

# ESTEP 2025 Annual Event

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Udine (ITALY)

How decarbonisation, digitisation  
and circular solutions forge the  
sustainable European steel future?

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## INSIGHTS FROM CURRENT STEEL AND SLAG PRODUCTION FOR NEXT- GENERATION PROCESSES

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**DIGIMET**



**DANIELI AUTOMATION**



**UNIVERSITÀ  
DEGLI STUDI  
DI UDINE**  
HIC SUNT FUTURA

## Objectives

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- Next generation iron and steelmaking process to decrease CO<sub>2</sub> by using direct reduced iron with varying reduction degrees, hot briquetted iron, hydrogen plasma smelting reduction or by operating electrical smelters for low-grade ores will result in increase of EAF and other slags with different properties to currently produced slags.
- Currently, there is no large-scale production using DRI/HBI in EAFs or smelters in Europe.
- While some steelworks have begun transitioning by closing BF/BOF facilities and constructing EAFs, a solution for managing the resulting increase in EAF slag has not yet been established.
- At present, BF slag is sold as ground GBFS to the cement industry. However, if a viable method for utilizing EAF slag in cement production is not developed, this industrial symbiosis is at risk of disappearing.
  - **InSGeP project objective: To understanding the possibility to valorise future slags in the present value chain and define innovative applications to assure smooth transition process.**

# InSGeP project

## Partners

- 5 RTO
- 5 steel works
- 2 plant manufacturers
- + ESTEP



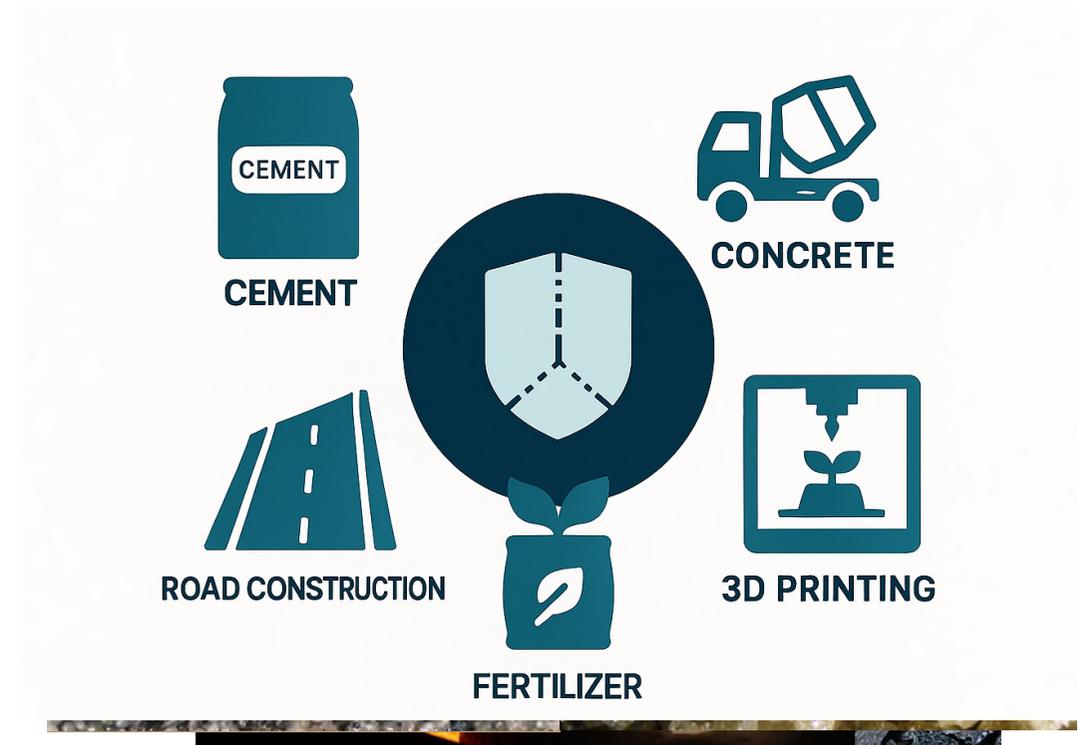
# InSGeP project Structure

Data gathering of current steel and slag production

Collection and production of slag samples from next generation steel making

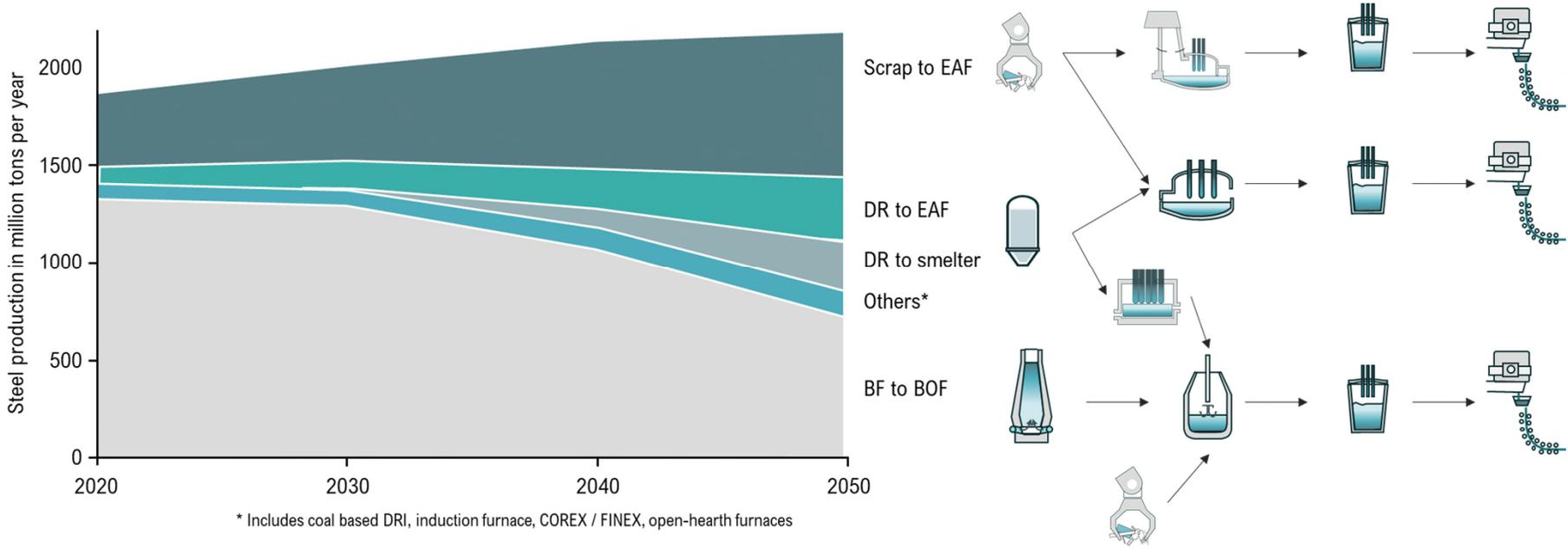
Slag modification

Slag applications



# Steel production

## Global steel production volume by route

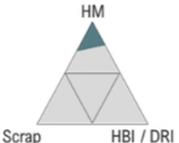
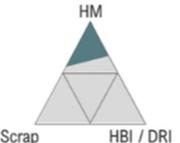
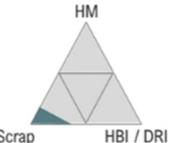
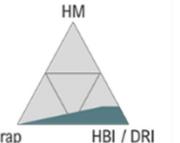


Based on Primetals Technologies: Metals Magazine: Innovation and technology for the metals industry, Special Edition METEC 2023



# Steel production

## Comparison of typical reference data from BOF and EAF operation

KPI	Unit	BOF	KOBM	Scrap EAF	Flexible EAF	DRI EAF
Typical charge mix						
Hot metal / scrap / direct reduced iron	[%]	80 / 20 / 0	65 / 30 / 5	0 / 100 / 0	40 / 40 / 20	0 / 30 / 70
Yield	[%]	90.5	91.5	89.0	89.5	87****
Tap to tap time	[min]	40	40	50	45	55
Nitrogen level EOT*	[ppm]	16 – 50	16 – 50	60 – 100	35 – 80	25 – 60
Refractory lifetime	[heats]	~4000	~4000 (2000**)	500 – 1500	500 – 1500	~1000
Energy output / heat losses	[%]	20 – 30	20 – 25	35 – 40***	40 – 45	45 – 50
Slag	[%]	13	10	13	12	18
Offgas	[%]	9	8	12 – 18***	18 – 28	18 – 28
Cooling water & others	[%]	3	3	10	10	10

\* End of treatment (before tapping)

\*\* Hot bottom exchange

\*\*\* Depending on scrap preheating

\*\*\*\* Direct reduction grade pellets, lower for blast furnace grade direct reduced iron



# Slag production

## Current use of EAF and LF slag

Spain

Italy

Austria

Carbon EAF (EAF-C) slag	Stainless EAF (EAF-S) slag	LF slag
Road construction	Usage in special concretes in rock filling (filling material or support material in mining areas)	Cement

Belgium

Carbon EAF (EAF-C) slag	Stainless EAF (EAF-S) slag	LF slag
<b>Road applications</b>	<b>Road building</b>	<b>Cement</b>
	Concrete	
	Products mixed with binder	
	<b>Civil engineering</b>	

France

Carbon EAF (EAF-C) slag	Stainless EAF (EAF-S) slag	LF slag
Public works	Public works	Public works
Internal recycling	Internal recycling	Hydraulic binder production
Construction	Construction	Construction
		Internal recycling

Germany

Carbon EAF (EAF-C) slag	Stainless EAF (EAF-S) slag	LF slag
<b>Landfilling</b>	<b>Landfilling</b>	<b>Landfilling</b>
Landfill replacement	Landfill replacement	Landfill replacement
Building material	Building material	Building material
<b>Aggregate</b>	<b>Metal extraction</b>	<b>Aggregate/Sand</b>
Unbound and hydraulically bound mixtures		Unbound mixtures
Bituminous mixtures		Cement
Armourstone		<b>Fertilizer</b>
Gabions		<b>Internal recycling</b>
Railway ballast		
Embankments and fill		
<b>Slag Sand</b>		
Blasting		

Carbon EAF (EAF-C) slag	LF slag			
<b>Landfilling</b>	<b>Landfilling</b>			
Landfill replacement	<b>Aggregate</b>			
Building material	Cement			
<b>Aggregate</b>				
Concrete (many types)				
Bituminous mixtures				
Surface treatment of roads, airports and other paved areas				
Granular layers				
Layers treated with hydraulically bond mixtures				
Mortars				
Embankments				
Backfill				
Railway sub-ballast				
Sonic shield for road structures				
Road base and sub-base				

Carbon EAF (EAF-C) slag	Stainless EAF (EAF-S) slag	EAF slag as "slag sand"	LF slag	LF slag as "slag sand"
<b>Landfilling</b>	<b>Landfilling</b>	Acid mine drainage prevention, treatment and remediation	<b>Landfilling</b>	Acid mine drainage prevention, treatment and remediation
Landfill replacement	Landfill replacement	Soil stabilization and road base reclamation	Landfill replacement	Soil stabilization and road base reclamation
Building material	Building material	Road base and sub-base	Building material	Sludge solidification and stabilization
<b>Aggregate</b>	<b>Metal extraction</b>	General construction engineered fill, embankment, and backfill	<b>Liming material</b>	Hazardous waste stabilization
Unbound and hydraulically bound mixtures		Sludge solidification and stabilization	Agriculture – pH adjustment and plant available silicon	Flowable fill and excavatable backfill
Bituminous mixtures		Hazardous waste stabilization	<b>Replacement of lime in EAF</b>	
Concrete		Flowable fill and excavatable backfill	<b>Cement</b>	
Mortar		Cement and concrete		
Armourstone		Asphalt		
Gabions		Blasting material		
Railway ballast				
Roofing				
Embankments and fill				
Sealants				
Waste-water treatment				
Air quality control				

# Regulations

## Road construction – leaching tests

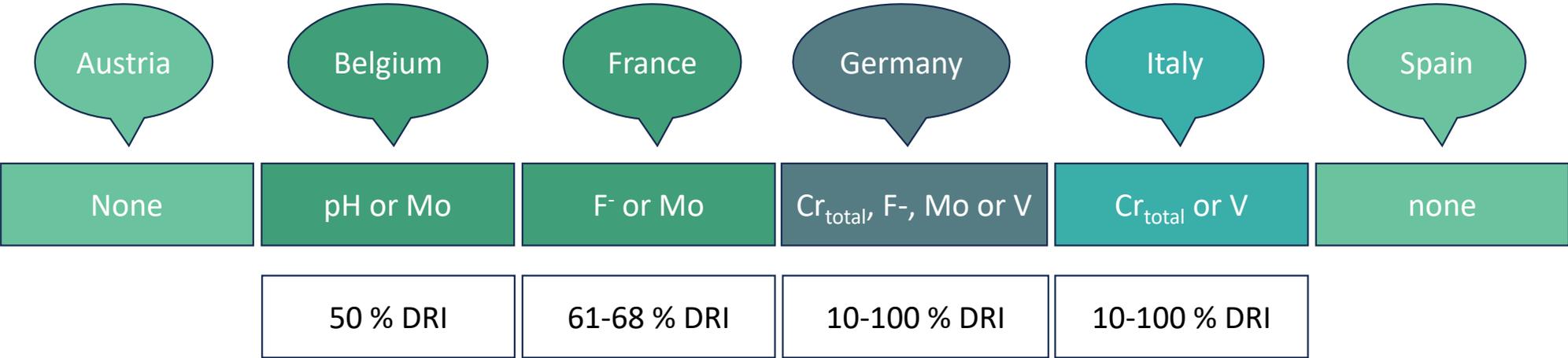


	Austria	Belgium	France	Germany	Italy	Spain
<b>Leaching test</b>	EN 12457-4	EN 12457-4	EN 12457-4	DIN 19529	EN 12457-2	EN 12457-4
<b>solid:liquid</b>	1:10	1:10	1:10	1:2	1:10	1:10
<b>grain size</b>	< 10 mm	< 10 mm	< 10 mm	< 22.4 mm	< 4 mm	< 10 mm
<b>parameters</b>	pH, Ba, Cd, Co Cr <sub>total</sub> , Mo, Tl, V, W, F <sup>-</sup>	pH, EC, As, Al, Cd, Co Cr <sup>6+</sup> , Cu, Hg, Mo, Ni, Pb, Sb, Ti, Zn, CN <sup>-</sup> , F <sup>-</sup> , NO <sup>3-</sup> , SO <sup>4+</sup>	As, Ba, Cd, Cr <sub>total</sub> , Cr <sup>6+</sup> , Cu, Hg, Mo, Ni, Pb, Sb, Se, Zn, Cl <sup>-</sup> , F <sup>-</sup> , SO <sup>4+</sup>	pH, EC, Cr <sub>total</sub> , Mo, V, F <sup>-</sup>	pH, COD, As, Ba, Be, Cd, Co Cr <sub>total</sub> , Cu, Hg, Ni, Pb, Se, V, Zn, Cl <sup>-</sup> , CN <sup>-</sup> , F <sup>-</sup> , NO <sup>3-</sup> , SO <sup>4+</sup>	As, Ba, Cd, Cr <sub>total</sub> , Cr <sup>6+</sup> , Co, Cu, Hg, Mo, Ni, Pb, Sb, Se, V, Zn, Cl <sup>-</sup> , F <sup>-</sup> , SO <sup>4+</sup>
<b>units</b>	mg/kg	mg/L	mg/L	mg/L	mg/L	mg/kg

# InSGeP DRI samples

## Road construction – leaching tests

Based on analysis of 15 slag samples collected around the world with 10-100 % DRI (63% average), elements that would need further treatment to comply with the local regulations:



## Regulations

# Cement and concrete

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- There are no specific European regulations with respect to slag use in cement or concrete, national regulations apply.
- Most countries allow the use of slag (or specifically GBF slag) in cement production
  - Adopted from EN 197-1
    - Cr(VI) leaching needs to be below 2 mg/kg in solid
    - Slag needs to be more than 2/3 of glass content
    - Environmental behavior – limiting values specific to each country
- Currently EAF slag in cement is limited
- In some countries EAF slag is used in concrete
  - Adaptation of EN 206 or EN 15167 specifically for ground-GBF slag
  - Limited use in building construction due to regulations

# InSGeP project

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Slag modification

Slag applications



# Slag modification

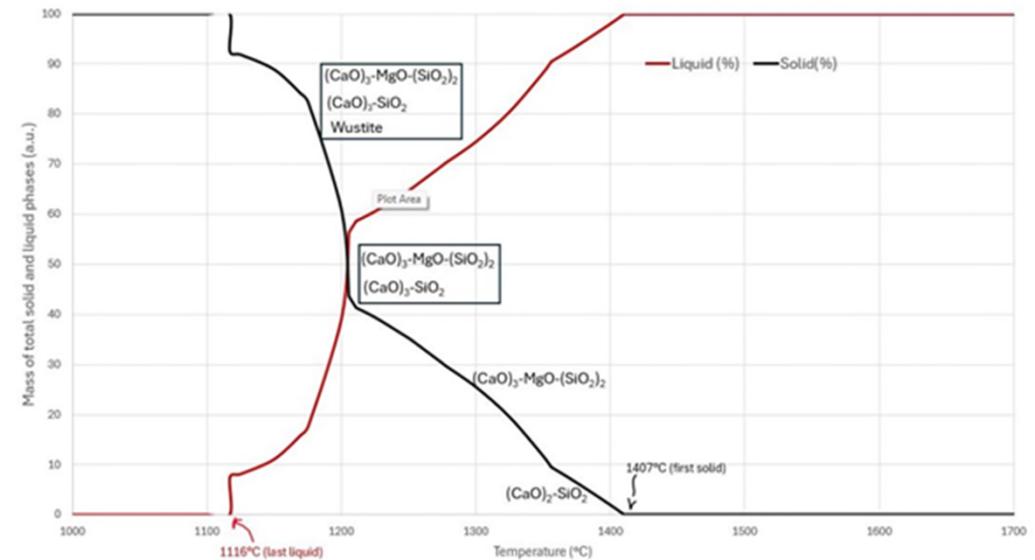
## Slag properties

### Slag sample Y1-I (100% DRI)

100% DRI FEED		SLAG COMPOSITION	
Chemical compound	% WEIGHT	Species	% WEIGHT
Fetot.	84.4	SiO <sub>2</sub>	18.7
Al <sub>2</sub> O <sub>3</sub>	1	TiO <sub>2</sub>	1.3
CaO	1.2	CaO	37.1
MgO	0.7	MgO	6.9
SiO <sub>2</sub>	4.7	FeO	24.1
ZnO	0.03	MnO	1.6
S	0.01	Al <sub>2</sub> O <sub>3</sub>	9.4
C	3.3	Na <sub>2</sub> O	0.5
Metallization	95.5	K <sub>2</sub> O	0.2

### Slag properties given by CSM

Temperature	1550	°C
Density @T	3081	Kg/m <sup>3</sup>
Surface tension @T	0.539	N/m
Viscosity @T	0.0261	Pa*s
Thermal conductivity @T	0.08	W/m/K
Specific heat @T	1401	J/kg/K



Slag modification

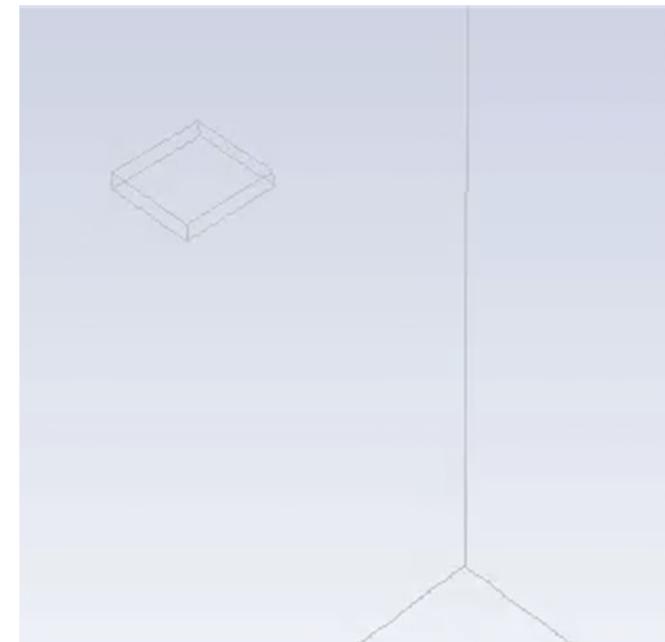
## Dry Slag Granulation

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### Slag Primary Break-up and Granulometry Model setup

The system is described in a transient way by means of a multiphase model called **VOF-to-DPM**. The energy is enabled and the **turbulence model** used is the  $\kappa$ - $\omega$  SST.

- ✓ Capture instabilities and large structures formation (**primary breakup**)
- ✓ The dispersion phase (**DPM**) consists in the **spherical droplets** formed during primary breakup
- ✓ **The output is the granulometry**, temperature and properties of the individual particles



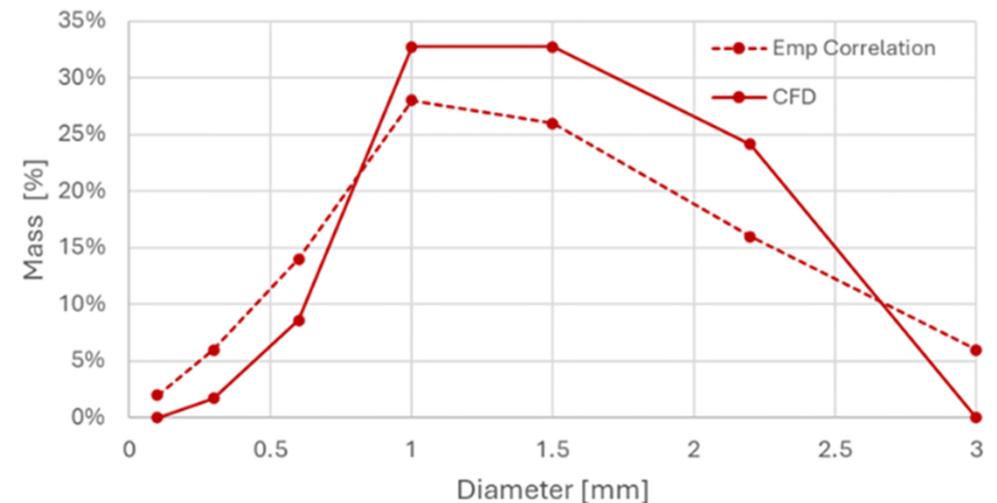
# Slag modification

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#### Average diameter

CFD

2.02 mm

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# Slag modification

## Dry Slag Granulation

### Test @ Rina-CSM Pilot Plant



XRD: the spectrum of the three collection zones shows that:

- Nozzle: The proportion of amorphous is 64.41 %, the proportion of crystalline is 35.59 %
- Prechamber: The proportion of amorphous is 56.55 %, the proportion of crystalline is 43.45 %
- Chamber: The proportion of amorphous is 75.47 %, the proportion of crystalline is 24.53 %



Average diameter	
Exp	1.86 mm
CFD	2.02 mm

## Conclusions

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- Not all applications are regulated in the same way in each country, in some cases there are no regulations as to slag use, in other case there are regulations to a particular slag type, but not necessarily EAF and LF.
- In order to assess slags from next generation steelmaking it is crucial to understand what applications they are being used in currently and if the new application that is being investigated is allowed (if not steps need to be taken to obtain permission).
- Slag resulting from smelters can be recycled in the cement industry as they have similar basicity to BF slag, however EAF slag will require modifications.
- Rapid cooling of EAF slag increase the amount of amorphous phase, improving the possibility to valorize it.

# InSGeP

## Thank you

[www.insgep.eu](http://www.insgep.eu)

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