 BOS slag valorisation

Internal valorisation, reducing raw material input of lime and iron ore, is an immediate use. As substitute for aggregates, after sizing, the BOS finds an application in open road construction, water works or backfilling applications. The finer fractions can be sold as fertiliser in agriculture. Nevertheless, 17% of BOS still ends up in landfill and another 8% goes to internal storage awaiting an opportunity for valorisation. The use of BOS as substitute of relatively lower value products makes that the transport cost acts as an additional barrier.

New applications for BOS are being researched, *e.g.* as filters against acidification of rain & groundwater in mining operations or the suitability of BOS for ballasting in off-shore windfarms is demonstrated.

Best practices

ArcelorMittal would applaud all further harmonisation of the EU regulatory framework for the valorisation of by-products and wastes. Unfortunately, the applicable framework conditions still vary among member states, resulting in different levels of valorisation.

For blast furnace slags, the important CO_2 savings made with **GBS** support their uptake in the market. To maximise granulation of blast furnace slag, the internal

[a] 4th Slag Valorisation Symposium (2015), The carbon cost of Slag production in the blast furnace.

capacity is expanded. Also, the technical performance of GBS is further optimised and tailored towards the market requirements. Even without the legal status fully harmonised across Europe, a 100% valorisation of the ArcelorMittal output occurred in 2018.

BOS faces more up-hill market conditions with a majority valorised in "fill" applications. Its legal status and technical criteria for its use differ among EU member states. Rather than incentivising, some public bidding contracts do exclude slags rather than promote their use. Positively, reference can be made to the use of BOS as amourstone for water works in the Netherlands and Belgium. The use of fine fraction of BOS in the fertiliser market is inhibited by the technical criteria imposed in various member states. In practice, Germany has created the best legal framework to enhance the market for this type of BOS valorisation. The take-off in the market of newer applications - *e.g.* ballast for off-shore windmill towers - further depends on efforts towards their commercial development. New technologies - *e.g.* the steam box treatment (Harsco) that reduces the swelling by 30% while abating the emission of dust – should widen appeal of BOS in road construction.

EAF slags represent a minor share in the total amount of slags generated by ArcelorMittal. No regulatory (nor technological) roadblock seems to prevent their valorisation in road works in the member states where ArcelorMittal operates. R&D efforts are dedicated to the valorisation of EAF SMS to cope with their powdery nature.

Conclusions: tapping the full potential

Important **CO_2 emission and resource savings** can be **realised today** if public authorities assure the maximum use of the higher added value by-products already produced. Importantly, GBS is a main by-product of iron making process that offers significant CO_2 emission savings by making the production of virgin alternatives redundant.

Green public procurement criteria aimed at valorisation of by-products should **evolve from a voluntary into a more mandatory framework** to create additional incentives for the uptake of by-products that substitute products with a lower added value. The voluntary Green Public Procurement (GPP) criteria for BOS in road construction result only in a partial valorisation today. Tender specification shall include BOS as an option and have their use reported *e.g.* "% content of secondary material and % of by-product" indicators.

Harmonised **technical criteria shall be based on science** and ensure market trust. The emergence of market barriers prevented from standardisation that can be dominated by the incumbent market actors. Examples of discrepancies limiting the valorisation: GBS as addition in concrete has in France a maximum content < 30% while no such limit applies in the UK; ground BOS can be used in cement/concrete in China; Cr related limits differ for fertiliser within Europe.

Evidently, also the slag producers carry responsibility to achieve higher valorisation ratios. ArcelorMittal ensures **dedicated organisational support** to the valorisation of the by-products by a central unit that implements best practices in the Group and coordinates the R&D resources (3M€ yearly budget) allotted to the development of its by-products. Examples of best practices are slag segregation and characterisation to allow deferring from internal/external landfill; guidance documents informing customers on correct use and prevent reputational damage due to accidents caused by inappropriate operational procedures; collaboration with dedicated associations *e.g.* FEhS (DE), CTPL (FR), UNESID (ES) for the promotion of slag valorisation.