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GreenHeatEAF

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

Report of the market study results and the biomass/biochar characterization

Deliverable D2.1

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1. Introduction

1.1 Purpose and Scope of the present document

The WP2 of the GreenHeatEAF project approaches the Integration of renewable C-sources exploitation in EAF operation.

With the aim to avoid CO_2 emissions in the melting process for the steel production, specifically in the Electric Arc Furnace (EAF), one option is to substitute the fossil fuels by other renewable organic materials based on carbon like biomass/biochar. Depending on the C-content and other chemical characteristics, this material could directly substitute the anthracite and coal that are used during the process.

After an analysis and selection of the most suitable biomass/biochar to substitute fossil fuels in the EAF, industrial trials will allow the demonstration of the technical feasibility of this solution. The industrial trials will be complemented by simulations with a dynamic process model for the EAF to investigate the influence of biomass/biochar on energy and material flows and chemical composition of the liquid steel. By validating the process model under industrial production conditions, reliable operating and control strategies for the substitution of fossil carbon with respect to chemical target values and optimisation of resource consumption will be provided.

This document includes the work carried out in Task 2.1 “Characterization and selection of renewable C-sources (preparation for tests)”. The main work is related to the analysis of the use of biochar/biomass instead of fossil fuels from non-renewable sources (coke, anthracite, coal…), although C-content of the biochar is sensibly lower, to make metallurgical processes more sustainable.

The biomass available at regional and international level, has been characterized and the demanded technical requirements for the materials substituting coke and anthracite have been defined. Finally, the most suitable biomass available in the market will be selected for the industrial trials.

1.2 Structure of the document

This document is structured following the different activities carried out in the Task 2.1, which are the following:

1. Study of the available biomass/biochar in the market.
2. Characterisation of the biochar samples from different sources (%C, %S, %N, moisture, volatiles, ashes, HHV, etc.).
3. Determination of the conditioning requirements to be used in the plant trials.
4. Study of the influence of the different types of biomass/biochar in the process.
5. Selection of the material for the industrial trials: results analysis and selection of the best biochar and process parameters for feeding EAF furnace at the industrial trials.

1.3 Industrial use cases

Three industrial partners will conduct industrial trials substituting different C-sources during the melting process in the EAF. Carbon can be introduced in the EAF in different shapes and ways. In the case of anthracite, due to the higher size of the material, it can be added in the scrap basket or through the 5th hole (a hole in the EAF roof, Figure 1). On the other hand, foaming coal requires finer grain size and is added through injectors (Figure 2).

In Sidenor, during the melting process, there are two C-sources, which are the anthracite and the foaming coal. The anthracite added by the 5th hole is in briquette form, with high resistance, low volatility and high C amount, whilst the foaming coal is introduced through two injectors on the walls. The objective of carbon materials during the melting process is to provide chemical energy, control de oxidation, increase the metallic yield and protect the refractory.

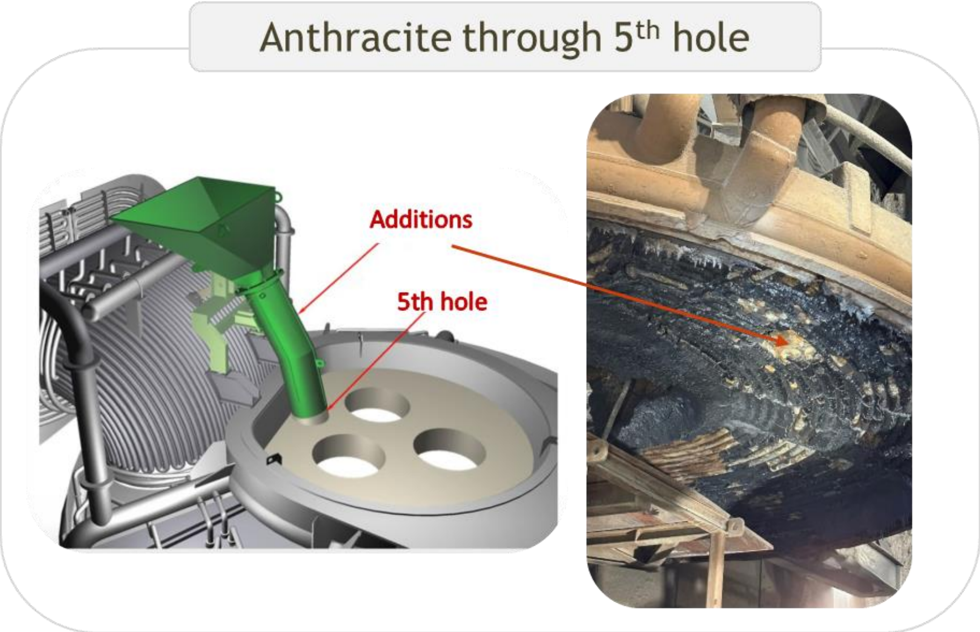

Figure 1. Anthracite added through the 5th hole in Sidenor

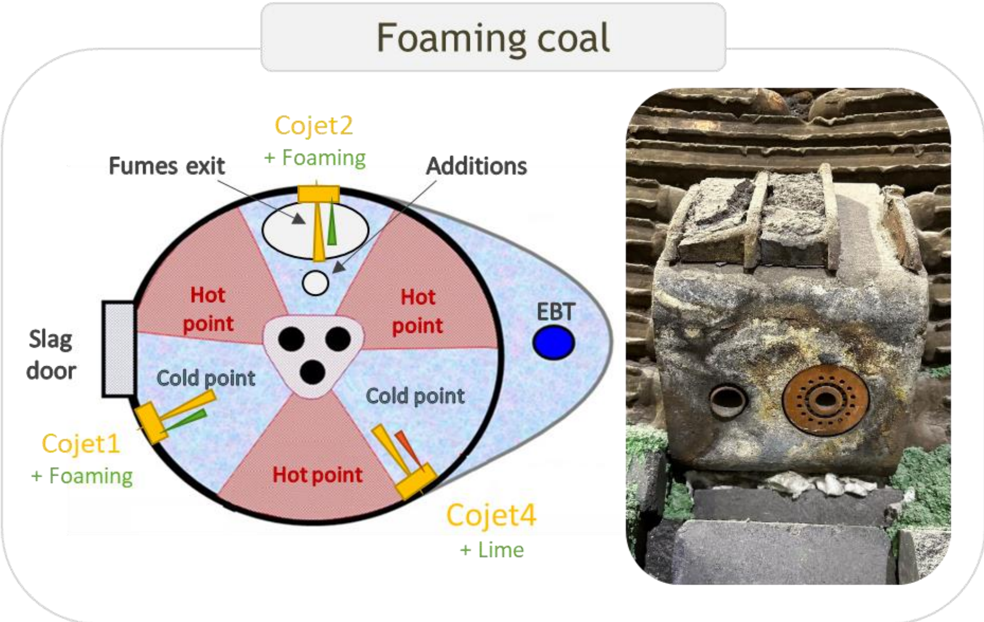

Figure 2. Foaming coal injected through the two cojets in Sidenor

In Sidenor, the carbon consumption (without considering the natural gas) amounts to 200 kg/heat (1.5 kg/t steel) of anthracite and 1500 kg/heat (10 kg/t steel) of foaming coal on average.

In the case of CELSA, a mixture of micronized anthracite and shredded rubber, is injected in the EAF as foaming agent. The consumption of this material amounts to 10 kg of carbon per ton of steel for a production of 700 kt steel/year.

In Höganäs, there are two applications which are considering to replace anthracite by biochar:

1. Sponge Iron Process
   A Höganäs patented process where the iron ore is directly reduced to iron with the help of coke, lime and clay. However, this is not included in Green Heat EAF project.

2. Electric Arc Furnace (EAF)
   Höganäs used to add 800-900 kg of anthracite directly to the charging basket when there was no HBI in the recipe. In the case of HBI, the added anthracite could increase up to 1000-1200 kg. However, they departed from this approach due to two main reasons:
   - Low and inconsistent efficiency of the melt final carbon content from added anthracite directly to the basket.
   - Changing tapping strategy from medium carbon to low carbon content. Today, the target is carbon content of 0.05-0.1% right before tapping compared to 0.2-0.3% C in the past.

   Thus, Höganäs started using 100% anthracite injection with 0-3 mm particle diameter with an average weight of 600 kg anthracite per heat (~52 ton steel).

2. Study of the process requirements for the biochar utilisation in the EAF

2.1 Influence of the different types of biomass/biochar in the process

Most of the industrial partners have not performed any industrial trials using biochar/biomass in EAF process. In the case of Sidenor, a preliminary trials were conducted before the project started, but the employed amount was not enough to obtain conclusions. One of the aims of performing both pilot and plant industrial trials within GreenHeatEAF is to explore the effect of different biomass/biochar on the process stability as well as injection efficiency.

However, a study of the features of the biomass that could affect most the operation in the EAF has been carried out. The most significate ones are included below:

- **Carbon content:** this is the most important feature, since it is directly related to the heating value. It provides chemical energy due to the oxidation reactions, controls the excessive oxidation of the steel/slag before the foaming slag generation, increases the metallic yield while reducing the losses of FeO, and slows the slag penetration in the refractory. It is important to analyse the Carbon fixed content, since it is referred to portion of coal that remains as residue after volatile matter distils off.
- **Higher Heating Value:** energy content of the carbon.
- **Sulphur content:** Affects the chemical composition of the steel and the desulphuration practice since it extends the melting process and the desulphuration in the ladle furnace.
- **Volatile (H_2, N_2…):** reduces the reaction rate of coal by forming a gas film that slows down reactions with the slag. This could imply yield losses and also generate flares, fires, bag filter failures… that could induce safety problems. This is why volatiles must be controlled very well.
- **Ashes:** a higher ashes content could provoke the acidification of the slag, what increases the attack of the refractory. To compensate this effect, it is required to consume more lime and the amount of slag generated is also greater. In addition, the metallic yield loss is also increased.
- **Moisture:** an increase in the H_2O content would imply a decrease in the heating value and a destabilization of the system. It would also require to consume more energy and the appearance of the risk of clogging.
- **Particle size:** this feature is directly related to the injection problems and the risk of clogging. Moreover, with a smaller grain size the surface contact is higher and thus the reaction rate. There are also problems associated to the aspiration of the fumes and the adherence to CO bubbles.

It is difficult to foresee the influence of the different types of biochar in the process. Nevertheless, taking into account the parameters of the selected materials, we can confirm that biomass derived from wastewater sludge can behave violently in the system if they have a high moisture percentage. The percentage of fixed carbon is important to give the biomass enough Higher Heating Value (HHV). It's important to remark that particle size is a key parameter since the new biochar will be introduce to the system by injection. High levels of volatility and ashes are important to avoid, since both parameters are directly related to yield loss. The reduction of volatility implies the reduction of yield loss, which ends up being savings for the steelworks.

2.2 Determination of the conditioning requirements to be used in the plant trials

Considering the main features that could affect the performance of the biomass/biochar in the EAF, each industrial partner studied their technical and conditioning requirements to be used in the plant trials, distinguishing between the use cases and applications.

In the case of Sidenor, the two main applications are included: substitution of the anthracite that is introduced through the 5th hole, and the substitution of the foaming coal that is injected through the cojets. In general, it is demanded to obtain the same performance than with the current carbon materials.

The industrial technical requirements of the biomass/biochar materials to be used in Sidenor are included in Table 1.

Table 1. Technical requirements of the biochar/biomass to be used in Sidenor

Feature	**Anthracite 5th hole**	**Foaming coal injected**
Carbon consumption	200 kg/heat	1300 - 1500 kg/heat
Particle size	Avoidance of clogging	
Performance	Similar heating value	
Carbon content	>70%	
Volatile	Low, currently <8%	>8% OK
Ash	Currently 8%	

In the case of CELSA Nordic, the biochar considered will replace the current carbon-bearing foaming agent. The current carbon-bearing material has mainly five specific conditions which can become a limiting factor in this use-case. Specifically for the CELSA Nordic use-case, the selected biochar should accomplish the parameters included in Table 2.

Table 2. Technical requirements of the biochar/biomass to be used in CELSA

Feature	**Carbon injection**
Carbon content	83%-89%
Particle size	2-4 mm
Moisture	0.01%-0.08%
Volatile	0.2%-0.4%
Ashes	11%-14%

In the case of Höganäs, there are different criteria to consider for application of biochar in the processes. Table 3 demonstrate different requirement for biochar to be used in sponge iron and EAF processes at Höganäs steel plants.

Table 3. Technical requirements of the biochar/biomass to be used in Höganäs

Feature	**Sponge Iron Process**	**EAF / Ferroalloys**
Fixed carbon	≥75%	≥85%
Volatile matter	≤15%	≤5%
Moisture	10-20 %	<5%
Ash	≤10%	≤10%
Phosphorous	≤0.05%	≤0.02%
Sulphur	≤0.5%	≤0.4%
K+Na	≤0.3%	-
Size	1-10 mm	1-3 mm (injection), 5-40 mm (charge)
Bulk density	≥ 400 kg/m^3	≥ 500 kg/m^3

On the other hand, there are also some criteria to consider when injecting bio-carbon in pilot trials at Swerim EAF:

- Max size for carbon particle is 3 mm
- Max moisture 5%
- C-fix is a parameter that can be change but over 90% is good for the process
- Ash and volatile content are parameters that should be as low as possible
- High density

Based on earlier trials conducted with injection of bio-carbon in Swerim EAF and due the limitations in the injection equipment the particle size that can be injected is max 3 mm and the moisture content need to be less than 5% due to the risk of clogging. A high carbon content is preferable due to less material needed and better yield. In addition to moisture, the content of ash and volatile substances should be low, partly to obtain a high C-fix and partly because high levels of ash and volatile substances affect the process, such as more wear in the furnace, more slag and a higher amount of exhaust gas.

3. Analysis of the biomass/biochar available in the market

3.1 Study of the available biomass/biochar in the market

For the study of the available biomass/biochar, a market research has been carried out, contacting a total of 20 companies specialised in biomass, identifying 24 different materials from 9 countries (Figure 3).

Table 4. List of contacted biomass/biochar suppliers

	Supplier	Source	Country	Anthracite substitution	Foaming coal substitution
1	FERROSADIM	*Olive residue*	Spain	X	
	FERROSADIM	*Olive pomace*	Spain	X	
3	PRECO	*Forest residue*	Spain	X	
4	CPL INDUSTRIES	*30% Vegetal carbon and Olive residue + 70% anthracite*	UK	X	
5	CPL INDUSTRIES	*30% Vegetal carbon and Olive residue + 70% anthracite*	UK	X	
6	ARBAFLAME	*Forest wood*	Norway	X	
7	CANDEL ENERGIA	*Almond shell*	Spain	X	
8	CANDEL ENERGIA	*Almond pellets*	Spain	X	
9	SAN CUCAO	*Vegetal carbon*	Spain	X	
10	TORRCOAL	*Consultants*	Netherlands	-	-
11	AIREX	*Sawmill and forestries residues*	Canada	X	X
12	ENVIGAS	*Wood pellets*	Sweden	X	X
13	BTG WORLD	*Consultants*	Netherlands	-	-
14	INGELIA	*Organic residues*	Spain	X	X
15	BIOFUELREGION	*Projects development*	Sweeden	-	-
16	GREEN FUEL NORDIC OY	*Bio-oil*	Finland		
17	GOODFUELS	*Biofuel*	Italy		
18	SIGNUS	*Tires*	Spain		X
19	IBLU	*Plastics*	Italy		X
20	FUTURE ECO	*Research Institute*	Sweeden	-	-
21	VOWASA	*Equipment manufacturer*	France	-	-
22	NEXTFUEL	*Elephant grass, bagasse, wood waste*	Sweeden		
23	AGBAR (Subcoal)	*Vegetal carbon*	Spain		X
24	AGBAR	*Olive kernel*	Spain		X

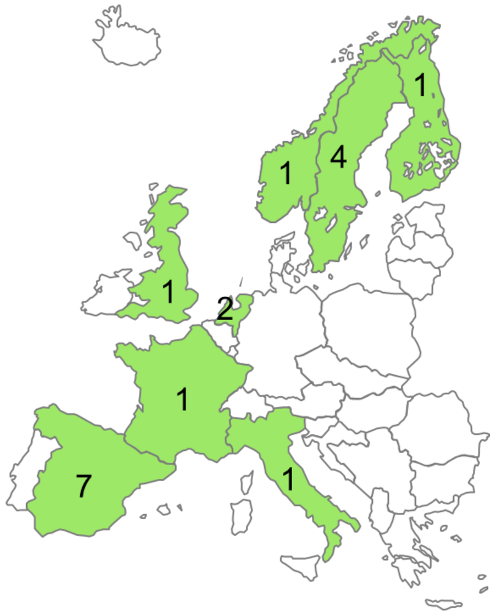

Figure 3. Number of companies (extracted from Table 4) related to biomass production activities in Europe

The majority of the available biochar in the market is placed in Spain and in Sweden, what is very positive for the industrial trials since the partners are located in both countries. In addition, there is another Canadian company, AIREX, which is interesting to explore due to the high quality of the material.

There are companies whose activity is related to the biomass, but they are not suppliers. These companies are highlighted in red colour in Table 4, and are mostly consultants, research institutes or equipment manufacturers.

Depending on the format of the biomass/biochar, the identified materials have been classified in two groups, according to the final application: anthracite substitution or foaming coal substitution. In addition, there are other materials C-renewable that could also be considered in the project, such as the plastics and the tires.

By examining the available biomass/biochar in the market, researchers from the GreenHeatEAF project could evaluate the feasibility and viability of utilizing these resources in the steel industry. The study involves analysing the types and quantities of biomass and biochar available, considering factors such as geographical location, source, composition, morphology, production processes and industrial process target. Additionally, researchers delve into the characteristics of biomass and biochar, including their calorific value, nutrient content, moisture levels, and stability. These investigations not only contribute to identifying suitable biomass/biochar sources for specific applications but also facilitate the development of optimized production techniques to enhance resource efficiency and reduce environmental impact.

3.2 Characterisation of biochar samples from different sources

By characterizing these biochar samples, including their physical, chemical, and structural properties, researchers can gain insights into their composition, stability, and potential environmental impact, as well as predict the behaviour of the biochar inside the furnaces. This investigation plays a crucial role in evaluating the suitability of biochar from various sources for specific applications, informing decision-making processes, and promoting the development of sustainable biochar production practices.

For the characterisation of the biomass/biochar, most of the companies were contacted and asked for a sample and some information about the supply capacity in terms of amount and term.

The samples were analysed in the laboratory, specially focusing on the Carbon content, sulphur, nitrogen, moisture, volatile, ash and HHV.

From the 24 initial list, only 10 materials (the ones in Table 5 with “Supply capacity” as YES) could be considered within the project as potential substitutes of the carbon sources in the EAF, at least due to the supply capacity. The quality and chemical composition will be analysed in Section 4 when selecting the most suitable materials for the industrial trials.

The results of the characterisation of the biomass/biochar samples are included in Table 5, and can be compared with the reference material, currently used in Sidenor as anthracite. In some cases, there are some products that must be discarded due to the significant differences between their chemical composition and the reference, or due to the low carbon content.

Table 5. Characterisation of the biomass/biochar samples

Supplier	Material	Format	C-fix %	S%	N%	Moisture %	Volatile %	Ash %	HHV	% biomass	Supply capacity
	Anthracite	stone	84	1	1,2	6	8	8	8250		
FERROSADIM	Biochar	fine	87,7			32,6	9,8	2,5	8048	100%	NO
FERROSADIM	Biochar	fine	62,2			12,9	18,3	19,5	6090	100%	NO
PRECO	Biochar	fine	64					24	6000	100%	NO
CPL INDUSTRIES	Biochar	briquette	80	0,8	2	13	12	8	6360	30%	YES
CPL INDUSTRIES	Biochar	briquette	70	0,85	2	13	21	7,5	5776	30%	YES
ARBAFLAME	Biochar		41,3	0,26			24,9	33,8	5259	100%	YES
CANDEL ENERGIA	Biomass		20,4	<0,1			78,3	1,31	4481	100%	NO
CANDEL ENERGIA	Biomass	pellets	13,9	<0,1			86	0,14	4529	100%	NO
SAN CUCAO	Biomass		20,3	0,01			79,4	0,0035	4802	100%	NO
TORRCOAL	-	-	40								NO
AIREX	Biochar		80	0,03		7	8,9	4,16	7214	100%	YES
ENVIGAS	Biochar		95	0,01	0,29	0,8	3	1,4	8264	100%	YES
BTG WORLD	-	-									NO
INGELIA	Biochar	pellets/ powder	60	0,2	2	10	50	4-12		100%	YES
BIOFUELREGION	-	-									NO
GREEN FUEL NORDIC OY	Bio-oil										NO
GOODFUELS	Biofuel										NO
SIGNUS	Tires		28,7	1,8	0,54	0,49	64	7,29	8938		YES
IBLU	Plastics	Densified	97,2	0,03	-	0,15	0,23	2,57	9715	0%	YES
FUTURE ECO	-	-									NO
VOWASA	-	-									NO
NEXTFUEL	Biocoal	briquette									NO
AGBAR (Subcoal)	Charcoal	pellets	48	0,08	0,58	5,3	69,3	13,5	4691	50%	YES
AGBAR	Charcoal		85,05		0,1	26,71	11,91	3,04			YES

4. Selection of the material for the industrial trials

4.1 Selection of the material for the industrial trials in Sidenor

In the case of Sidenor, with the technical requirements for the industrial trials, 5 different materials have been preselected and their chemical composition summarised in Table 6.

Table 6. Chemical composition of the selected materials

Supplier	Material	Format	C-fix%	S%	N%	Moisture %	Volatile %	Ash %	HHV	% biomass
	Anthracite REF	stone	84	1	1,2	6	8	8	8250	
CPL INDUSTRIES	Biochar	briquette	80	0,8	2	13	12	8	6360	30%
AIREX	Biochar		80	0,03		7	8,9	4,16	7214	100%
ENVIGAS	Biochar		95	0,01	0,29	0,8	3	1,4	8264	100%
SIGNUS	Tires		28,7	1,8	0,54	0,49	64	7,29	8938	
IBLU	Plastics	Densified	97,2	0,03	-	0,15	0,23	2,57	9715	0%

- **Anthracite substitution (5th hole)**

The materials are introduced in order of preference.

1. Envigas

The source of this material (Figure 4) is wood pellets and the company is located in Sweden. It is the biochar material with the highest carbon content, 95%, and a HHV similar to the reference material. The volatile and ashes are also very low, as well as the moisture, what is positive for this application. Due to the chemical composition, it would also be valid for the foaming coal substitution.

Figure 4. Envigas biochar

2. AIREX

This biochar material (Figure 5) comes from Canada, and despite the chemical composition shows a proper material for the industrial trials, it is placed in the 2nd position due to the transportation costs.

Figure 5. AIREX biochar

3. CPL Industries

This is a mixture material that combines 30% of vegetal carbon and olive residue with 70% of anthracite. It comes from United Kingdom in briquette form (Figure 6). Carbon content is high, 80%, thanks for the anthracite.

In Sidenor this material was tested during 278 heats in November 2022, and the performance was good, at least from an operative point of view.

Figure 6. CPL Industries biochar

- **Foaming coal substitution (injection)**

The materials are introduced in order of preference.

1. iBLU

Instead of biomass, plastic grains (Figure 7) can be a good C-renewable substitute of the foaming coal because it has very good chemical properties but it differs significantly from anthracite. This is why the challenge lies on the design of adapted injection system for plastic waste.

Figure 7. iBLU plastics

2. <u>Signus</u>

This material correspond to a waste that comes from the tires (Figure 8). Despite the chemical composition shows a low carbon content, 28.7%, it is referred to the carbon fixed; but in the volatile part, which is quite high, the carbon content is greater. After receiving positive feedback from other industrial companies that have already conducted trials with this material, it is worth to make some tests in Sidenor.

Figure 8. Signus tires

4.2 Selection of the material for the industrial trials in CELSA

The material selected for the industrial trials in CELSA should mandatory accomplish the specifications from section 2.2. None of the biochar characterized fit a 100% CELSA's requirements, so we will have to conduct a pre-treatment in order to ensure that the specifications are met. Materials will be ranked depending on the carbon content.

4.3 Selection of the material for the industrial trials in Höganäs

There are a wide range of biochar/biomass supplier in Sweden and Europe; (see Table 4) which could be used for the plant trials at Höganäs. The most suitable biochar for the EAF trials would be from Envigas due to high carbon content 95%, low moisture 0.8%, low volatile content of 3% and low ash content 1.4%.

Höganäs has already started negotiations with some suppliers, but due to the dynamic climate of the biomass market and the market uncertainties in Europe the final candidate for Höganäs trials will be selected during Q4 2023.

For the pilot trials at Swerim, the final selection of the biochar will be more discussed with CELSA, Höganäs and SSAB.

5. List of Figures

6. List of Tables

7. List of acronyms and abbreviations

Acronym	Full Name
EAF	*Electric Arc Furnace*
C	*Carbon*
HHV	*High Heating Value*
S	*Sulphur*
N	*Nitrogen*
EBT	*Eccentric Bottom Tapping*
HBI	*Hot Briquetted Iron*
K	*Potassium*
Na	*Sodium*