AISTech2025

Simulation of slag composition resulting from Electric Arc Furnace fed with DRI or HBI

Ismael Matino, Valentina Colla, Teresa A. Branca

TELECOMMUNICATIONS, COMPUTER ENGINEERING, AND PHOTONICS INSTITUTE

Sant'Anna School of Advanced Studies – Pisa

European Commission

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

ICT COISP

Information and Communication Technologies for Complex Industrial Systems and Processes

Content

- Introduction
- The InSGeP Project
- Flowsheet model of EAF-based steelmaking route
- Scenario analyses
- Conclusions
- Future Works

European Commission

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

Introduction
The European Green Deal

Among the different undertaken and foreseen activities, significant efforts are being spent for **making the steel sector climate-neutral and resource-efficient**

AISTech2025

European Commission

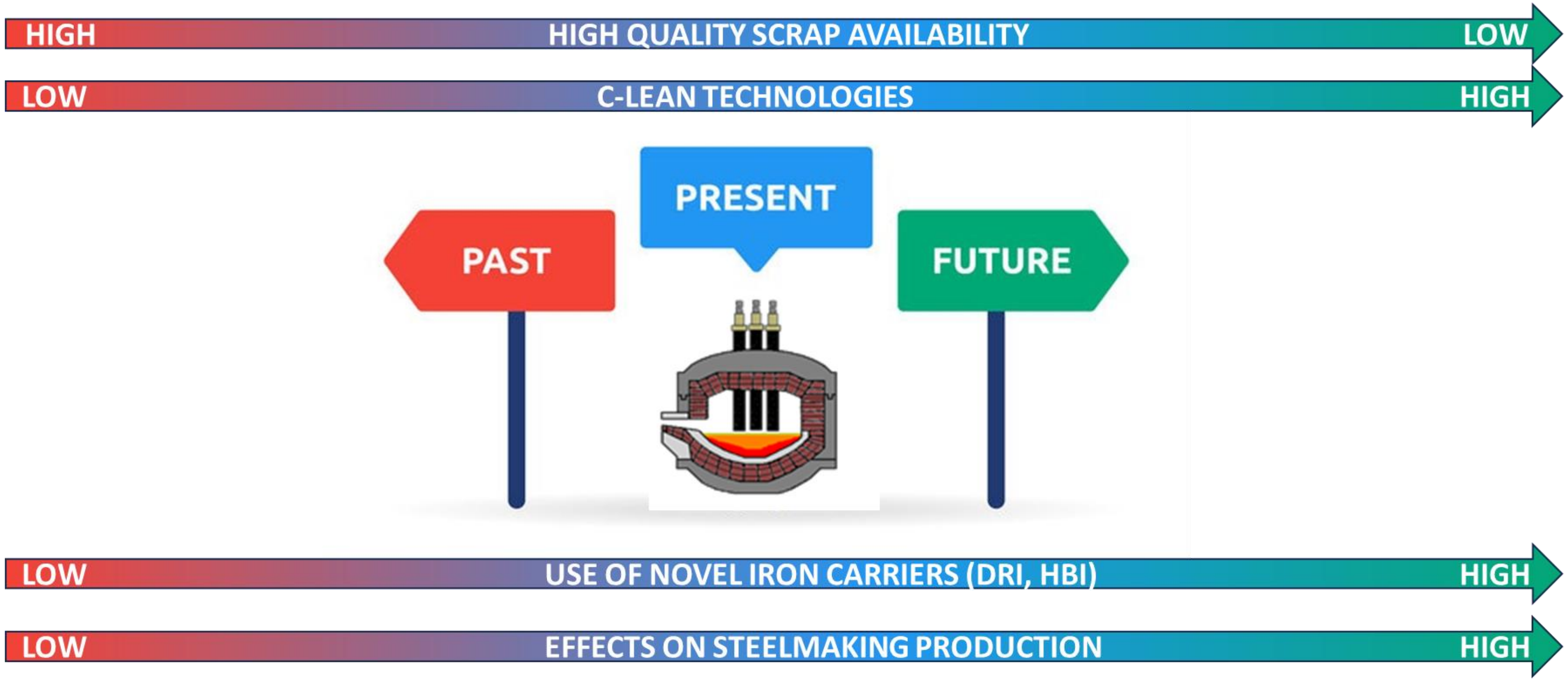
The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

Introduction
Electric steelmaking role in decarbonization

Electric steelmaking is playing a crucial role in decarbonization:

- it intrinsically implements a circular economy practice
- its environmental impact is lower compared to that of the integrated steelmaking route



AISTech2025

European Commission

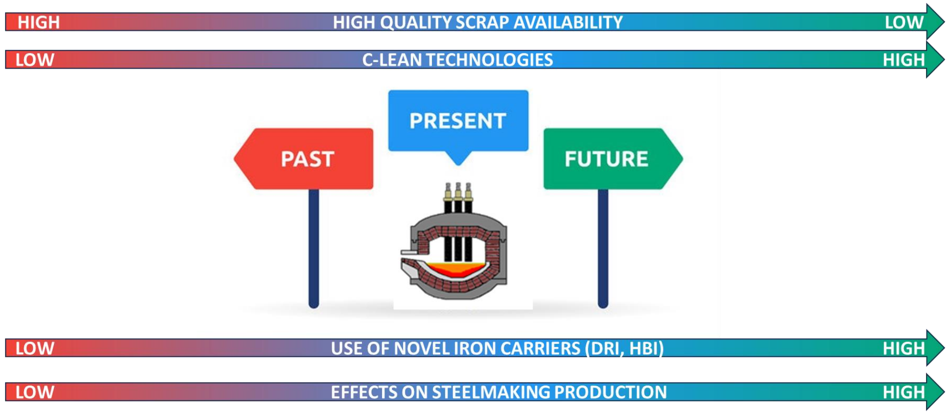
The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

ICT COISP

Information and Communication Technologies for Complex Industrial Systems and Processes

Introduction
Electric steelmaking role in decarbonization

Taking this in mind…



- **Changes are expected both in terms of process, product and by-products such as slags**

- **Resource efficiency, steel quality and slag recycling must be ensured to keep the process competitive and included in a circular economy loop**

AISTech2025

European Commission

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

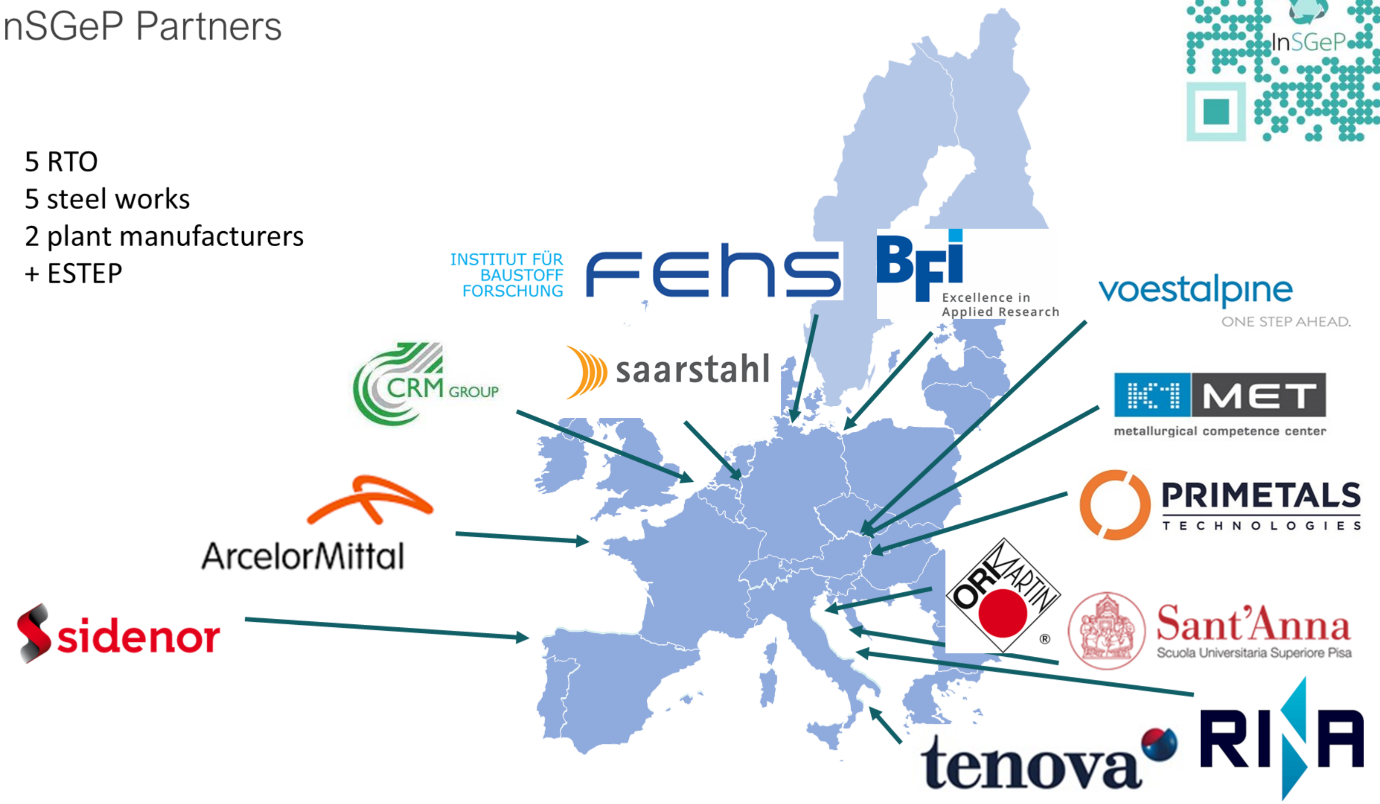
The InSGeP Project

Investigations of Slags from Next Generation Steel Making Processes InSGeP

The project will create guidelines for the use of slags obtained during steelmaking transitions and from next generation steelmaking

InSGeP Partners

5 RTO
5 steel works
2 plant manufacturers
+ ESTEP



AISTech2025

European Commission

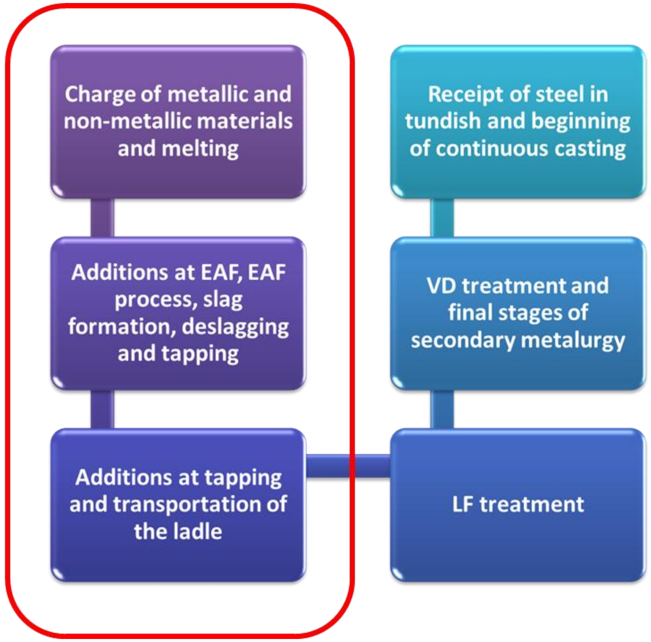
The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

ICT COISP

Information and Communication Technologies for Complex Industrial Systems and Processes

Flowsheet model of EAF-based steelmaking route
Overview

- One of the exploited model is a **flowsheet model of EAF-based steelmaking process** developed in Aspen Plus®
  - It was developed and improved in several years and projects
  - It can be **run by using standard available information and data**
  - **It allows simulating EAF steelmaking route until the start of continuous casting, and the effects of changing operating conditions and feeds**
  - **Several unit blocks and customized calculators are combined** to represent the involved phenomena, i.e. mass and energy transfer, chemical reactions, thermodynamic equilibria, physical state transitions, etc
  - **Among others it allows computing and monitoring the evolution of main process parameters during the different process steps: temperatures, liquid steel and slag amount and composition, energy exploitation, CO_2 emissions, efficiencies**
  - Only the primary steelmaking part is used in InSGeP



Matino, I., Alcamisi, E., Colla, V., Baragiola, S., & Moni, P. (2016). Process modelling and simulation of electric arc furnace steelmaking to allow prognostic evaluations of process environmental and energy impacts. Matériaux & Techniques, 104(1), 104.

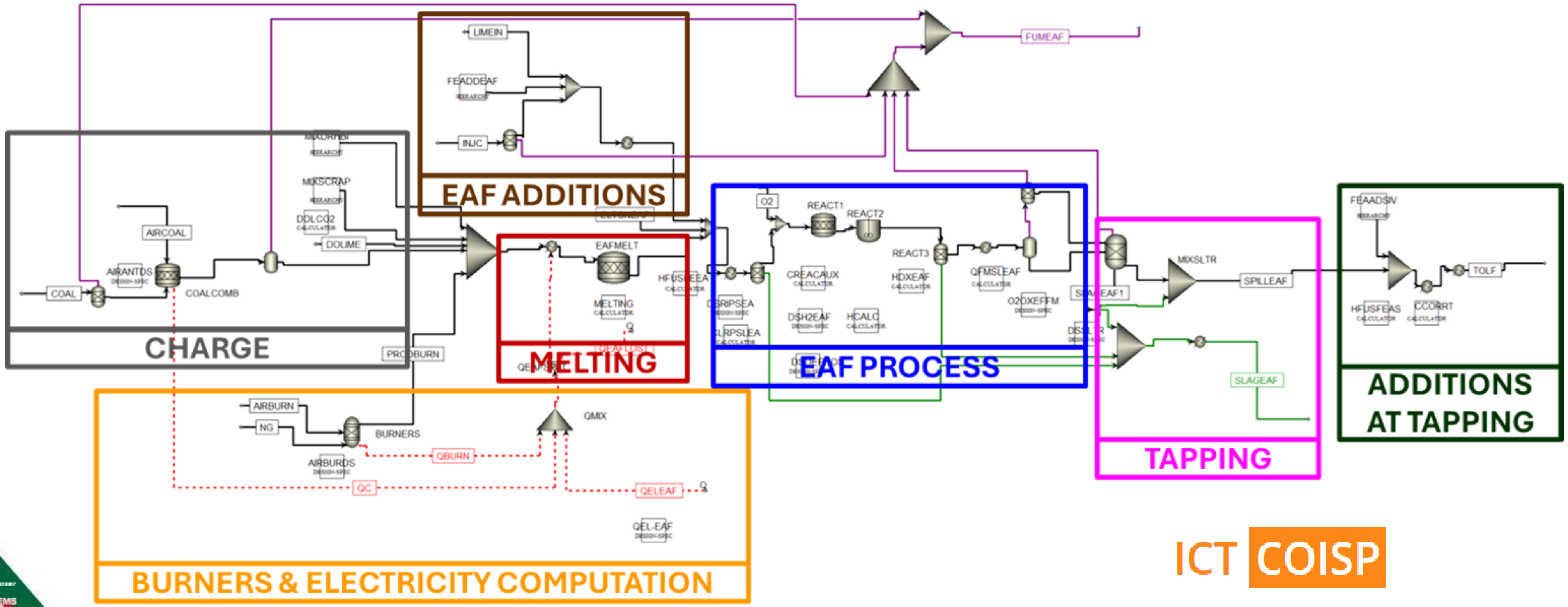
Matino, I., Petrucciani, A., Zaccara, A., Colla, V., Prieto, M. F., & Pérez, R. A. (2025). Characterization of EAF and LF Slags Through an Upgraded Stationary Flowsheet Model of the Electric Steelmaking Route. Metals, 15(3), 279.

European Commission

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

Flowsheet model of EAF-based steelmaking route
Adapted model

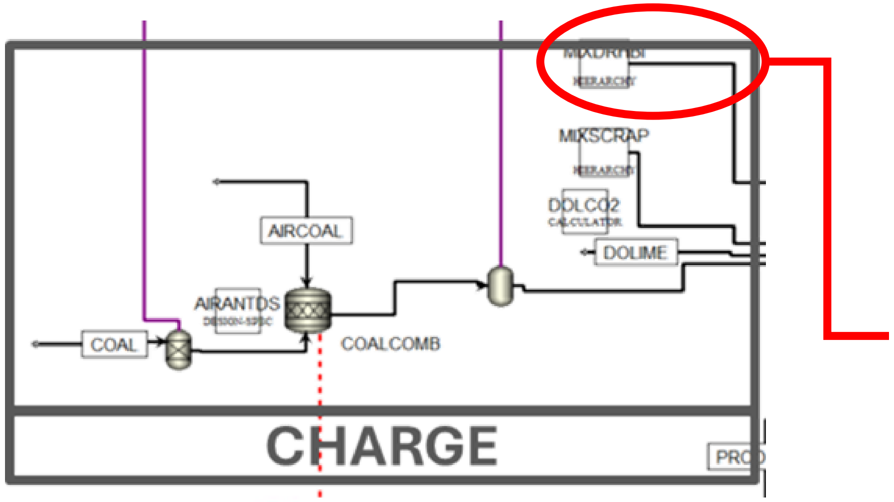
- **The flowsheet model of EAF-based steelmaking process**
- **was adapted, tuned and validated for allowing simulations considering the use of DRI/HBI in EAF**
  - Industrial and Technology Provider data were used for the scope



European Commission
The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

Flowsheet model of EAF-based steelmaking route
Adapted model

- **The flowsheet model of EAF-based steelmaking process**
- **was adapted, tuned and validated for allowing simulations considering the use of DRI/HBI in EAF**
  - Industrial and Technology Provider data were used for the scope



Metallic and non-metallic charge are represented through several streams (sometimes included in hierarchical blocks) **characterizing the different metallic** (e.g. different types of scraps) **and non-metallic materials** (e.g. flux materials, scorifying agents)

- With respect to model previous version, **different streams were added referring to different HBI and DRI qualities**
  - Obtained from BF grade or DR grade pellets
  - Produced by using natural gas or hydrogen-based reducing gas
  - Hot or cold

AISTech2025

European Commission

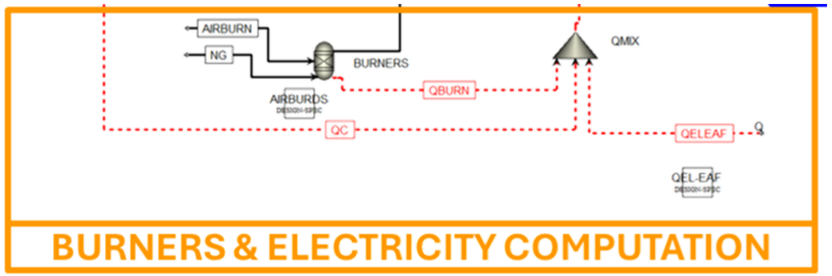
The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

ICT COISP

Information and Communication Technologies for Complex Industrial Systems and Processes

Flowsheet model of EAF-based steelmaking route
Adapted model

- **The flowsheet model of EAF-based steelmaking process**
  - **was adapted, tuned and validated for allowing simulations considering the use of DRI/HBI in EAF**
  - Industrial and Technology Provider data were used for the scope



Besides the chemical energy provided by exothermic reactions and from fossil sources (e.g. coke), **the other energy for melting and EAF processes is provided with burners and electricity**:

- **Burners are simulated with a dedicated unit block,** representing an equilibrium reactor based on Gibbs free energy minimization, **coupled with a design specification block**

- **Electricity is computed by the model to ensure the desired temperature at tapping**
  - **a dedicated design specification block is used for the scope**

AISTech2025

European Commission

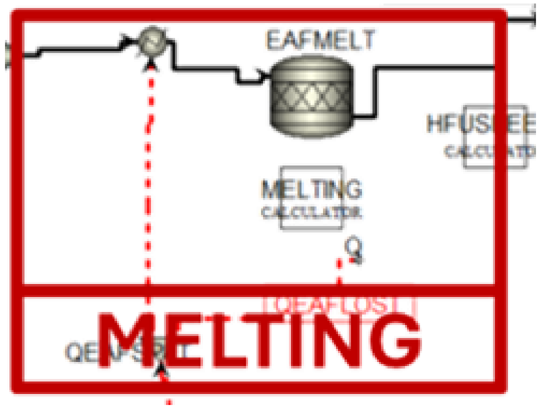
The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

ICT COISP

Information and Communication Technologies for Complex Industrial Systems and Processes

Flowsheet model of EAF-based steelmaking route
Adapted model

- **The flowsheet model of EAF-based steelmaking process**
  - **was adapted, tuned and validated for allowing simulations considering the use of DRI/HBI in EAF**
  - Industrial and Technology Provider data were used for the scope



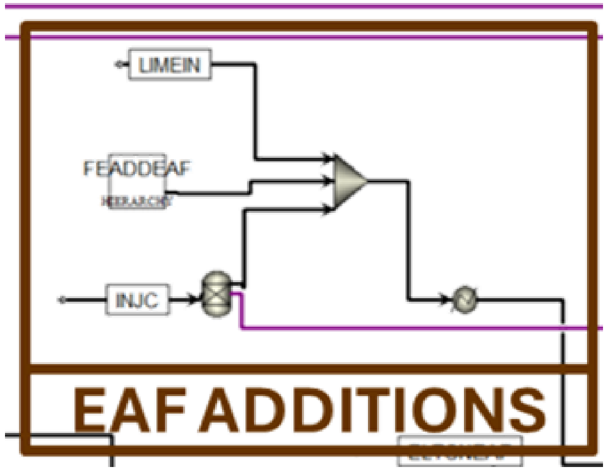
The melting of charged materials is simulated through the combination of heat exchangers, calculator blocks and dedicated reactor block

- **Liquidus temperature is computed** depending on the weight percentage of C, Si, Mn, Ni, Cr, Mo, S, N in the charge mix
- **if the charge receives enough heat to reach or exceed this value, the charge is melted** and related enthalpy of fusion is removed

AISTech2025
European Commission
The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665
ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

Flowsheet model of EAF-based steelmaking route
Adapted model

- **The flowsheet model of EAF-based steelmaking process**
  - **was adapted, tuned and validated for allowing simulations considering the use of DRI/HBI in EAF**
  - Industrial and Technology Provider data were used for the scope



During the EAF process, related additions are considered in the model through related streams

- Enthalpy of fusions are considered and removed from the bath

AISTech2025

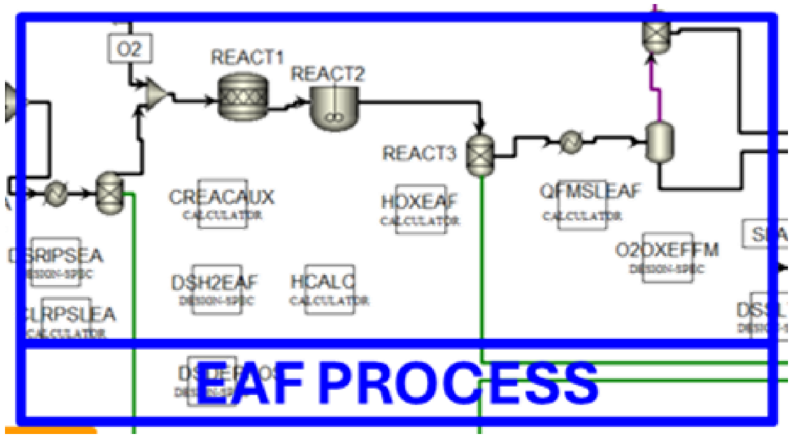
European Commission

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

Flowsheet model of EAF-based steelmaking route
Adapted model

➢ **The flowsheet model of EAF-based steelmaking process**
- **was adapted, tuned and validated for allowing simulations considering the use of DRI/HBI in EAF**
- Industrial and Technology Provider data were used for the scope



Several reactions, chemical equilibria and compounds partitions are considered (e.g. related to oxidations, decarburization, desulphuration, dephosphorization phenomena) **by combining different unit blocks:**

➢ **Related parameters** (e.g. reaction yields, kinetic factors, equilibrium constant, partition parameters) **are obtained from analyses of the available data, from literature, directly from the software or empirically**
- Particularly linked with the effects of DRI or HBI use in EAF charge on slag composition, **S and P partitions between slag and steel are considered with the implementation of theoretical or literature curves/relations considering slag basicity and the content of specific compounds** (e.g. FeO)

AISTech 2025

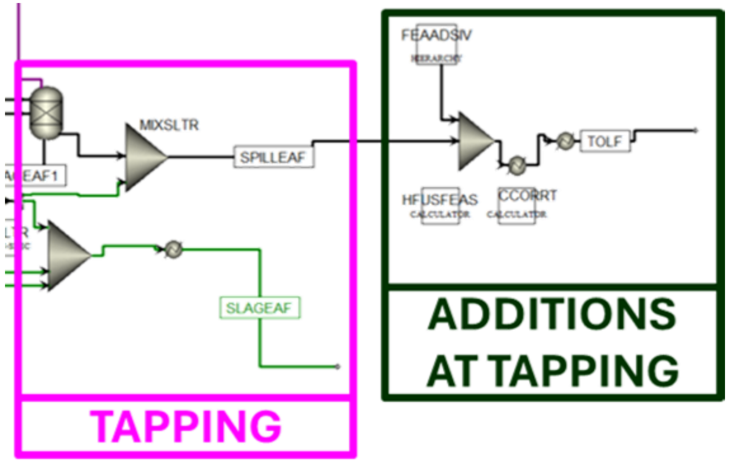
European Commission

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

Flowsheet model of EAF-based steelmaking route
Adapted model

- **The flowsheet model of EAF-based steelmaking process**
  - **was adapted, tuned and validated for allowing simulations considering the use of DRI/HBI in EAF**
  - Industrial and Technology Provider data were used for the scope



- In the model, **fumes and slag are separated** in different steps (for modelling purposes) and then mixed in a single stream whose **amount and composition is computed**
- The **model computes the amount and composition of tapped steel**
- **Additions during tapping are considered** with related streams

AISTech2025

European Commission

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

Flowsheet model of EAF-based steelmaking route
Adapted model

- **The model can be customized and used for simulating the production of different steel families** (i.e. groups of different steel grades) **or for different facilities**
  - **sometimes some empirical correction factors are included in the correlations**

Main Inputs and Outputs

Inputs: scraps amount and type, amount of other metallic and non-metallic charge materials, natural gas consumption, desired temperature at tapping

Inputs: amount of injected carbon and oxygen, and EAF additions amount and type

Inputs: amount and type of additions at tapping, and, if available, average time to transport ladle

Outputs: steel composition before tapping (including hydrogen), steel amount and temperature at tapping, EAF slag amount, composition and temperature, EAF fumes amount, composition and temperature, required electric energy

Outputs: steel amount, temperature and composition (including hydrogen) before secondary metallurgy

AISTech2025

European Commission

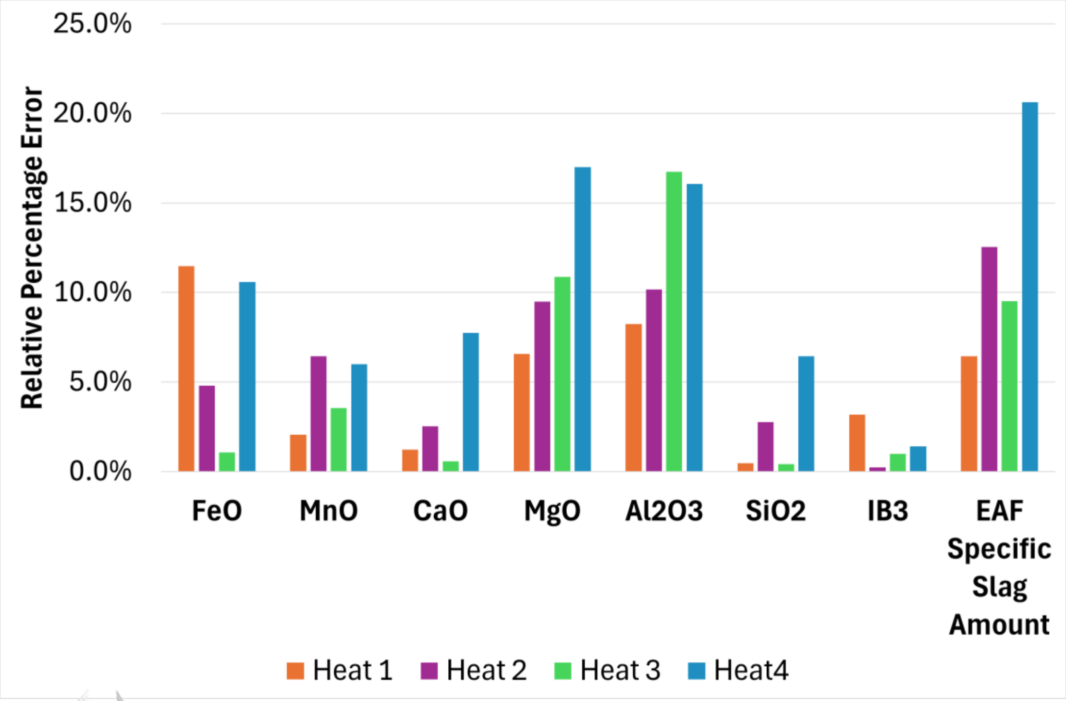
The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

ICT COISP

Information and Communication Technologies for Complex Industrial Systems and Processes

Flowsheet model of EAF-based steelmaking route
Validation of adapted model

- **Validation dataset** (part of available dataset) **was used to simulate some production heats and compare original data with simulation results to check the model accuracy**
  - As can be observed in the reported examples, **accuracy is good**
    - **higher error values correspond to variables showing higher Percentage Variation Coefficient** (PVC), which is the percentage ratio of the standard deviation over the mean value.



European Commission

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

Scenario analyses
Overview

- **The current version of the model is being used for simulations to analyse the effects of charging EAF with different HBI or DRI ratios, different DRI qualities** (e.g. BF or DR qualities) **and DRI produced with different reducing gases** (i.e. based on natural gas or hydrogen)
  - Results of the first analysed scenario are shown, belonging to the **simulation of the production of two different steel grades with different scrap mixes and with gradually increasing ratios of HBI (Scenarios A) or DRI (Scenarios B) used in the charge**
    - The change in HBI and DRI ratios in the charge is done while **ensuring the same amount of fed iron**; furthermore, in these simulations **all the other inputs** (e.g. further non-metallic charge materials and additions) **are kept fixed**

- **Besides the composition and the amount of EAF slags**, depending on the scenario, **the following further parameters are monitored**:
  - **Tapped steel composition** (especially in terms of tramp element, e.g. P)
  - **EAF electricity**
  - **Resource consumptions**

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

European Commission

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

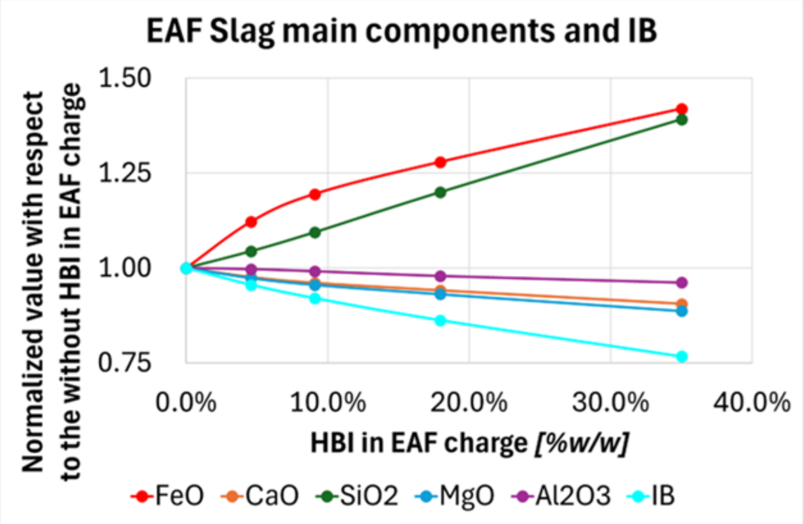
Scenario analyses

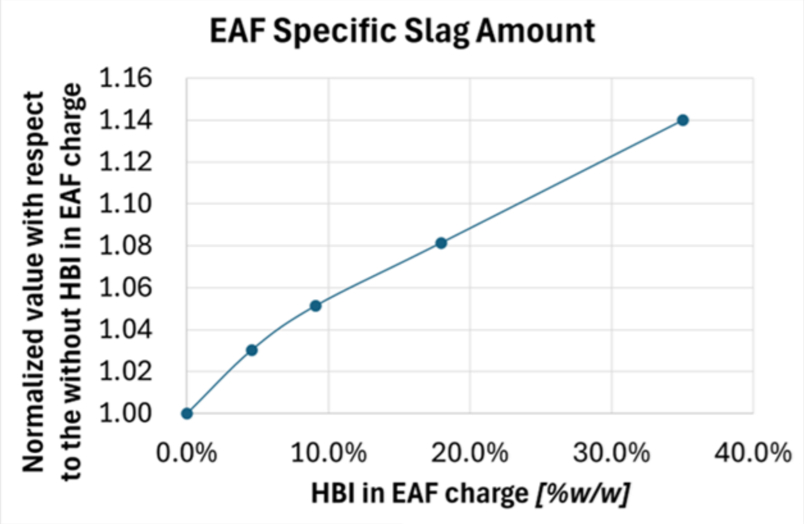
Scenarios A - Different ratios of scrap/HBI in EAF

For confidentiality reasons, the results are reported as normalized values with respect to the heat obtained with only scraps charged in EAF

EAF slag composition is affected by the HBI acidic gangue content and by its incomplete metallization. By increasing HBI in EAF there is:

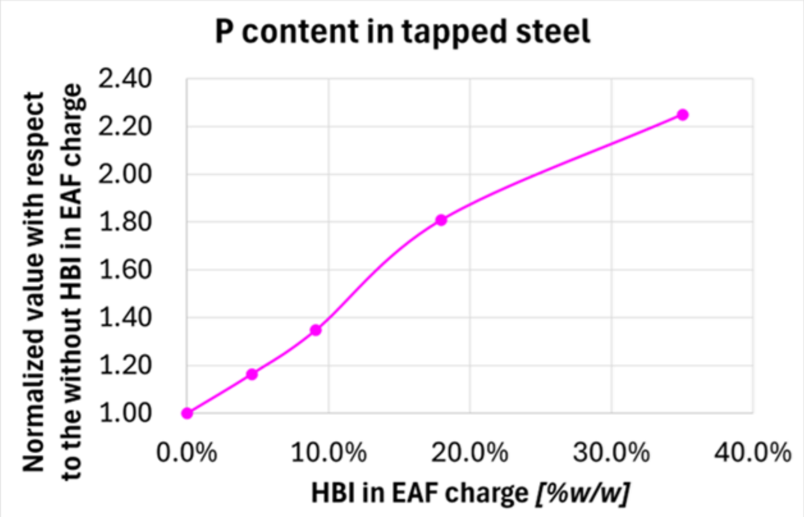
- **a noticeable increase of SiO_2 content**
- **a decrease of CaO and MgO contents**
- **An increase of FeO content**
- **An acidification of slag**





EAF specific slag amount increases with higher HBI in EAF charge because of the HBI gangue content

P content in tapped steel increases by increasing HBI in EAF because of the acidification of the slag



S content (not reported in figures) **slightly increases in the tapped steel**, because of the slag acidification and of the FeO content, which affect the S partition in favor of steel

ICT COISP

Information and Communication Technologies for Complex Industrial Systems and Processes

AISTech 2025

Scenario analyses

Scenarios A_P - Different ratios of scrap/HBI in EAF and P constant in tapped steel

In order to evaluate possible countermeasures to avoid P increase in tapped steel, Scenarios A_P were simulated

EAF slags basicity was modified by changing the amount of fed dolomitic lime to keep the P content in tapped steel constant although the increase of the HBI charged in EAF

It is important to highlight that **used HBI has higher P content compared to standard scrap mix**

AISTech2025

European Commission

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

ICT COISP

Information and Communication Technologies for Complex Industrial Systems and Processes

European Commission

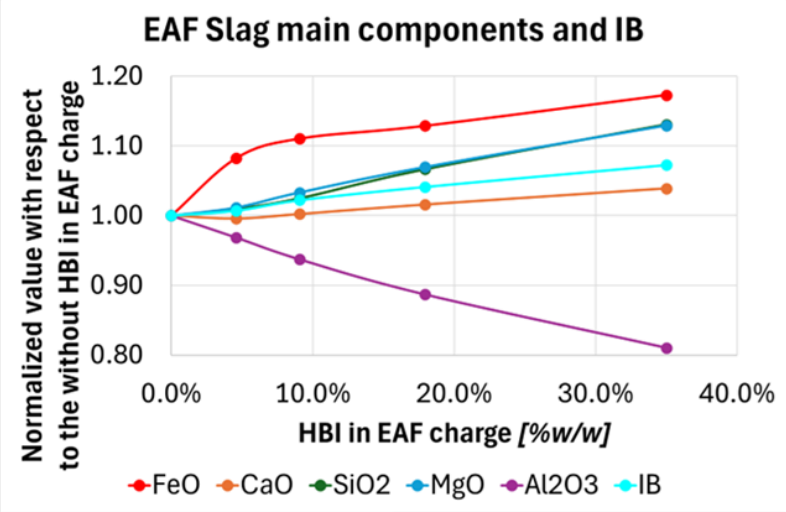
The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

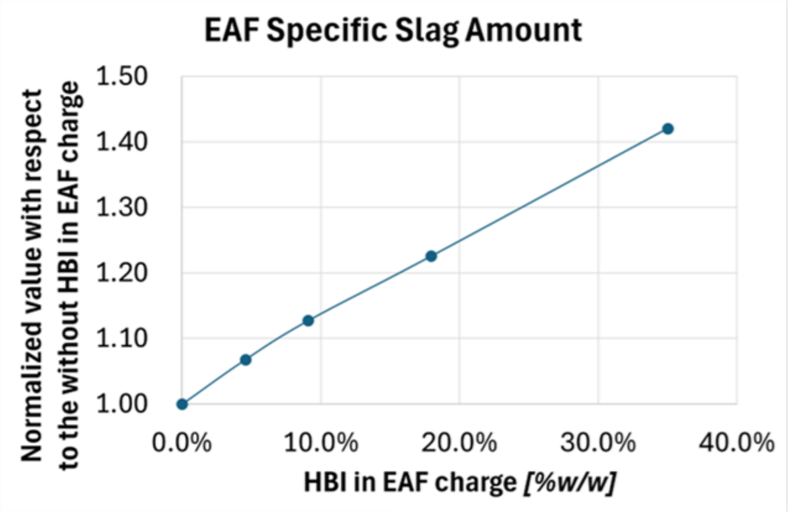
Scenario analyses

Scenarios A_P - Different ratios of scrap/HBI in EAF and P constant in tapped steel

For confidentiality reasons, the results are reported as normalized values with respect to the heat obtained with only scraps charged in EAF

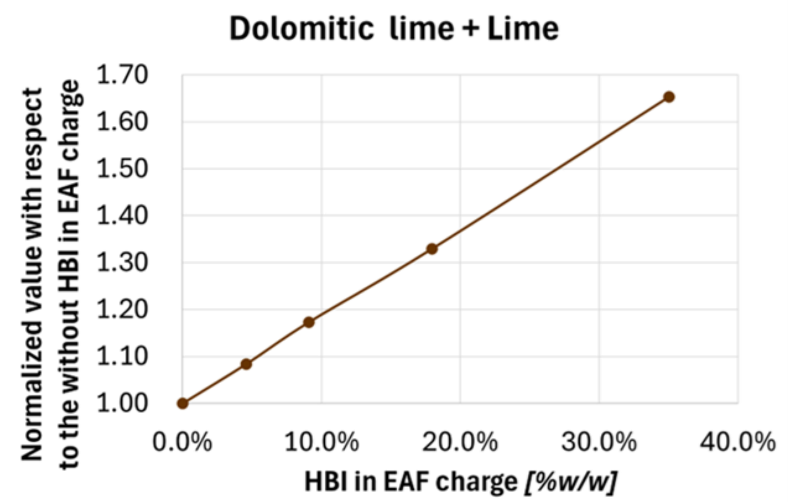
- **SiO_2 increase in slag is thwarted by increasing the CaO and MgO contents**
- **IB decrease is avoided**
    - IB slightly increases with the increase of the HBI charged in the EAF because of the increase of P content in the charge





EAF specific slag amount increases more than in Scenarios A due to the increase of flux compounds

Almost linear increase of flux compounds for counteracting the acidification of the slags



An increase of electric energy requirements was observed (not reported in figures):

- **about 17% in case of 35 % w/w of HBI in the charge** with respect to a full scrap charge

AISTech2025

ICT COISP

Information and Communication Technologies for Complex Industrial Systems and Processes

European Commission
The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

Scenario analyses
Scenarios B - Different ratios of scrap/DRI in EAF

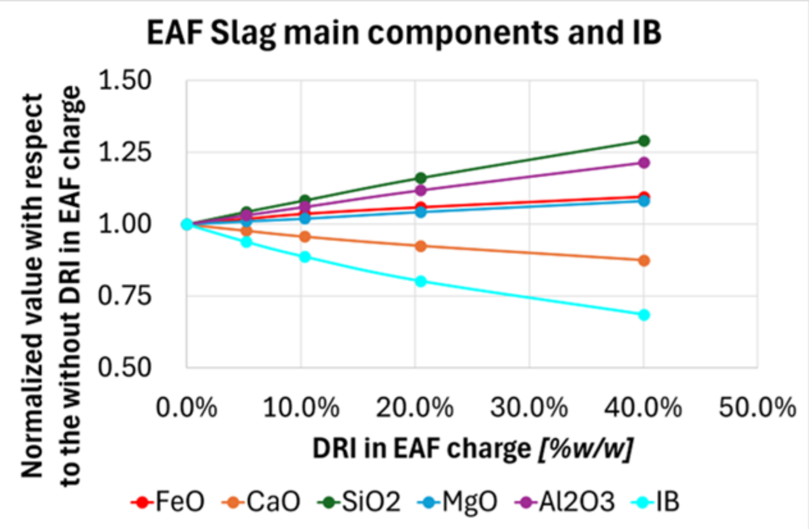
With respect to Scenarios A, **different steel grades were produced by using different mixes of scrap and DRI**

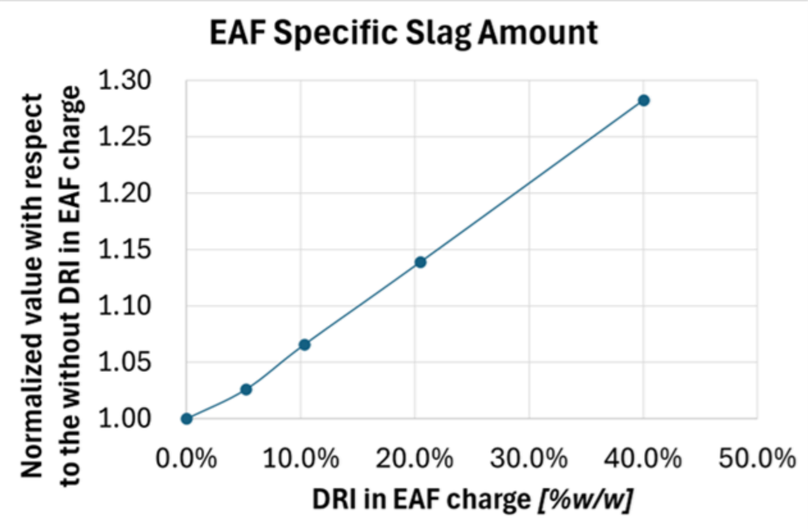
- Concerning the DRI, **a mix of BF- and DR- grade DRI is used with a BF-/DR-grade ratio of about 2:1**
  - **the DRI is assumed to be produced by using a high H_2 ratio in reducing gas**
  - **the used DRI mix holds a lower P content compared to used scrap mix**

EAF slag composition is affected by the DRI acidic gangue content and by its incomplete metallization.
By increasing HBI in EAF there is:

- **a noticeable increase of SiO_2 and Al_2O_3 contents**
- **a decrease of CaO content**
- **An increase of FeO content**
- **An acidification of slag**

For confidentiality reasons, the results are reported as normalized values with respect to the heat obtained with only scraps charged in EAF





EAF specific slag amount increases with higher DRI in EAF charge because of the DRI gangue content

- **Variations of P and S contents** (not reported in figures) in tapped steel are **negligible**
- **a slight increase in C content** (not reported in figures) is observed when increasing the DRI amount in the EAF charge

AISTech2025

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

Scenario analyses

Scenarios B_IB - Different ratios of scrap/DRI in EAF and costant EAF slag IB

To investigate the required process changes to ensure constant slag IB, Scenarios B_IB were simulated

Amount of fed dolomitic lime is increased with the increase of the DRI charged in EAF

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

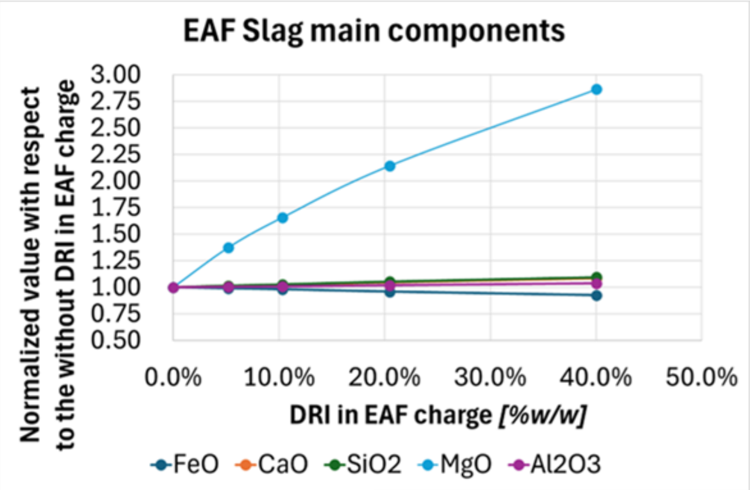
European Commission
The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

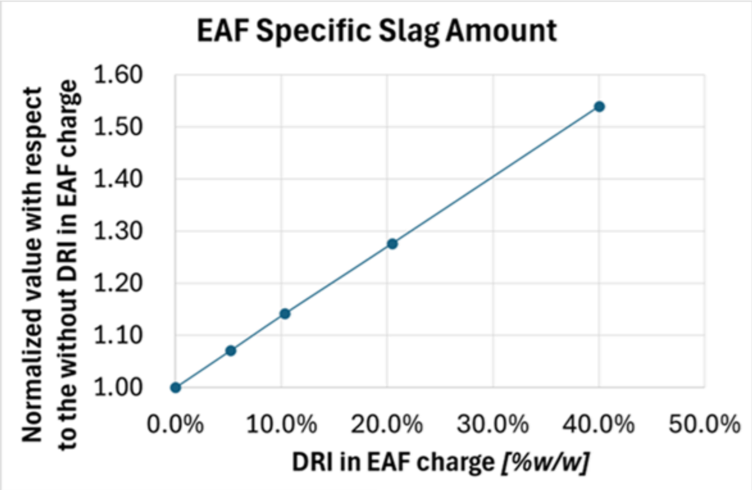
Scenario analyses

Scenarios B_IB - Different ratios of scrap/HBI in EAF and costant EAF slag IB

For confidentiality reasons, the results are reported as normalized values with respect to the heat obtained with only scraps charged in EAF

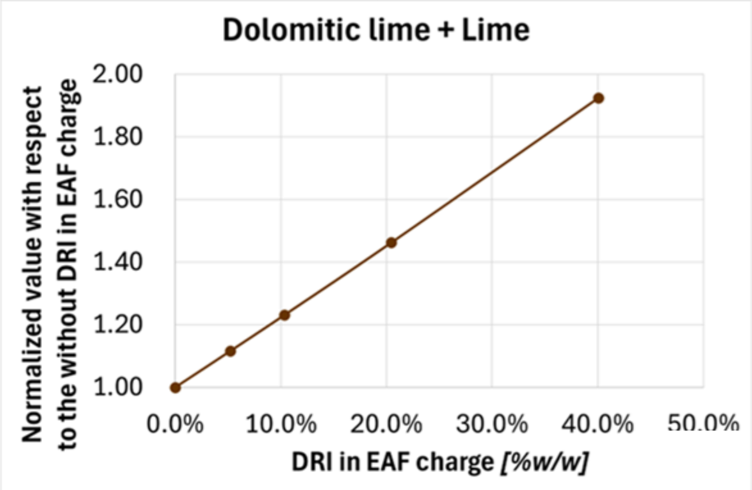
EAF slag composition is highly affected by the significant increase of dolomitic lime with the increase of DRI charged in EAF





EAF specific slag amount increases more than in Scenarios B due to the increase of flux compounds

An almost doubled amount of flux materials is needed in the case of 40% w/w of DRI in the EAF charge to keep EAF slag IB constant

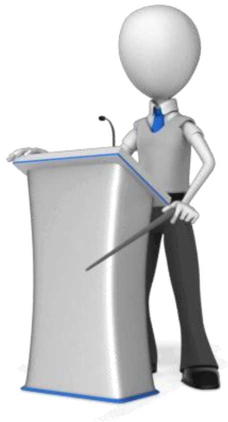


Although not reported in figures**, about 4% more electric energy is required with this process conditions in case of 40% w/w DRI in the EAF charge**

AISTech 2025

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes

Conclusions



The transition undertaken by the steel sector in Europe are leading to significant changes of well-known procedures and processes

- Concerning EAF steelmaking, **it is expected that the ratio of DRI and HBI fed to the EAF will increase**
  - **Both product and by-products will be affected**

It is important to know in advance what are the consequences of the use of high ratio of DRI and HBI in EAF charge not only on steel but also on slags

- This can **support slag valorization** and, consequently, **the implementation of circular economy concepts** can continue

A flowsheet model of EAF primary steelmaking was presented and is being used for scenario analyses

Results of first simulations show that slag is significantly affected in terms especially of acidification

- **Steel quality is affected** (e.g. in terms of P content)

Increasing dolomitic lime charge has ben proposed as countermeasure for ensuring almost stable basicity features of slags

- **The increase of required fluxes is significant**
- **Produced slag increases**
- **Energetic requirements increases**

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

Future Works

Further scenarios are being simulated with different HBI and DRI qualities, DRI mixtures and DRI/HBI/srap ratios

A model of smelter is under development for making invetigations of slags obtainable from this further process

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

TELECOMMUNICATIONS, COMPUTER ENGINEERING, AND PHOTONICS INSTITUTE

Sant'Anna
School of Advanced Studies – Pisa

Simulation of slag composition resulting from Electric Arc Furnace fed with DRI or HBI

Ismael Matino, Valentina Colla, Teresa A. Branca

ismael.matino@santannapisa.it
valentina.colla@santannapisa.it
teresa.branca@santannapisa.it

AISTech2025

European Commission

The research leading to these results has received funding from the European Union's Research Fund for Coal and Steel research programme under grant agreement number: 101112665

ICT COISP
Information and Communication Technologies for Complex Industrial Systems and Processes