SESSION 3: 10:15–10:30

ESTEP workshop

SecCarb4Steel

Preparation and use of biogenic and non-biogenic secondary carbon carriers (SCC) in processes for iron and steelmaking

Exploring the effects of the use of alternative carbon-bearing materials in EAF through dedicated simulations

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Content

1. Introduction
2. Modelling
3. Simulations
4. Industrial Trials
5. Conclusions

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Introduction: the Context

The **decarbonization of the electric steelmaking** route can contribute to the achievements of European Green Deal targets

Replacement of fossil C-bearing materials with non-fossil materials is envisaged as one of the promising solutions to avoid significant amount of fossil CO_2 emissions

Uncertainties and unknown aspects exist on the effect of these materials on:

- process behavior and evolution
- product

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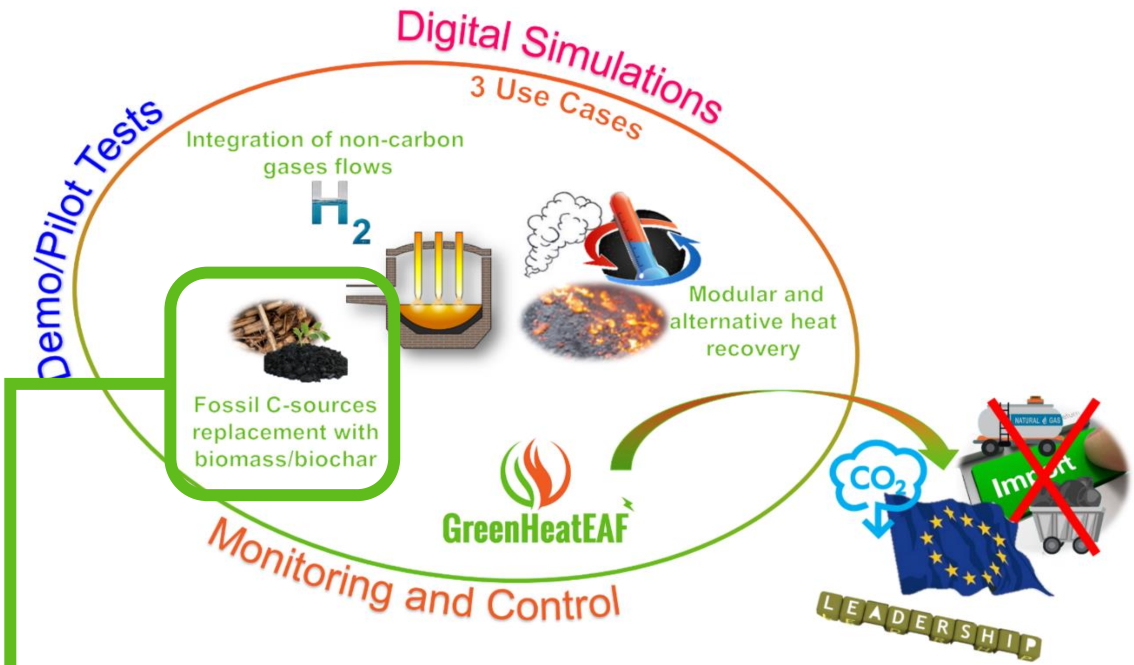
Introduction: GreenHeatEAF

"Gradual integration of Renewable non-fossil Energy sources and modular HEATing technologies in EAF for progressive CO_2 decrease" G.A. No. 101092328



- Among other activities, **the effect of alternative C-bearing materials usage in EAF are under investigations** by combining simulation and in field trials
- The **investigations of biomass upgrading opportunities** (biomass features are often unsuitable for direct use in metallurgical processes) **is** also **foreseen**
  - **to check the possibility of integrating these treatments directly in steelworks' facilities**
    - to recover available heat
    - to decrease steelworks dependence on an emerging market (i.e. biochar market)

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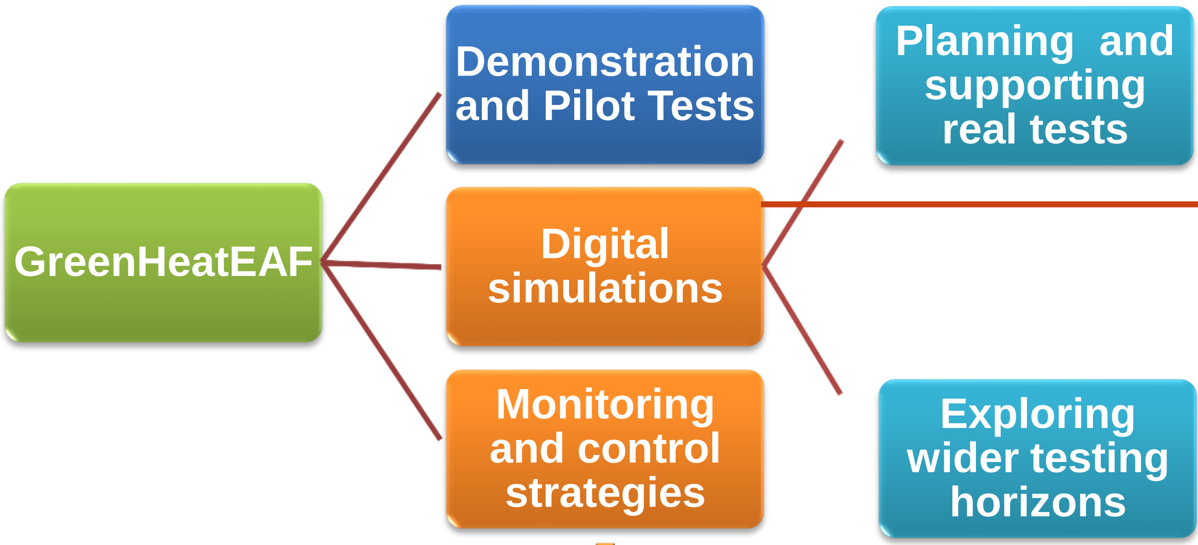
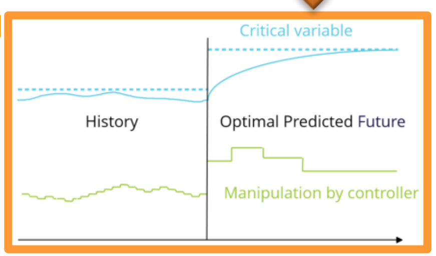
Introduction: Why Simulations?



Model Predictive Control



- **Avoiding issues with real experimentation**
  - On the process
  - Interrupting standard production plan
- **Obtaining complementary results with respect to industrial trials**
  - demonstrate the technical feasibility of the proposed solutions

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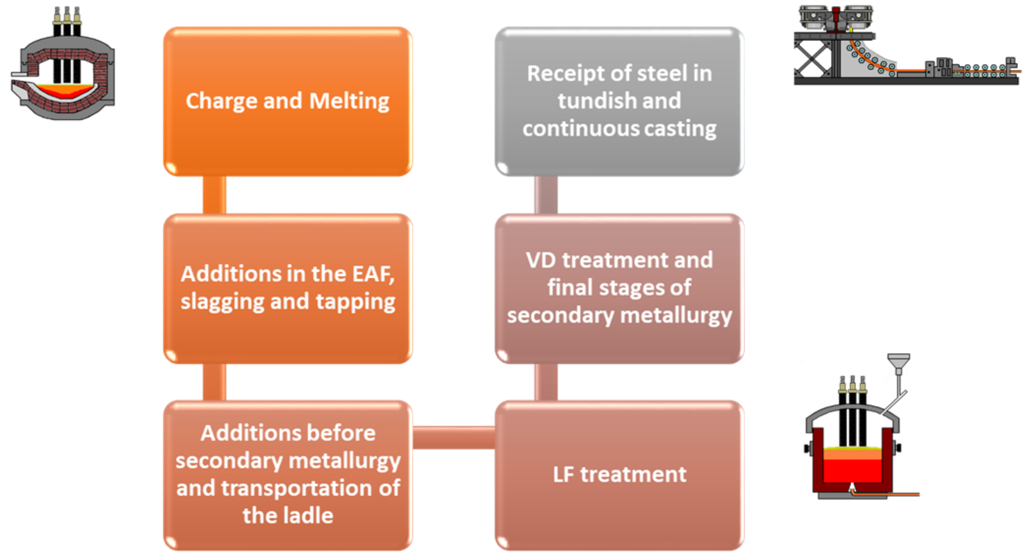
Modelling: Starting Point

- **The first version of the flowsheet model was developed in Aspen Plus during the EIRES RFCS project and gradually refined and upgraded within different projects** [1-3]
- **Main involved steps and considered phenomena are:**
  - sum of effects in terms of both mass and energy flows, chemical and physical balances, reactions and thermodynamic equilibria and transformations
  - Aspen Plus internal and customized unit blocks are combined together with ad-hoc calculators and design specs units to reproduce the various involved phenomena (e.g. melting, oxidation, tapping, refining, degassing, heat exchange)
- **The model is easily adaptable and transferable**
- **Tuning, validation and test on different steel families and on different steelworks** (e.g. Sidenor), generally industrial data related to some thousands heats are used



- **The flowsheet model allows simulating scrap-based EAF steelmaking route until start of continuous casting, and the effects of changing operating conditions and feeds**
- 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

[1] Matino, I. et al. (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.
[2] Petrucciani, A. et al. (2022). Flowsheet Model and simulation of produced slag in electric steelmaking to improve resource management and circular production. Chemical Engineering Transactions, 96, 121-126.
[3] Matino, I. et al. (2024). Esplorare l'uso di fonti alternative e non fossili di carbonio nelle acciaierie elettriche attraverso un modello flowsheet dedicato. La Metallurgia Italiana, 24.

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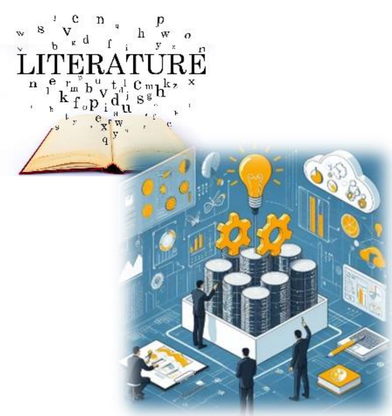
Modelling: Improvements

- Among the **model improvements** carried out in GreenHeatEAF some of them are finalized to:
  - **manage the use and injection of novel energy and carbon sources (e.g. biomass, biochar) and evaluate related effects;**
  - **investigate biomass upgrading opportunities.**



- Both **literature and real industrial data** (when available) **were exploited** to improve the model:
  - **available supplier data on alternative carbon carriers**
  - **available real industrial data** concerning preliminary trials **of the use of biochar introduced in Sidenor EAF through the 5th hole**

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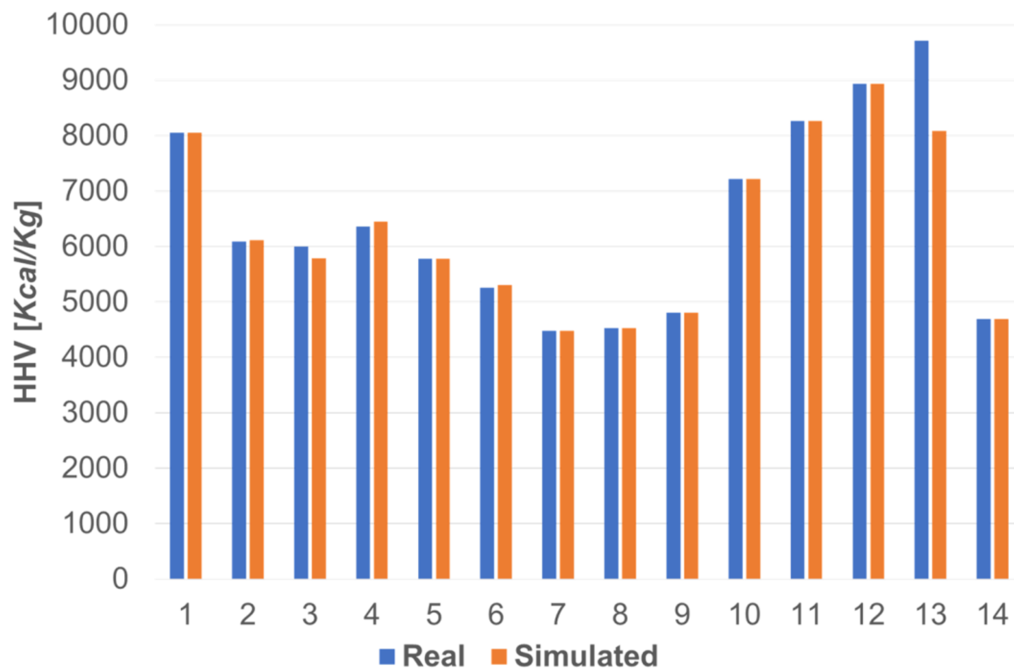
Modelling: Improvements

Modelling of alternative C-sources

- **As non-conventional solids**
  - materials that are not pure chemical species, for which generally there is a lack of equilibrium and physical property data
  - Characterized in terms of empirical factors (i.e. component attributes) representing component composition by one or more sets of constituents
    - Ultimate analysis, referring to the dry basis composition in terms of ash, carbon, hydrogen, nitrogen, chlorine, sulfur and oxygen;
    - Proximate analysis, referring to the content of moisture, ash, fixed carbon and volatile matter;
    - Sulphur analysis, referring to the type of sulphur compounds

- **Using suppliers data of 14 alternative C-sources and estimating missing information for fitting the known higher heating value**

Comparison of real and simulated HHV of considered C-sources



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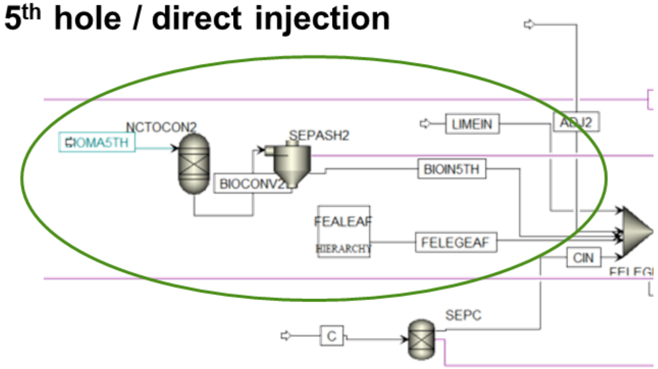
Modelling: Improvements

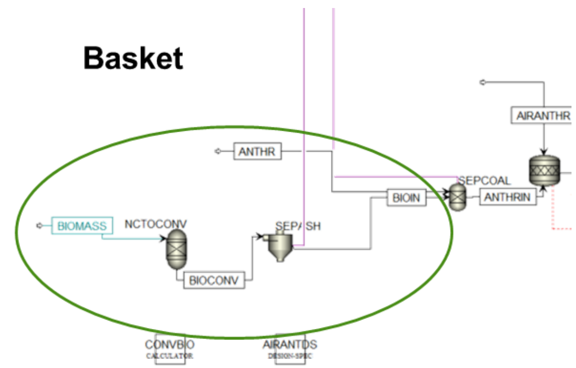
Addition/change/tuning of dedicated streams, blocks and reactions to allow use of alternative C-carriers in EAF and consider related effects (e.g. in terms of EAF electric energy, CO_2 emissions at EAF, C and S content in tapped metal, EAF metallic efficiency, EAF slag)

Added blocks and streams

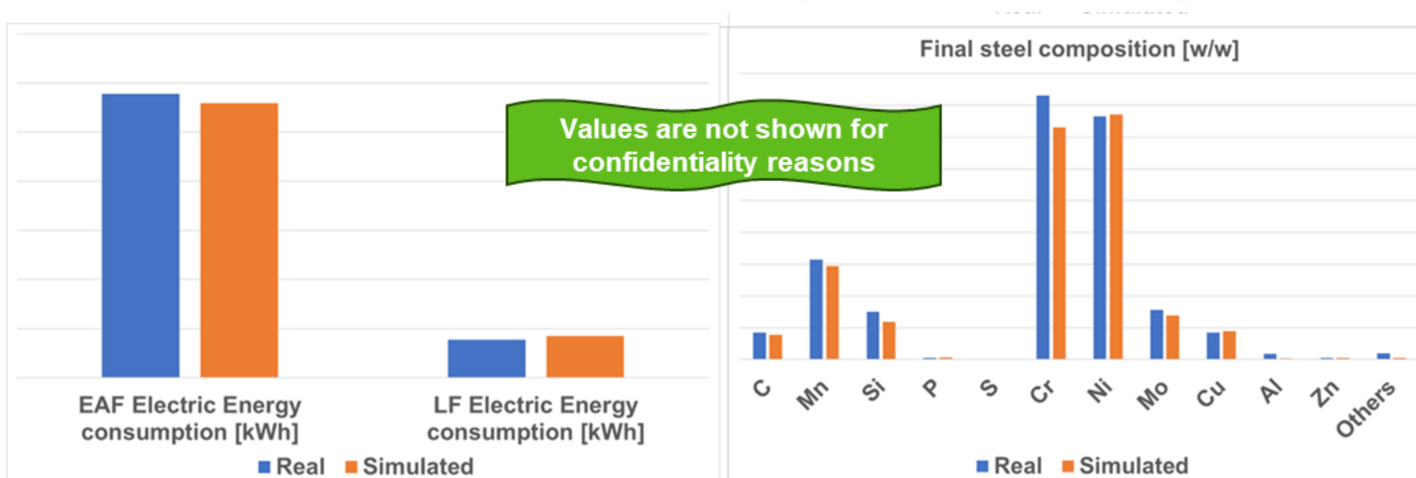
5th hole / direct injection



Basket



Model Test example for Alloyed Case Hardening



The adapted model has been **validated** for different steel families, then model has been **tested** simulating specific historical heats

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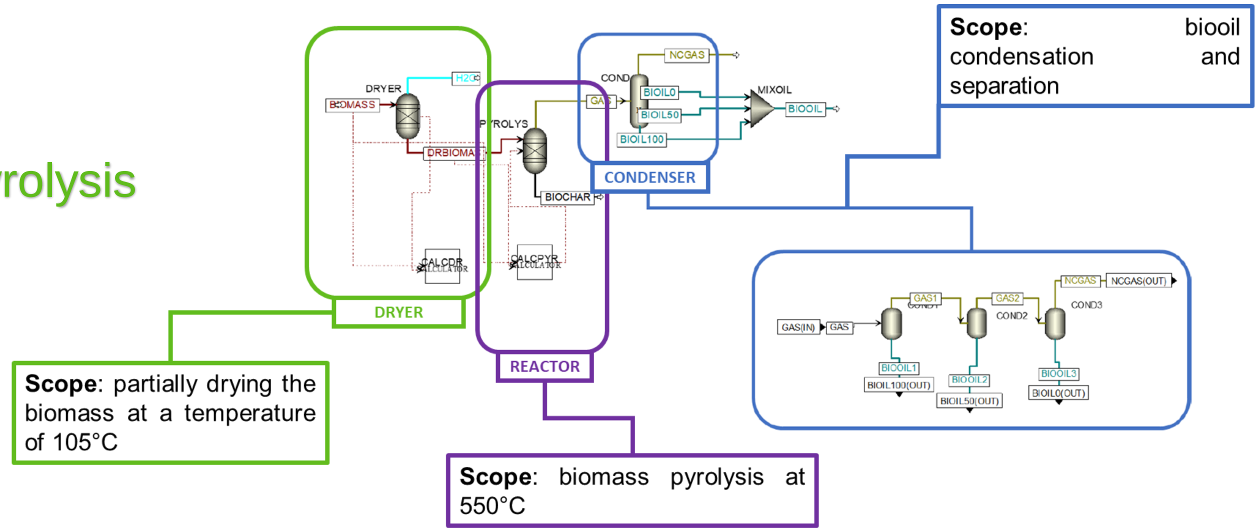
Modelling: Improvements

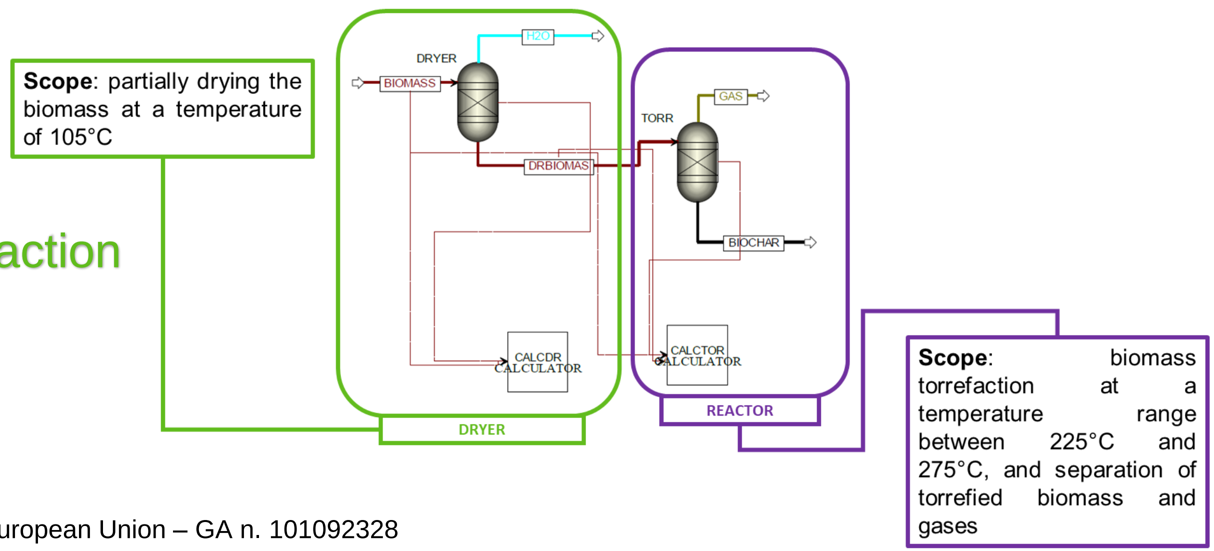
Development of biomass upgrading models to be integrated in the EAF route

Biomass Pyrolysis



Accuracy of Biomass Pyrolysis Model		
Parameter	Unit of Measurement of compared value	RE%
Inlet Biomass		
High Heating Value	MJ/kg	-15.3%
Produced Biochar		
Mass	kg	0.7%
C (ultimate analysis)	wt%	1.0%
HHV	MJ/kg	6.8%
Biooil		
Mass (separated at 100°C)	kg	-42.5%
Mass (separated at 50°C)	kg	4.2%
Mass (separated at 0°C)	kg	0.9%
Mass (total)	kg	-0.1%
NCG		
Mass	kg	8.1%
Water		
Mass (separated in Dryer)	kg	-2.0%

Biomass Torrefaction



Accuracy of Biomass Torrefaction Model		
Parameter	Unit of Measurement of compared value	RE%
Inlet Biomass		
High Heating Value	MJ/kg	-2.1%
Torrefaction at 225°C		
C (ultimate analysis)	wt%	-3.0%
High Heating Value	MJ/kg	-4.3%
Torrefaction at 250°C		
C (ultimate analysis)	wt%	-5.1%
High Heating Value	MJ/kg	-5.7%
Torrefaction at 275°C		
C (ultimate analysis)	wt%	-7.0%
High Heating Value	MJ/kg	-6.5%

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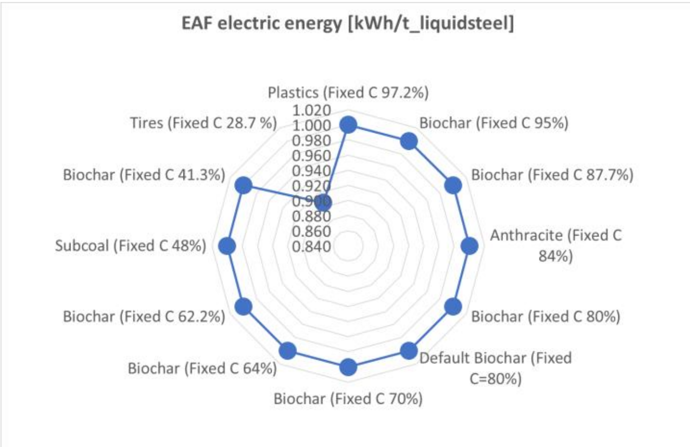
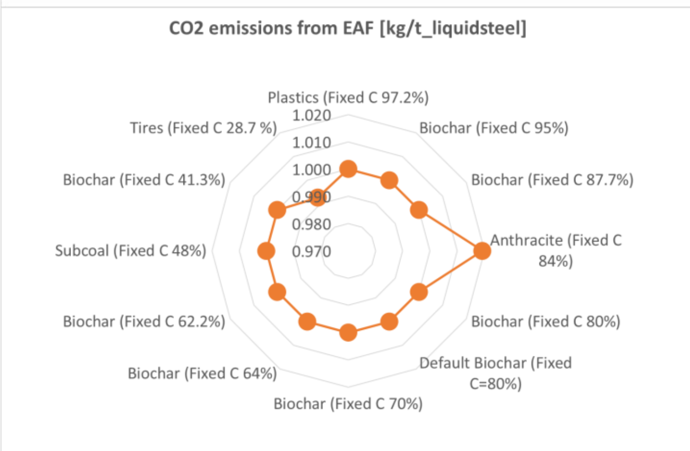
Simulations: Examples

Scenario 1: Replacement of fossil carbon charged in EAF through the 5th hole (to start foaming slag formation; only 5%-13% of the whole fossil carbon)

Examples of results related to Alloyed Quenched & Tempered steel family

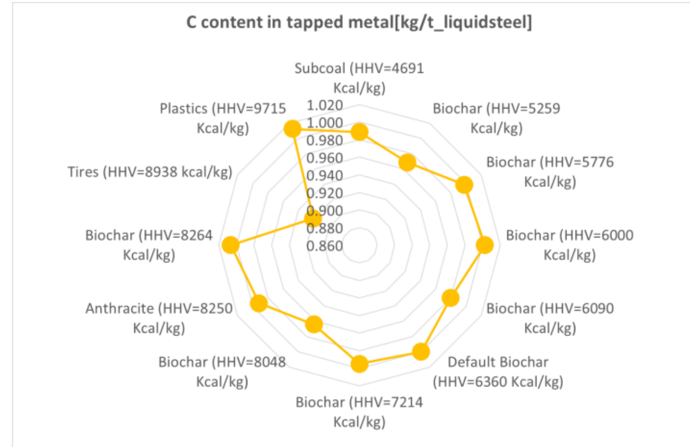
Fixed C fed

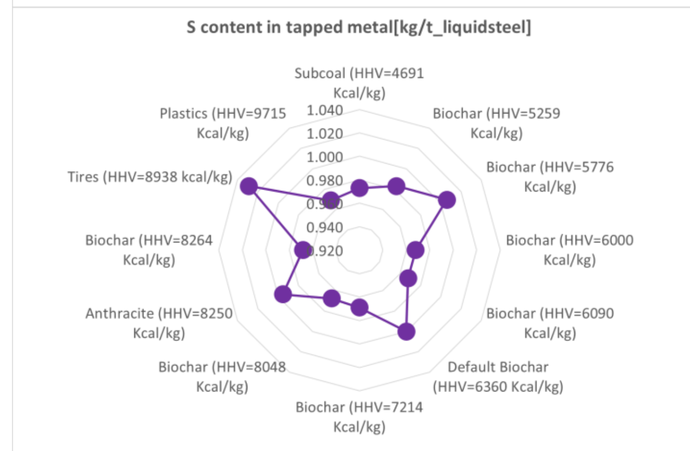




- **Tires lead to a decrease of required Electric energy** because high tires amount is required to reach the desired fixed C fed → higher chemical energy is provided
- **Anthracite leads to the highest CO_2 emissions** → emissions are fossil

Fixed energy supplied





Not all the monitored parameters are affected clearly by the alternative C-bearing materials

- **Tires** (having high volatiles content) **lead to lowest C content in tapped metal**
- **Tires** (having the highest S content) **lead to highest S content in tapped metal**

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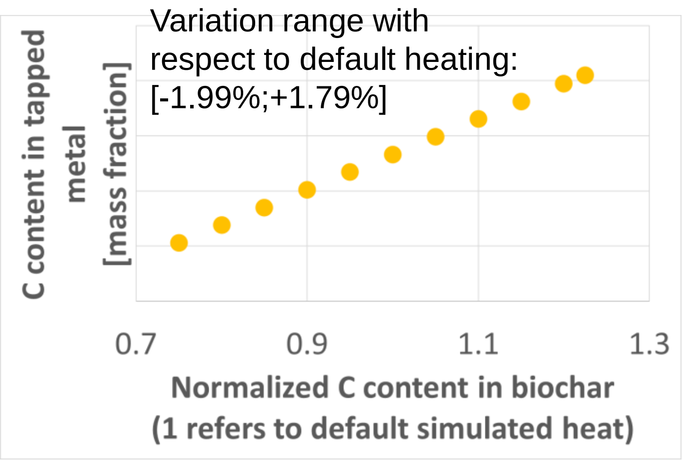
Simulations: Examples

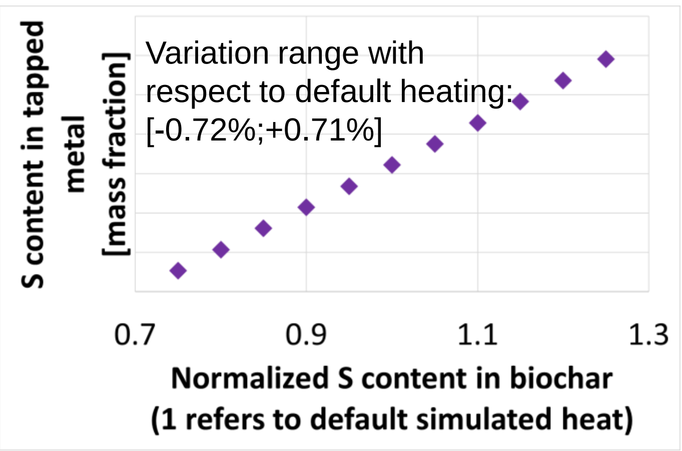
Scenario 2: Sensitivity analyses by changing the main compounds of the *Reference Biochar* used to replace fossil carbon in 5th hole

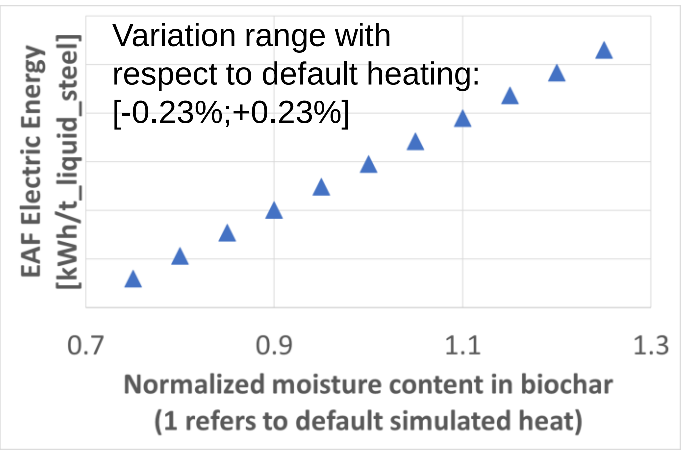
Reference biochar main features:

- **Fixed C=80%**
- **S=0.8%**
- **HHV=6360 Kcal/kg**

Examples of results related to Carbon Case Hardening steel family







Almost linear correlations seems existing for main monitored parameters with respect to C, S and moisture content in biochar

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Simulations: Examples

Scenario 3: Total substitution of fossil carbon with *Reference Biochar*

Reference biochar main features:

- **Fixed C=80%**
- **S=0.8%**
- **HHV=6360 Kcal/kg**

Examples of results in case of simulations done at fixed C fed

EAF Electric Energy [kWh/$t_{liquidsteel}$]

- Carbon Case hardening: +8.31%
- Alloyed Q&T: +1.95%
- Freecutting: -0.26%

CO_2 emissions from EAF [kg/$t_{liquidsteel}$]

- Carbon Case hardening: -15.31%
- Alloyed Q&T: -14.75%
- Freecutting: -15.77%

C content in tapped metal [mass fraction]

- Carbon Case hardening: +0.42%
- Alloyed Q&T: +0.03%
- Freecutting: +0.01%

S content in tapped metal [mass fraction]

- Carbon Case hardening: -8.22%
- Alloyed Q&T: -10.29%
- Freecutting: -10.63%

EAF Metallic Efficiency [$kg_{metalmaterial}$/$t_{liquidsteel}$]

- Carbon Case hardening: +0.40%
- Alloyed Q&T: +0.02%
- Freecutting: +0.01%

EAF slag [kg/$t_{liquidsteel}$]

- Carbon Case hardening: -3.20%
- Alloyed Q&T: -6.58%
- Freecutting: -6.69%

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Industrial Trials: Examples

Replacement of fossil carbon with plastics

Interaction of the foaming agents with the hot heel

FOAMING COAL

PLASTICS

- Foaming coal creates small flames on the surface of the slag
- **With plastics**:
  - **C is provided but foaming process is not good**
  - **the products burns even before reaching the slag, creating flames**
  - **fumes production and related temperature increase**
    - Plastic mixed with fossil foaming coal → Safety valve was gradually opened to reduce the temperature at the entrance of the bag filter
    - 100% plastics → Safety valve was 100% opened and emergency valve had to be puntually opened → **UNSAFE OPERATING CONDITION**
  - No negative effects on O_2 content at tapping and electric energy consumption
  - No clear effect on FeO in the slag

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Industrial Trials: Examples

Replacement of fossil carbon with tires

TIRES 30%

TIRES 50%

- **Tires foam a little less than coal**, especially due to the noise and the foaming index (worse when increasing %tires).
- **The temperature of fumes does not significantlyincrease but for the cases with 30% and 50% of mixture, where the alarms are activated.**
- No negative effects on O_2 content at tapping
- No clear effect on FeO in the slag

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Conclusions

Flowsheet models and simulations are useful to explore uncertanties arising when changes in standard procedures are investigated within electric steelmaking (e.g. replacement of fossil C-bearing materials)

From the simulation side, the use of alternative C carriers do not show significant critical effect neither on process nor on liquid steel quality and no significant deviations are observed on energy consumptions, while significant reduction of fossil CO_2 can be obtained.

From the industrial trials side, the use of alternative C carriers does not negatively affect some process/product parameters, but a high ratio of some of them can compromise safety of operations and lead to poor slag foaming

Some aspects are of the use of the considered alternative C-bearing materials are still unclear and under investigation

Simulation and industrial trials play a complementary role in providing useful information to understand advantages and drawbacks of the use of alternative C carriers in EAF and creating guidelines for their extensive usage.

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GreenHeatEAF

Gradual integration of REnewable non-fossil ENergy sources and modular HEATing technologies in EAF for progressive CO2 decrease

Thank you

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