

# The role of slags and other by-products within circular economy in the steel industry

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- Falco Lischke, tkSE

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*ESTEP Focus  
Group Circular  
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# The role of slags and other by-products within circular economy in the steel industry

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## In the Age of Decarbonization: Smelter-slag as a substitute for granulated Blast Furnace Slag

06.03.2025 | Falco Lischke tkSE



engineering.tomorrow.together.

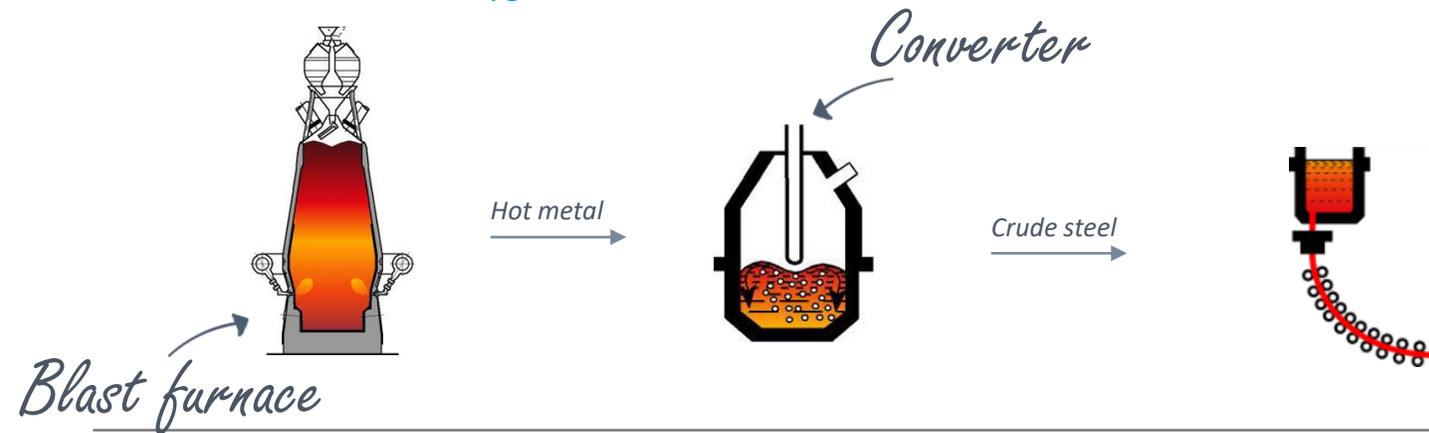


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# Ways of producing steel today

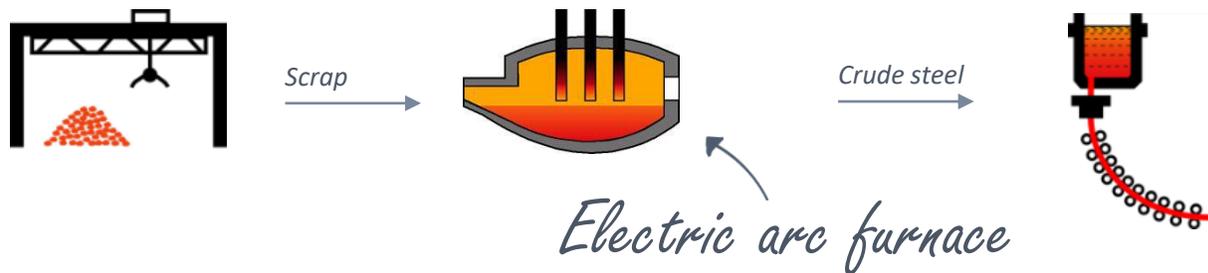
**Primary production:** Crude steel production based on iron ore.  
Ores are iron-oxygen compounds mixed with other impurities.

Reduction = removal of oxygen



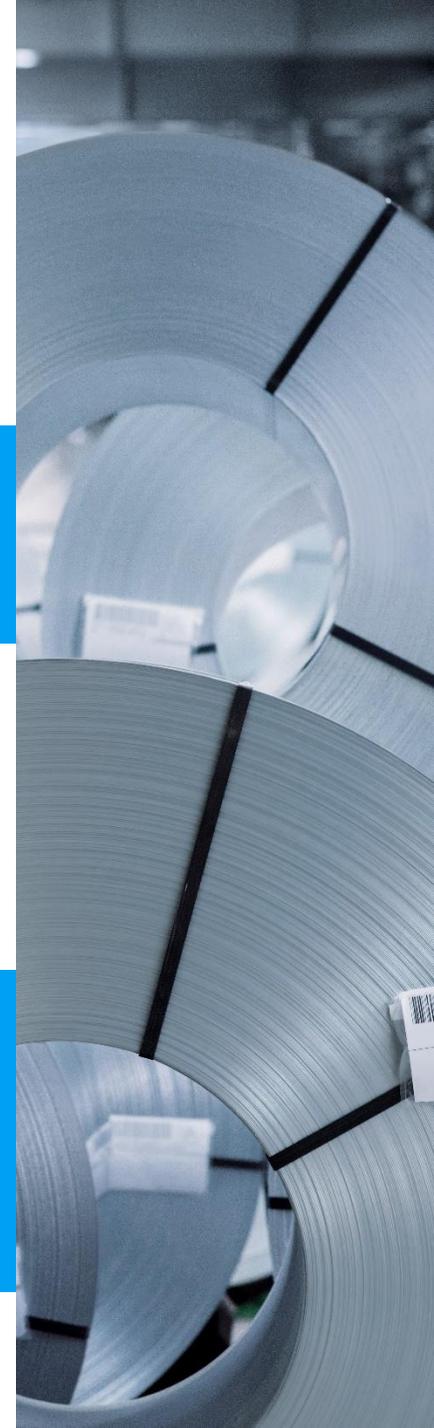
Granulated slag is used in cement industry to save CO<sub>2</sub>-emissions

**Secondary steel** is produced by melting down steel scrap.



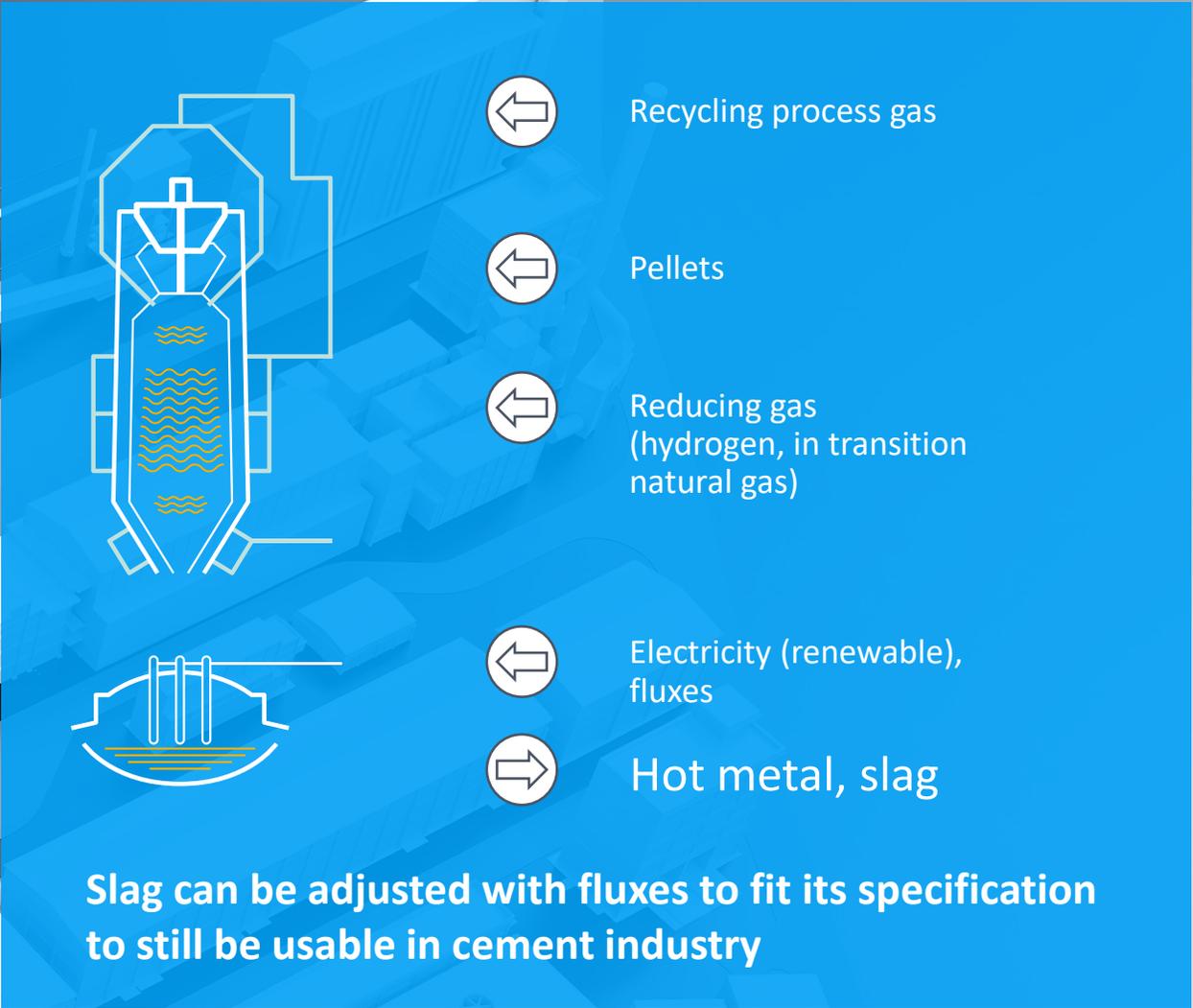
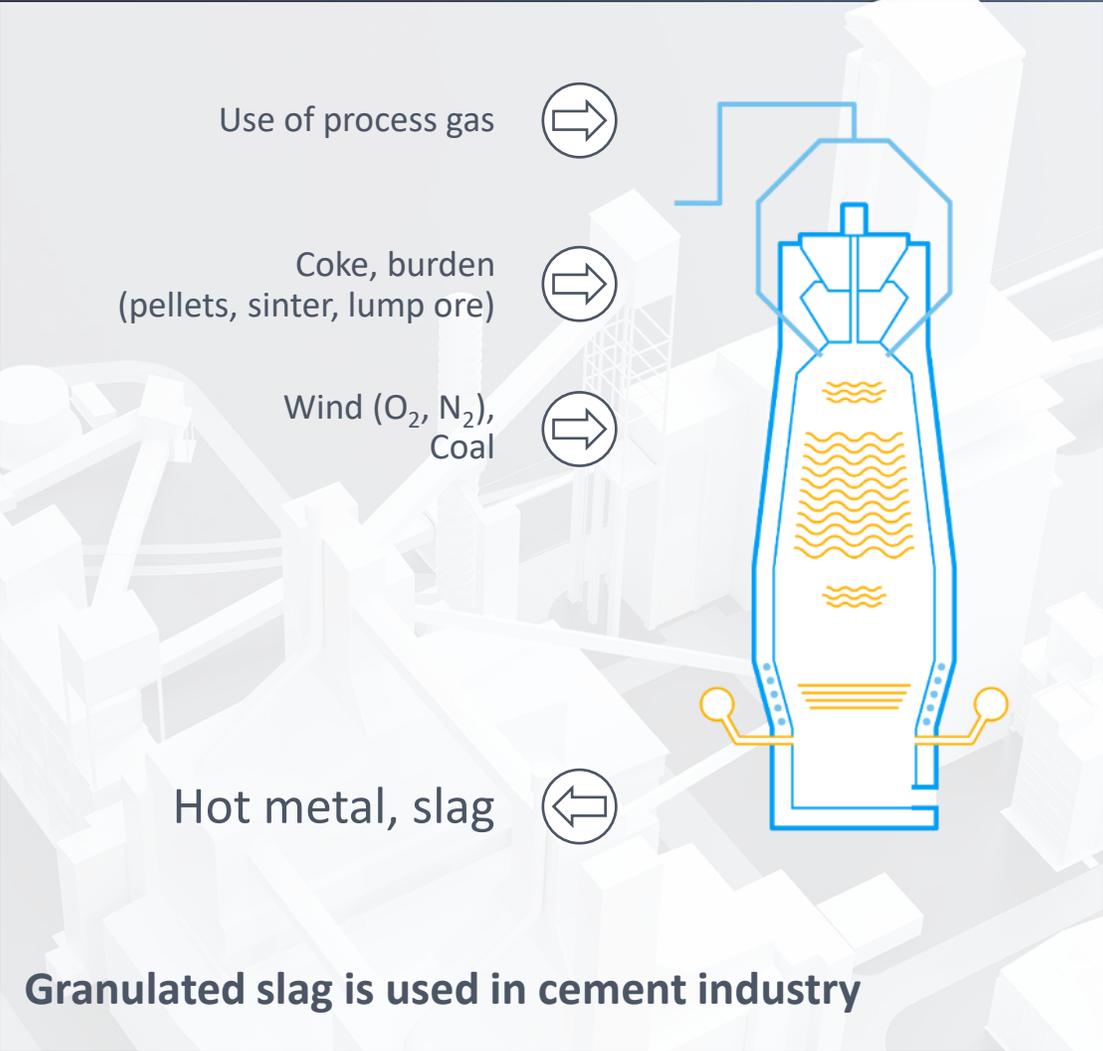
- chemical analysis nearby LD-slag
- High FeO-content
- Actually not suitable for cement industry

Note: Illustrations of the process routes are a clear simplification



# DECARBONIZING OUR STEEL PRODUCTION

## Gradual replacement of blast furnaces



# Objectives and procedure



In 2023 and 2024, along with FEhS and the University of Duisburg, melting trials of DRI were carried out in an industrial-sized smelter. The trials were funded by the “Federal Ministry of Education and Research”



**Input:**

|                           |               |                    |                        |
|---------------------------|---------------|--------------------|------------------------|
| 3.8 t Lime                | 64 t DRI      | 1.2 t Bauxit       | 10 t scrap (only 2023) |
| 14.6 t blast furnace sand | 14 t pig iron | 4.6 t lignite coke |                        |



## Main objectives of the investigations:

- Carburization behavior of the melt (2023)
- Production of slag for REACH-certification, similar to blast furnace slag (2024)
- Comparison of pile charging (2023) vs. electrode-near charging (2024)



Slag granulation



Angle of repose  
DRI-coke mixture



Sampling



Smelting of DRI-coke  
mixture

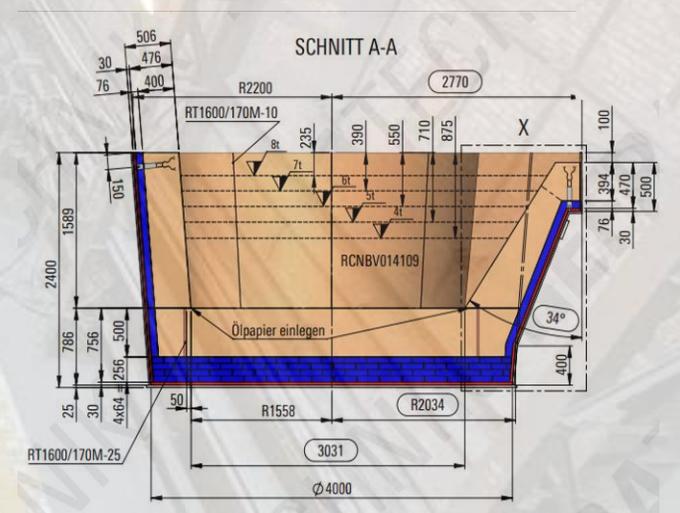
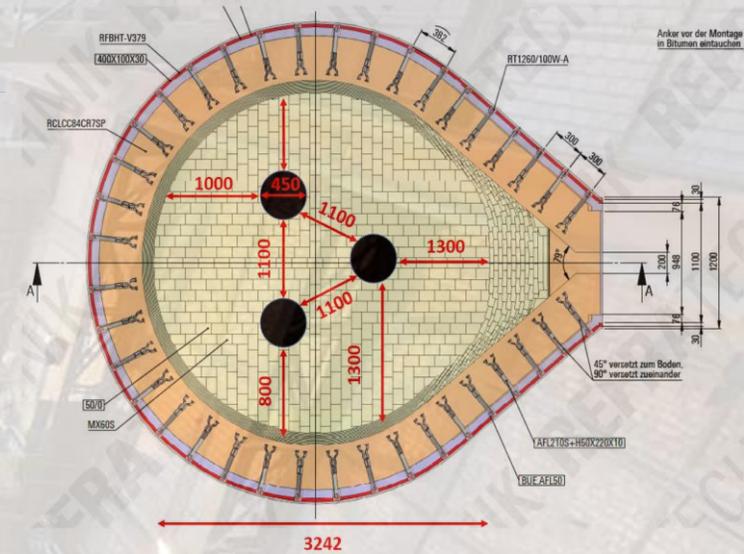


Casting hot metal



# Specification furnace :

- Transformer rating: 6.5 MVA AC
- Secondary voltage range: 110–320 V
- Max. electrode current: 22.08 kA
- Diameter electrode (3 pieces): 450 mm
- Usable diameter furnace: approx. 3.2 m
- Inner volume: approx. 10 m<sup>3</sup>



The smelter was lined with a new refractory for the trials



# Impression from the trials

Control center



Smelting



Slag-sampling



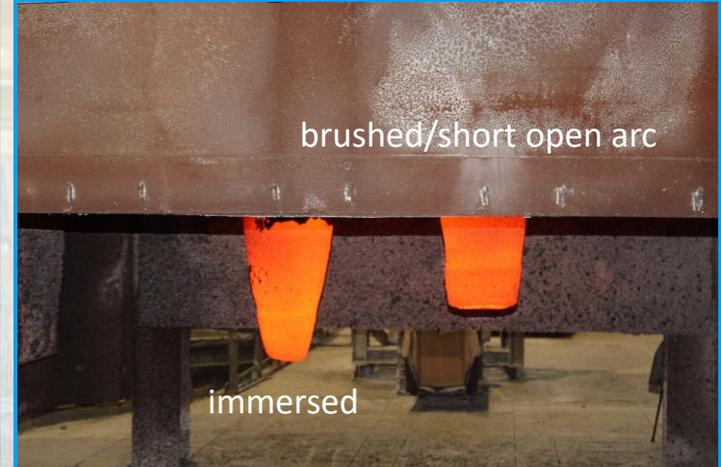
Trial hall



Casted hot metal (ca. 15 t)



Example electrodes

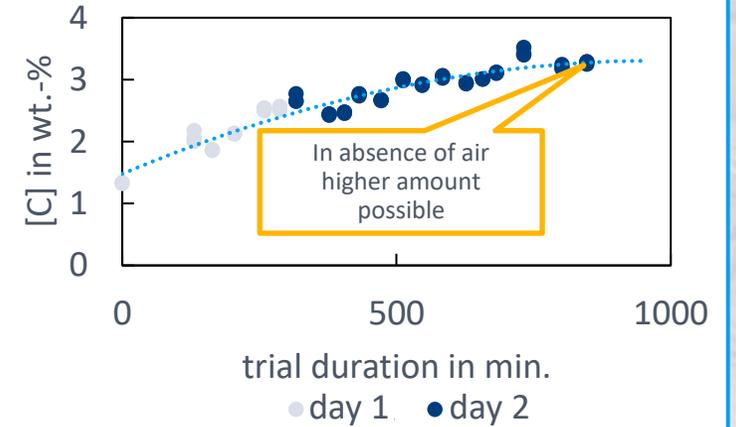


# Trial results 2023: Process



## Trial results: Hot metal

- Carbon efficiency assumed to be 50% for carburization and residual reduction due to open combustion
- Carburization behavior exhibited reduced efficiency due to increased carbon loss in the open furnace, attributed to the use of a vibrating chute
- After initiating the process with a 6-ton 'start melt' containing 1.3 wt.% [C], a quasi-steady state was reached with 3.2 wt.% carbon content in the cast hot metal



## Trial results: Process slag

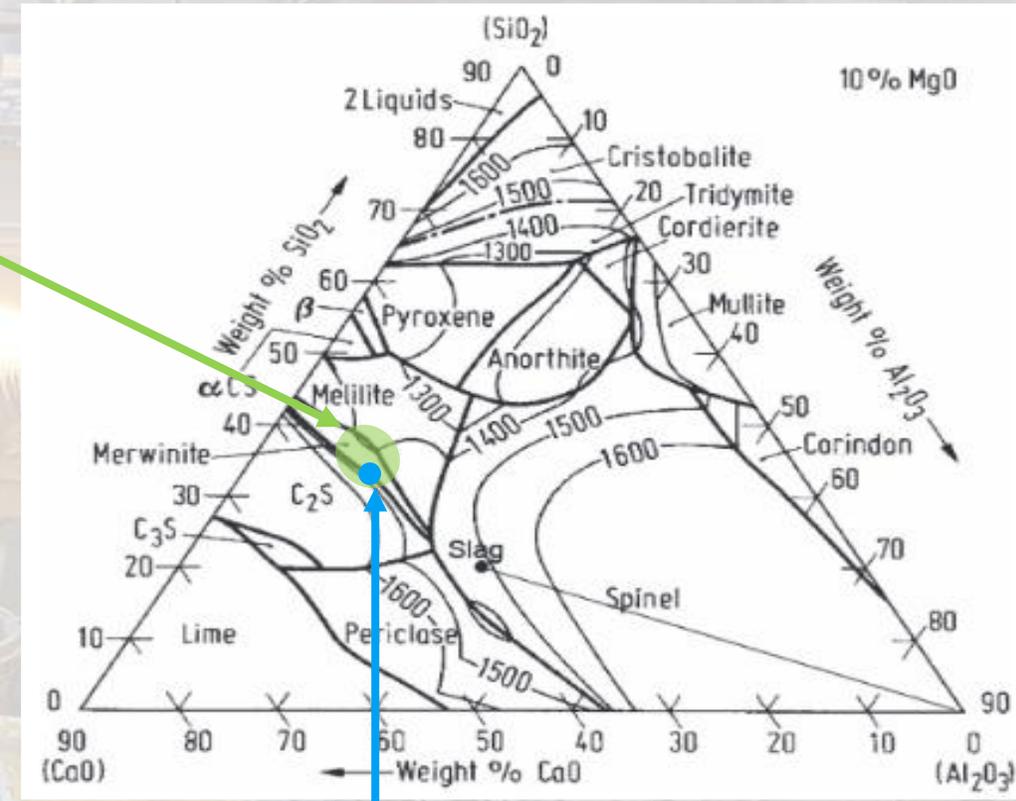
- Good flow behavior of the slag during decanting and granulation
- No significant 'floating' of carbon on the slag
- Almost complete reduction of iron oxide from the slag, (FeO) ~ 0.2 wt.%



# Trial results 2023: Granulated slag

- Slag was successfully granulated (>94% glass content)
- Composition of the slag conforms to current granulated blast furnace slag
- Initial strength tests promising

|                                |                                |      |       |
|--------------------------------|--------------------------------|------|-------|
| Al <sub>2</sub> O <sub>3</sub> | Aluminiumoxid                  | M.-% | 13,59 |
| CaO                            | Calciumoxid                    | M.-% | 43,18 |
| Cl                             | Chlorid                        | M.-% | 0,01  |
| Cr <sub>2</sub> O <sub>3</sub> | Chrom(III)oxid                 | M.-% | 0,04  |
| FeO                            | Eisen(II)oxid ber. aus Fe_ges  | M.-% | 0,20  |
| GV 950°C                       | Glühverlust (950 °C)           | M.-% | -0,66 |
| K <sub>2</sub> O               | Kaliumoxid                     | M.-% | 0,04  |
| MgO                            | Magnesiumoxid                  | M.-% | 7,36  |
| MnO                            | Mangan(II)oxid ber. aus Mn_ges | M.-% | 0,04  |
| Na <sub>2</sub> O              | Natriumoxid                    | M.-% | 0,15  |
| P <sub>2</sub> O <sub>5</sub>  | Phosphorpentoxid               | M.-% | <0,01 |
| S <sub>2</sub> -               | Sulfid                         | M.-% | 0,44  |
| SiO <sub>2</sub>               | Siliciumoxid                   | M.-% | 33,88 |
| SO <sub>4</sub>                | Sulfat                         | M.-% | 0,10  |
| TiO <sub>2</sub>               | Titanoxid                      | M.-% | 0,31  |



Trial-slag

After this results new trials with focus on slag-specification were planned for 2024



# Trial results 2024: Granulated slag



Requirements for REACH-certification:

|             | CaO  | MgO  | Al <sub>2</sub> O <sub>3</sub> | SiO <sub>2</sub> | TiO <sub>2</sub> |
|-------------|------|------|--------------------------------|------------------|------------------|
| Upper limit | 50,4 | 20   | 17                             | 53.47            | 2.4              |
| Lower limit | 21   | 1.33 | 3.02                           | 25.71            | 0.08             |



For the first time, slag was melted from a proportion of >70% DRI, almost 100 % glass content



Except for a slight exceedance of the Al<sub>2</sub>O<sub>3</sub> value, the essential limits have been adhered to; according to experts (FEhS, internal), this does not lead to problems



Upon confirmation of the values, a REACH-certification can be pursued. Also, the similarity to blast furnace slag is given.

| EWW Serie 2 - tkSE trial #3 (70% DRI)                            |       |      |            |
|--|-------|------|------------|
| parameter  | value | unit | method     |
| Aluminiumoxid  | 19.3  | M.-% | RFA        |
| Bariumoxid   | 0.13  | M.-% | RFA        |
| Bleioxid   | <0.01 | M.-% | RFA        |
| Calciumoxid  | 39.4  | M.-% | RFA        |
| Chrom(III)oxid   | <0.01 | M.-% | RFA        |
| Eisen(II)oxid ber. aus Fe_ges                                    | 0.83  | M.-% | RFA        |
| Kaliumoxid   | 0.09  | M.-% | RFA        |
| Kupferoxid   | <0.01 | M.-% | RFA        |
| Magnesiumoxid  | 4.65  | M.-% | RFA        |
| Mangan(II)oxid ber. aus Mn_ges                                   | 0.06  | M.-% | RFA        |
| Natriumoxid  | 0.3   | M.-% | RFA        |
| Nickeloxid   | <0.01 | M.-% | RFA        |
| Phosphorpentoxid   | <0.01 | M.-% | RFA        |
| Schwefel, gesamt   | 0.15  | M.-% | RFA        |
| Siliciumoxid   | 33.1  | M.-% | RFA        |
| Strontiumoxid  | 0.05  | M.-% | RFA        |
| Sulfat max. ber. aus S_ges                                       | 0.38  | M.-% | RFA        |
| Titanoxid  | 1.07  | M.-% | RFA        |
| Vanadiumpentoxid   | 0.03  | M.-% | RFA        |
| Zinkoxid   | <0.01 | M.-% | RFA        |
| Zirkoniumoxid  | 0.47  | M.-% | RFA        |
| Gesamter anorg. geb. Kohlenstoff (CO <sub>2</sub> )              | 0.04  | M.-% | IR         |
| Glühverlust (berechnet Summe CO <sub>2</sub> + H <sub>2</sub> O) | 0.08  | M.-% | calculated |
| Wasser   | 0.04  | M.-% | IR         |
| Basizität einfach CaO/SiO <sub>2</sub>                           | 1.19  |      | calculated |
| Basizität erweitert (CaO+MgO)/SiO <sub>2</sub>                   | 1.33  |      | calculated |
| C+M+S CaO+MgO+SiO <sub>2</sub>                                   | 77.08 |      | calculated |
| Natriumäquivalent  | 0.36  | M.-% | calculated |
| gesamter Kohlenstoff   | 0.048 | M.-% | IR         |
| Schwefel, gesamt   | 0.122 | M.-% | IR         |



Granulated slag



Granulation

Promising granulated slag produced for REACH certification – tests ongoing



# Observation/Estimations

Charging direct to the electrode



- No significant floating observed.
- Most of the material melts immediately/sinks.
- Burn-off of C-carrier due to oxidizing atmosphere

Slag granulation



- Decanting was unproblematic, with almost no metal carryover.
- The granulation water flow rate was set at 250 m<sup>3</sup>/h.
- The granulation result was fine, glassy sand.

Expectations regarding the granulation, melting and behavior depending on the charging location confirmed

