Application of hydrochar for sustainable EAF process with a focus on pilot-scale testing

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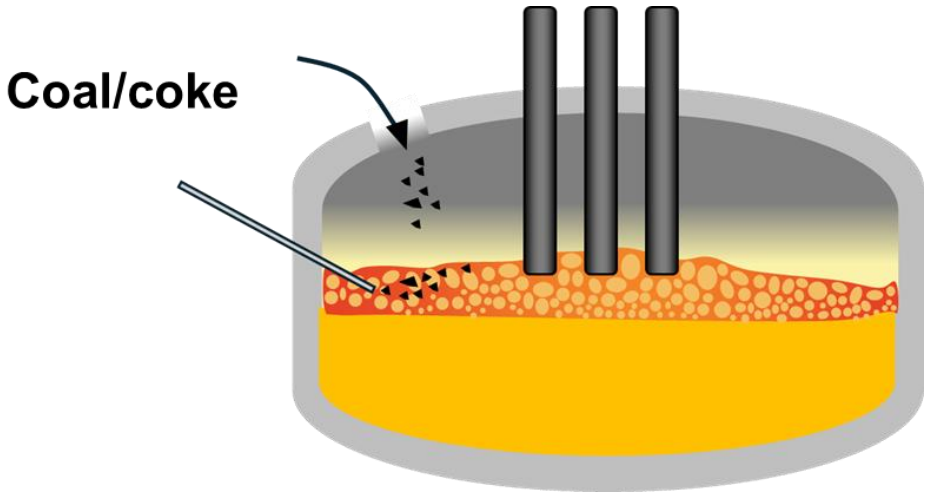
Background - Challenge of decarbonization of the EAF

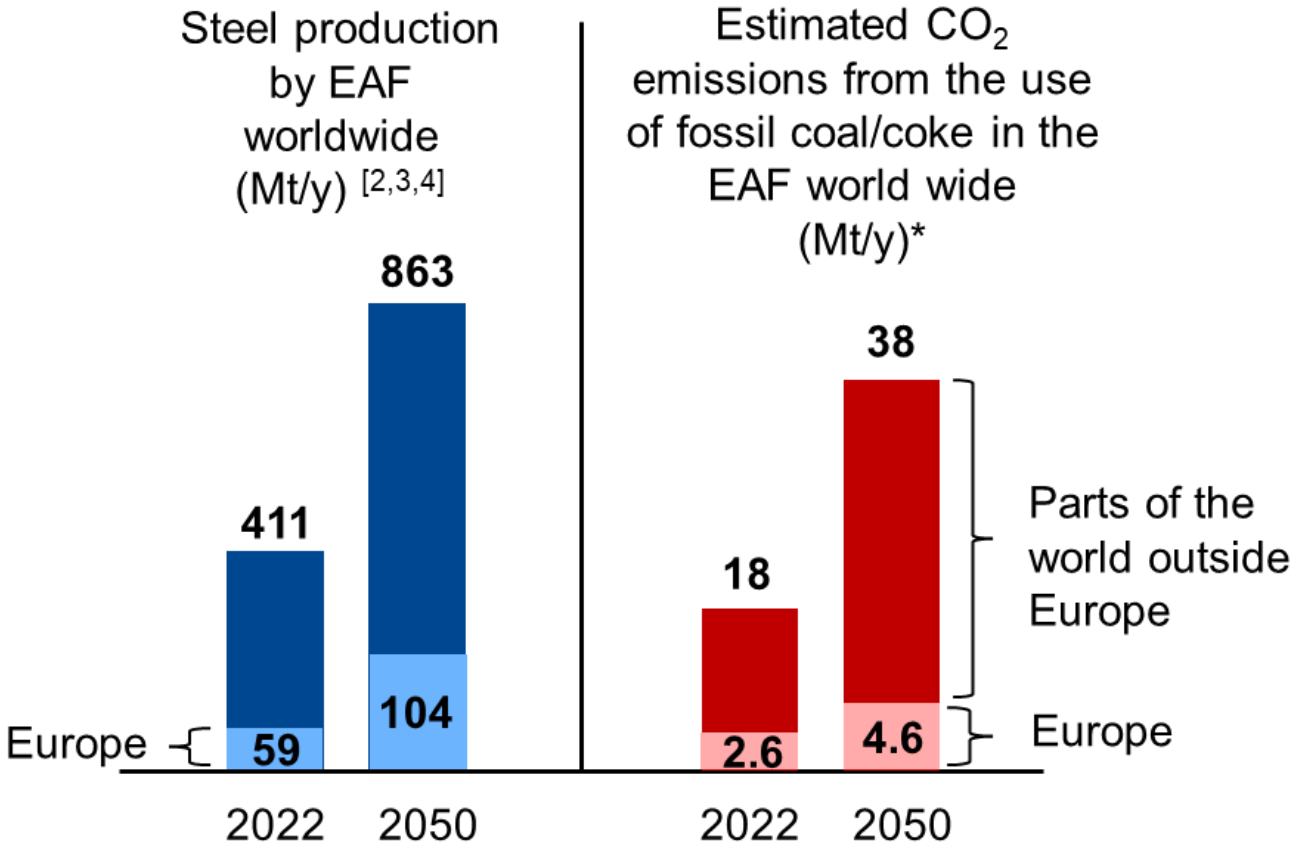
Electric arc furnace (EAF)

12 kg carbon/t-steel [1]

= **44 kg** CO_2/t-steel

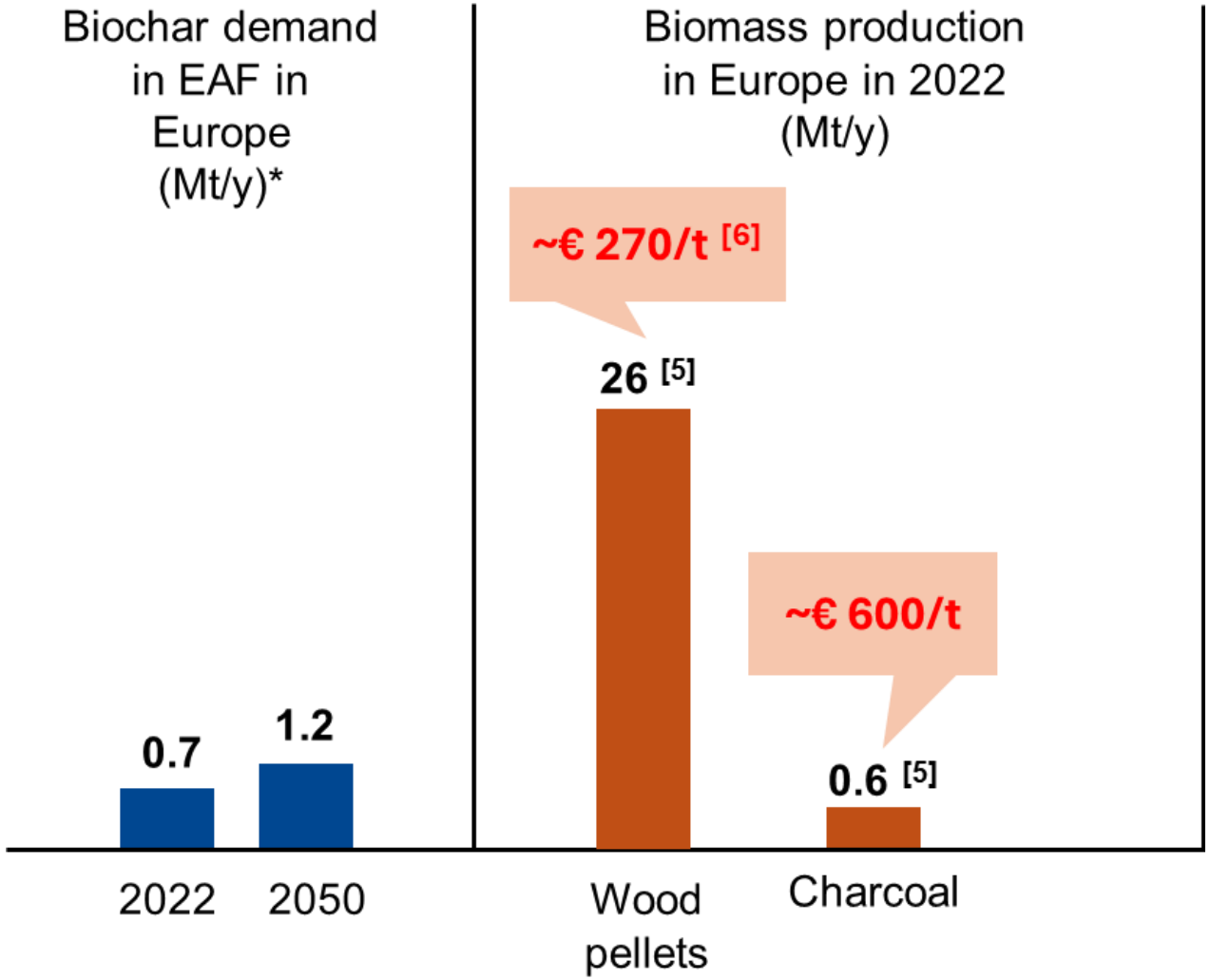


- Heating
- Reduction
- Carburization



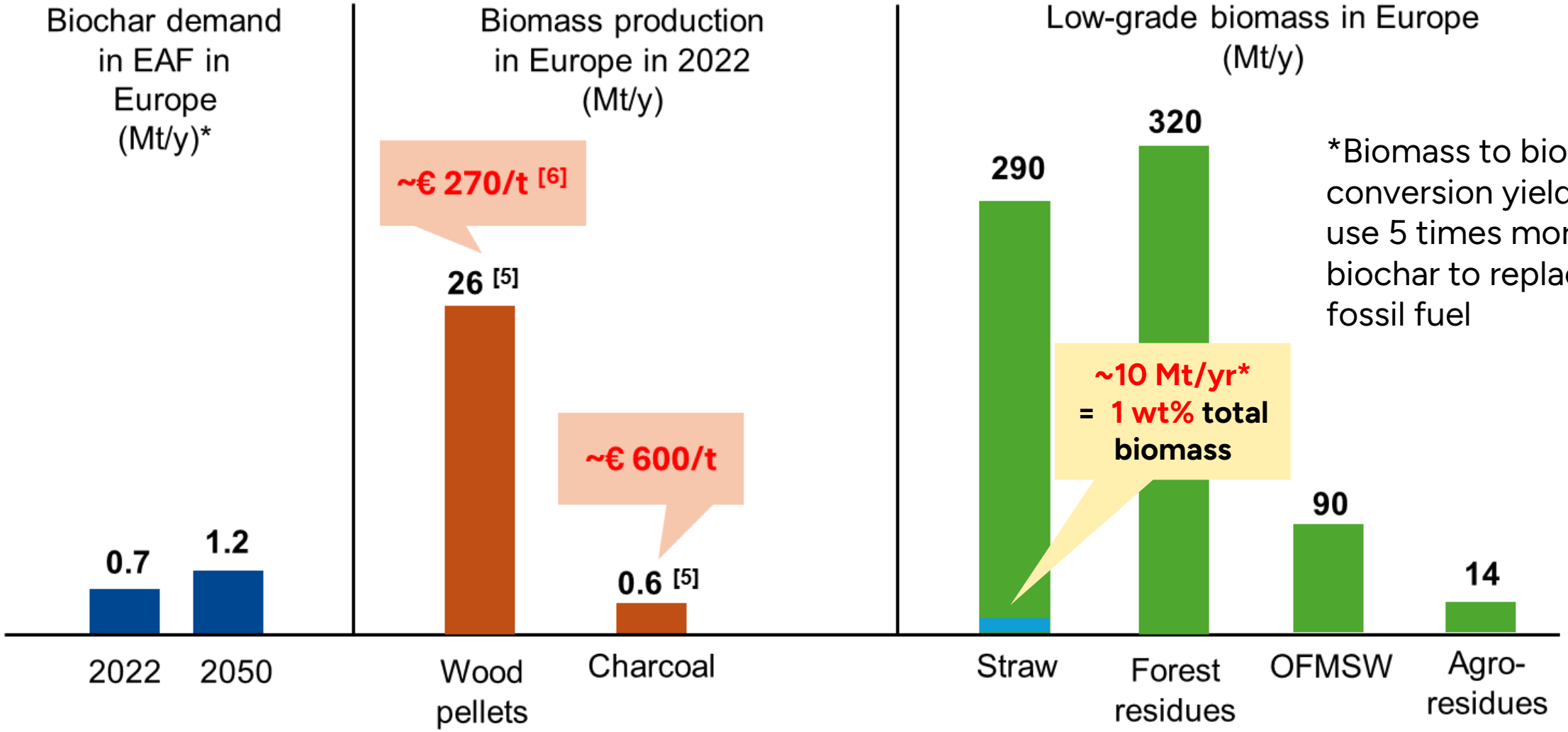
*Calculated based on the amount of steel produced in EAF and 0.044 t-CO_2/t-steel.

Background - Challenge of biochar supply



*Calculated based on the amount of steel produced in EAF and 12 kg-carbon demand per ton steel.

Background - Challenge of biochar supply



*Biomass to biochar conversion yield 50%, use 5 times more biochar to replace fossil fuel

*Calculated based on the amount of steel produced in EAF and 12 kg-carbon demand per ton steel.

Background – Hydrochar, a potential solution

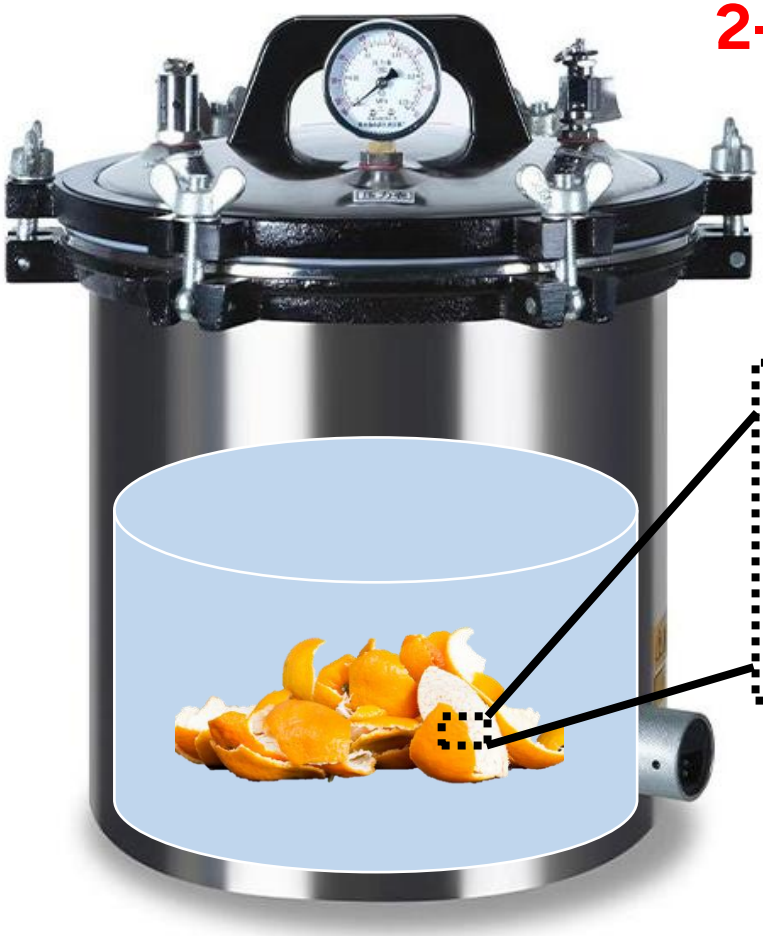
Hydrochar

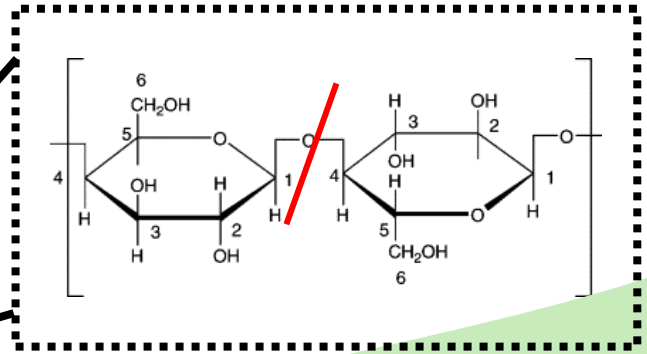


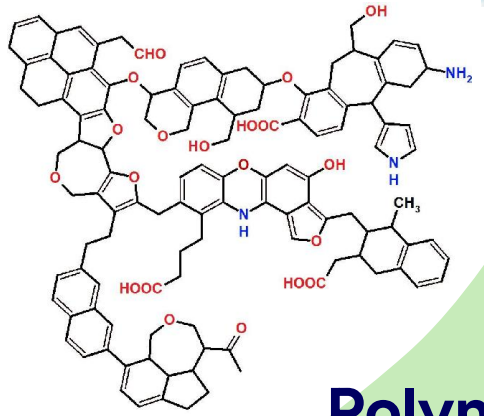
Low temperature, high pressure process!

180-250 °C

2-10 MPa [8]







Polymerization, Aromatization

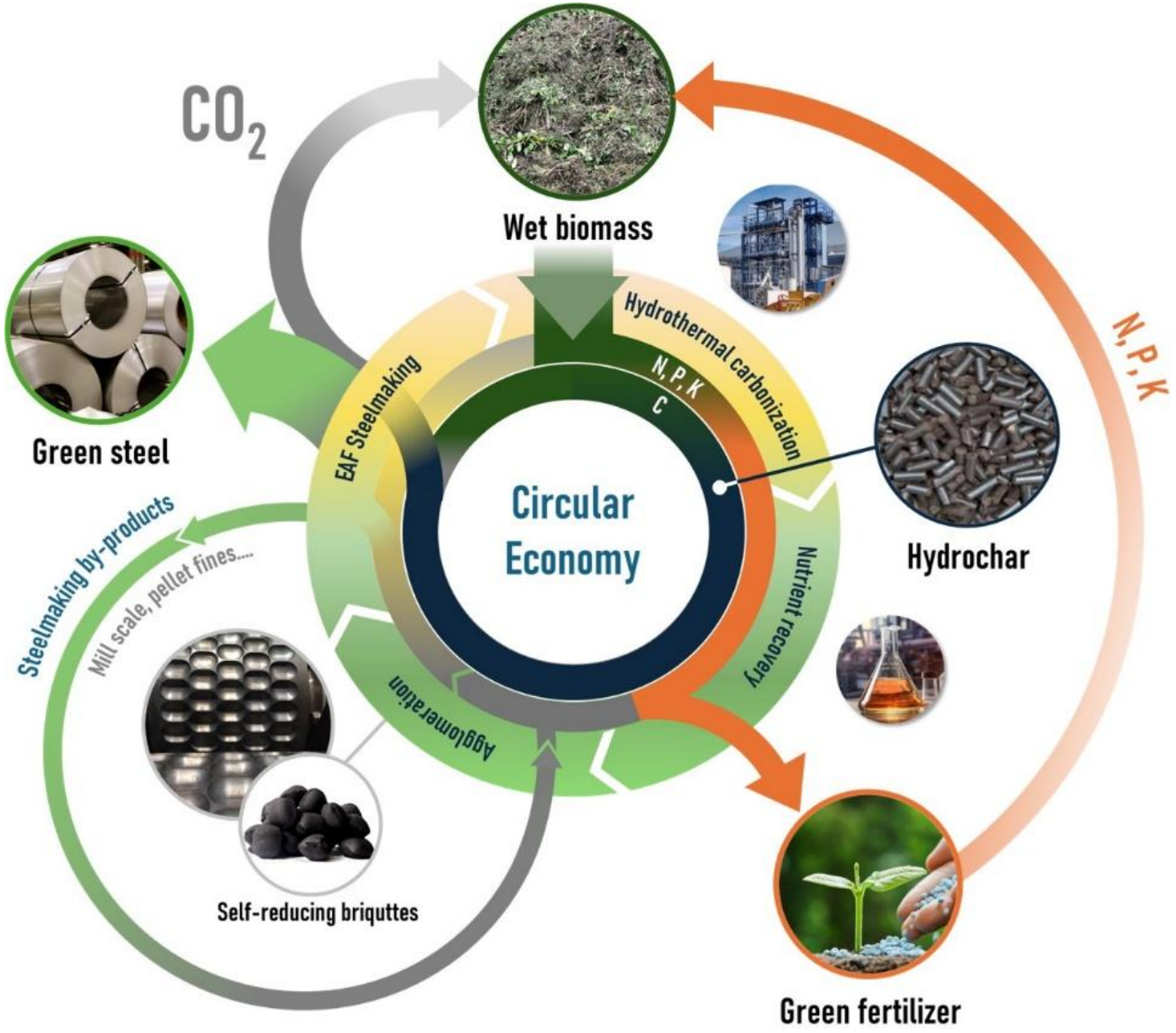
Chemical dehydration

BioReSteel concept

BioReSteel

Valorization of wet biomass residues for sustainable steel production with efficient nutrient recycling

- Coordinator: Chuan Wang, Swerim AB
- Call: RFCS-2022, RPJ
- Start date: 01/10/2023
- End date: 31/03/2027
- Total costs: 3 420 795.00 €



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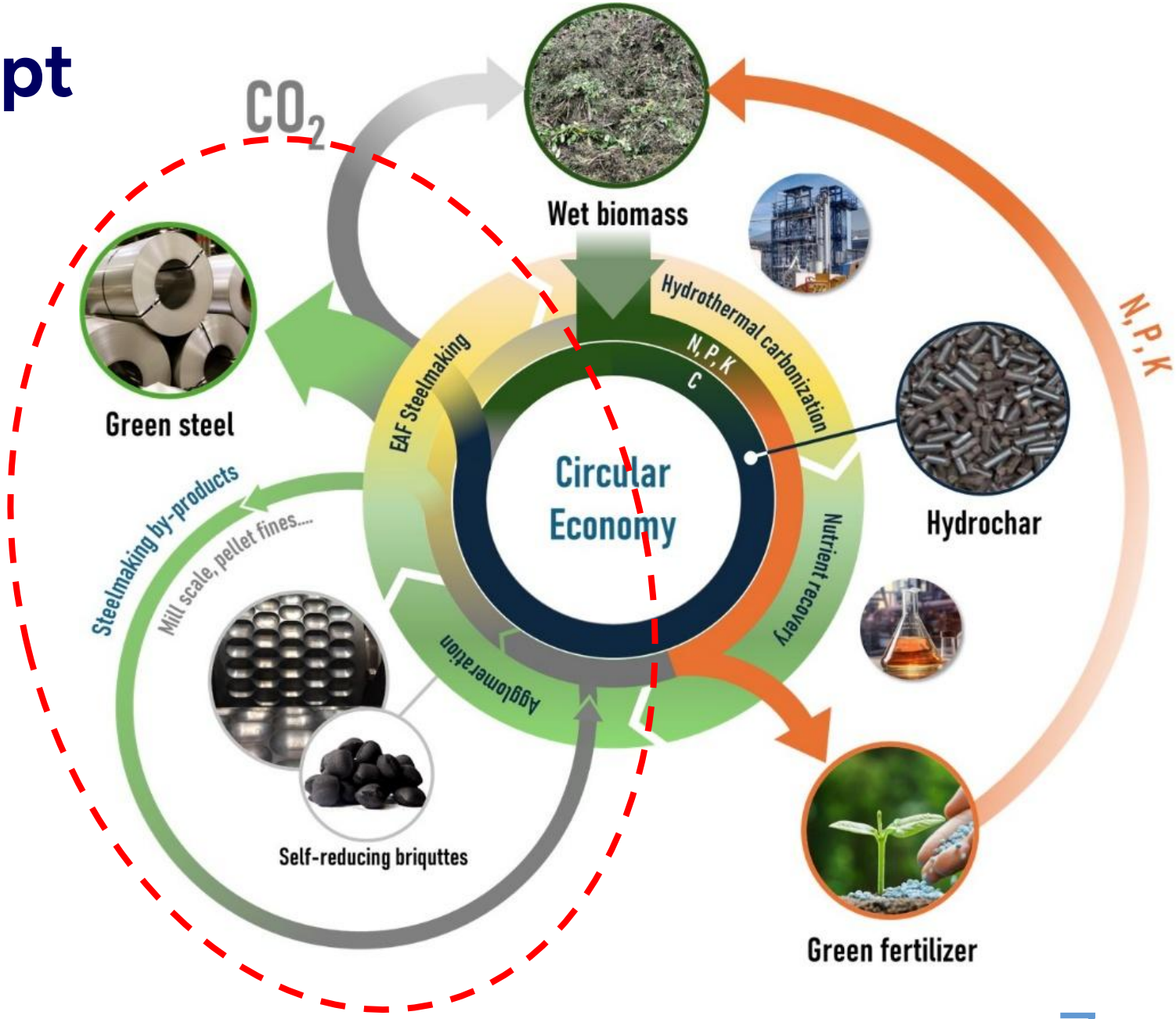
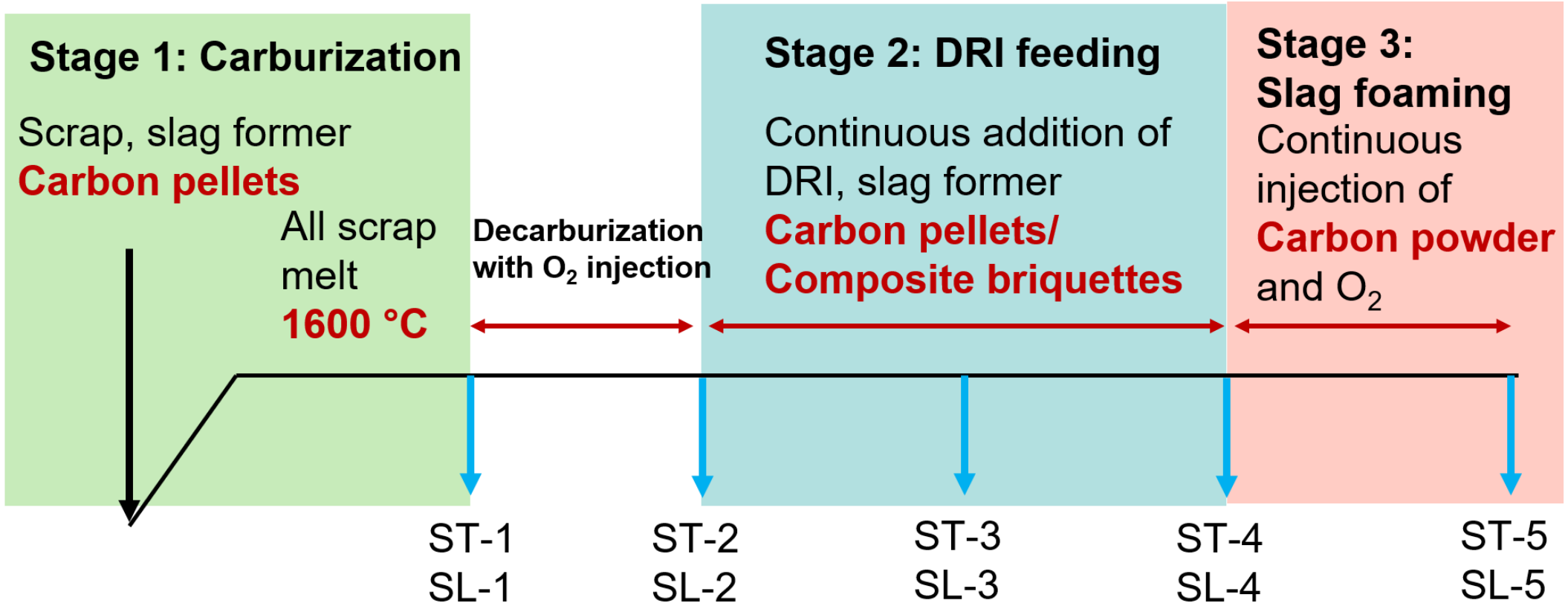


10t EAF pilot trial program





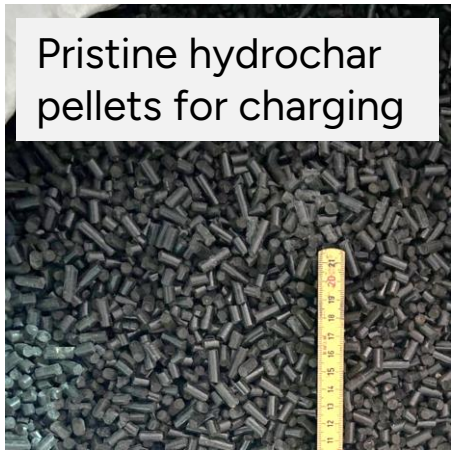
10 t pilot-EAF at Swerim, Luleå

Can hydrochar be added the same way as fossil coal and offer comparable performance?

Carbon materials

GWH=Green waste hydrochar
OLH=Olive pomace hydrochar
P=Pyrolyzed

Pristine hydrochar pellets for charging



Pyrolyzed hydrochar pellets for charging



Hydrochar fines for injection



Material	Anthracite	GWH	PGWH	OLH	POLH
Moisture, wt%	3.2	5.4	1.2	2.8	2.3
Volatile matter (db), wt%	8.7	62.7	19.8	69.1	19.5
Ash (db), wt%	**13.0**	**13.8**	**30.4**	**7.5**	**16.4**
Fixed carbon (db), wt%	**78.3**	**23.5**	**49.8**	**23.4**	**64.1**
C content (db), wt%	82.5	53.2	60.6	60.6	71.3
H content (db), wt%	2.1	5.2	1.9	6.7	2.3
N content (db), wt%	1	1.42	1.99	1.94	2.91
O content (db), wt%	1.0	26.0	4.8	30.6	6.8
S content (db), wt%	**0.372**	**0.148**	**0.331**	**0.174**	**0.291**
P content (db), wt%	**0.055**	**0.322**	**0.187**	**0.409**	**1.190**
Cl content (db), wt%	0.041	0.123	NA	0.069	NA

Composite self-reducing briquettes

Composition	Briquette A	Briquette B
Recipe	30 wt% OLH 66 wt% mill scale 4 wt% binder	15 wt% OLH 20 wt% POLH 61 wt% mill scale 4 wt% binder
C-tot	**24.3**	**26.1**
C-fix	**14.8**	**14.9**
Fe_2O_3	**56.0**	**38.9**
CaO	4.7	5.76
MgO	1.67	1.68
SiO_2	6.54	10.2
Al_2O_3	1.72	2.55
MnO	0.7	0.47
P_2O_5	3.08	3.48
Others	1.27	0.09



Material additions

Trial*	Stage 1-Carburization			Stage 2-DRI feeding					Stage 3-Slag foaming	
	Scrap [t]	Slag formers [kg]	**CM [kg]**	DRI [t]	Slag former [kg]	**CM [kg]**	Composite BR [kg]	O_2 [Nm^3]	**CM [kg]**	O_2 [Nm^3]
A	3	187	**46**	4.2	50	**78**	-	0-96	**46**	42
GWH		134	**198**		50	**135**	-	0-91	**178**	58
PGWH		138	**87**		61	**111**	-	0-44	**70**	49
OLH		164	**198**		91	**60**	600 (BRA)	0-17	**167**	47
POLH		134	**87**		97	**73****	200 (BRB)	-	**71**	46

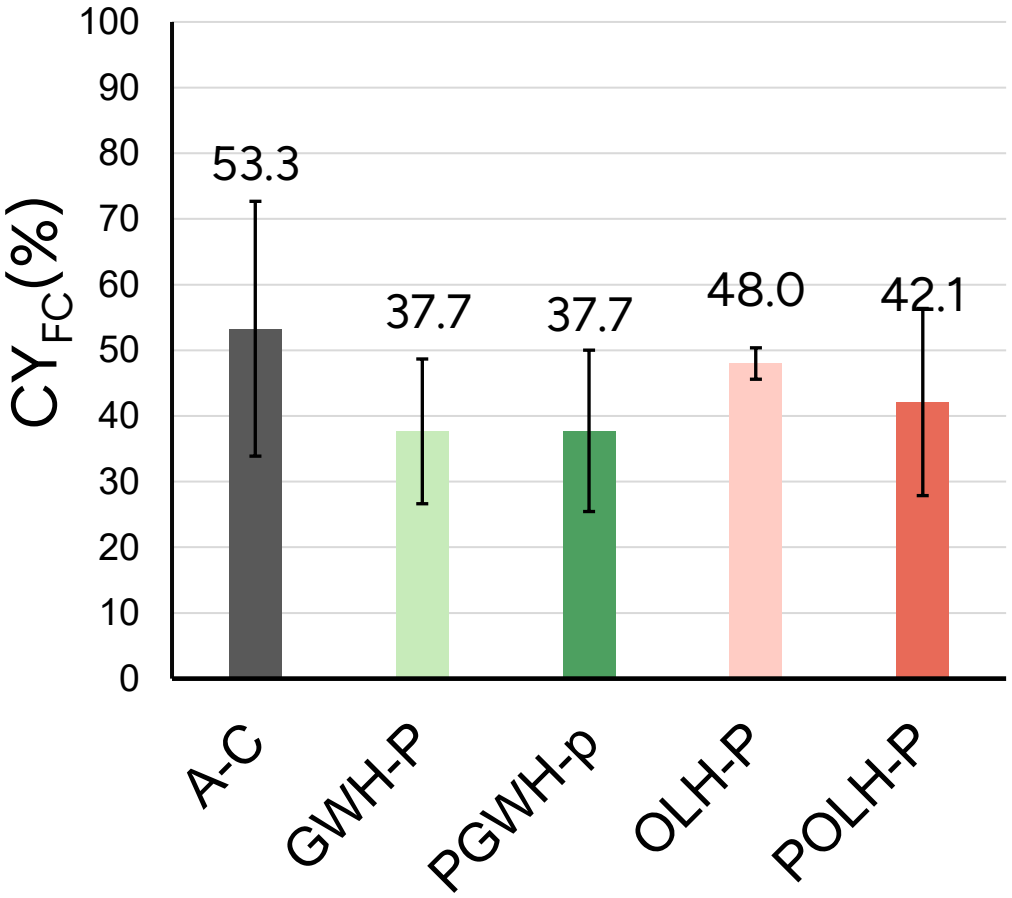
***3 heats per carbon material (CM)**

**55 kg PLPH + 18 kg A

Output:
Metal **7 t**, Slag **0.5-0.9 t**, Dust

Results – Stage 1 carburization

$$CY_{FC}(\%) = \frac{W_{Me} \cdot [(\%C)_{Me,1} - (\%C)_{scrap}]}{W_{CM} \cdot (\%C)_{CM,FC}} \cdot 100\%$$



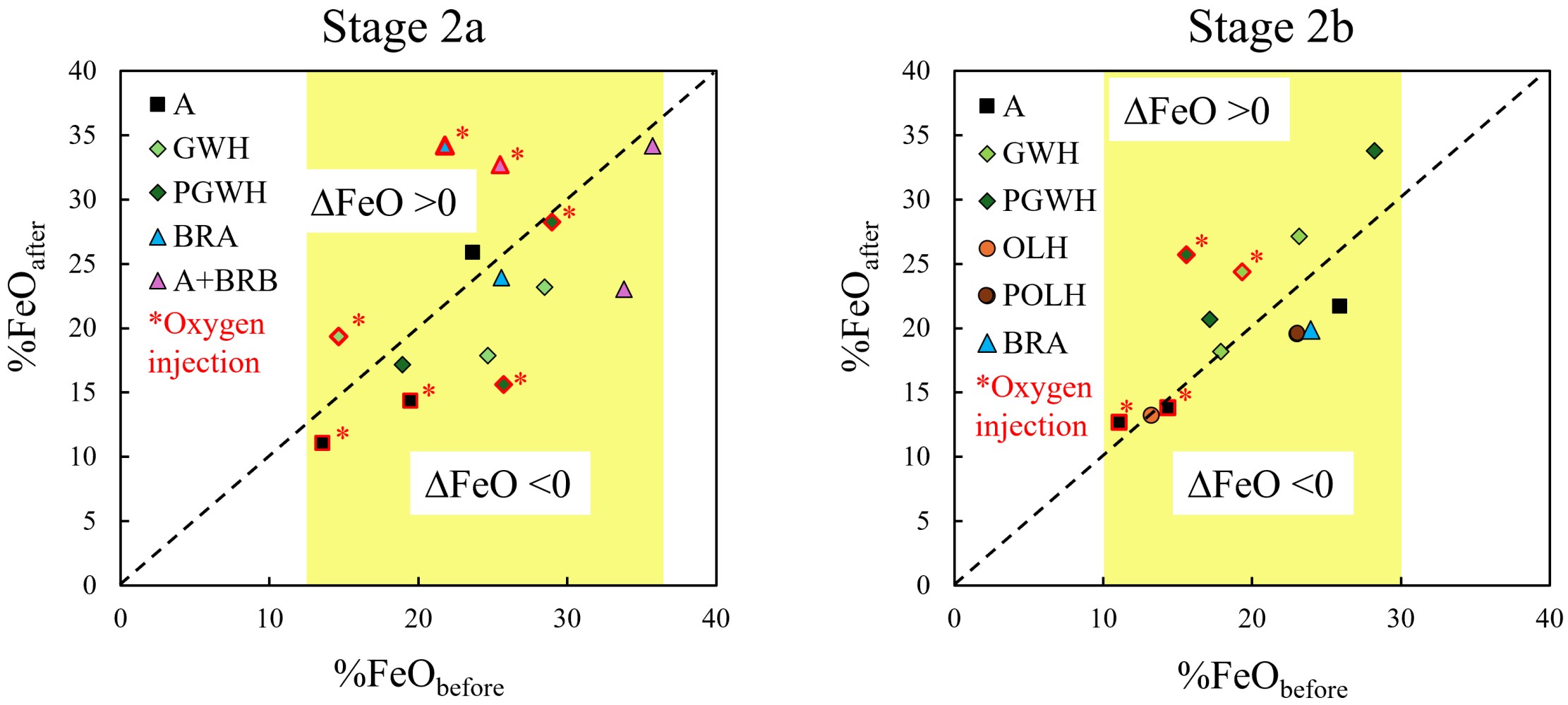
CM	FC (wt-%)	Addition during trial (kg/t-steel)	Amount required to replace 1 kg A (kg)*
A	78.3	15	1
GWH	22.7	64	4.9
PGWH	49.8	28	2.2
OLH	23.4	64	3.7
POLH	64.1	28	1.5

*Calculated based on= (FC_A*CY_A)/(FC_i*CY_i)

- Difference in CY due to differences in density and carbon structure
- POLH is the best carburizing agent, followed by PGWH, OLH, and GWH

Results – Stage 2 DRI feeding

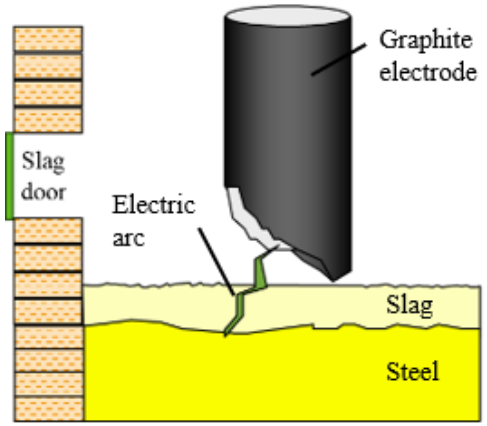
$$\Delta FeO = (\%FeO)_{after} - (\%FeO)_{before}$$



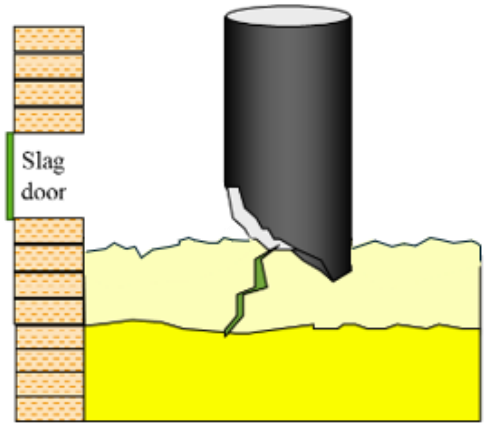
=> Oxygen injection, formation of ferroberg might interfere with FeO reduction by carbon

Results – Stage 3 Slag foaming

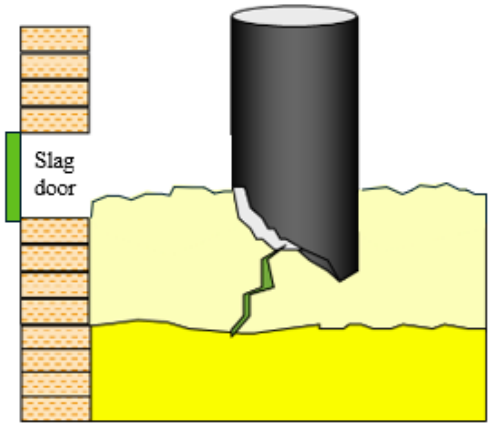
Level 1 – Poor



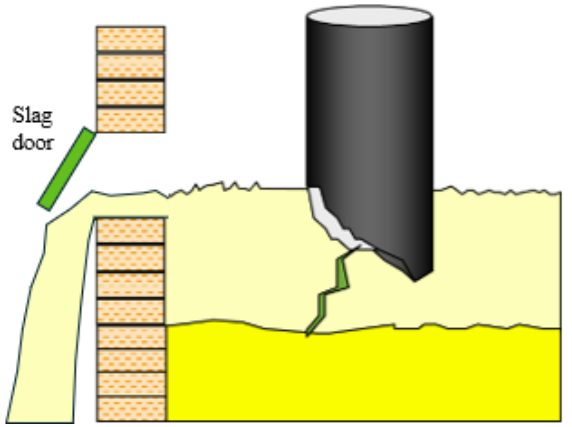
Level 2 – OK



Level 3 – Good



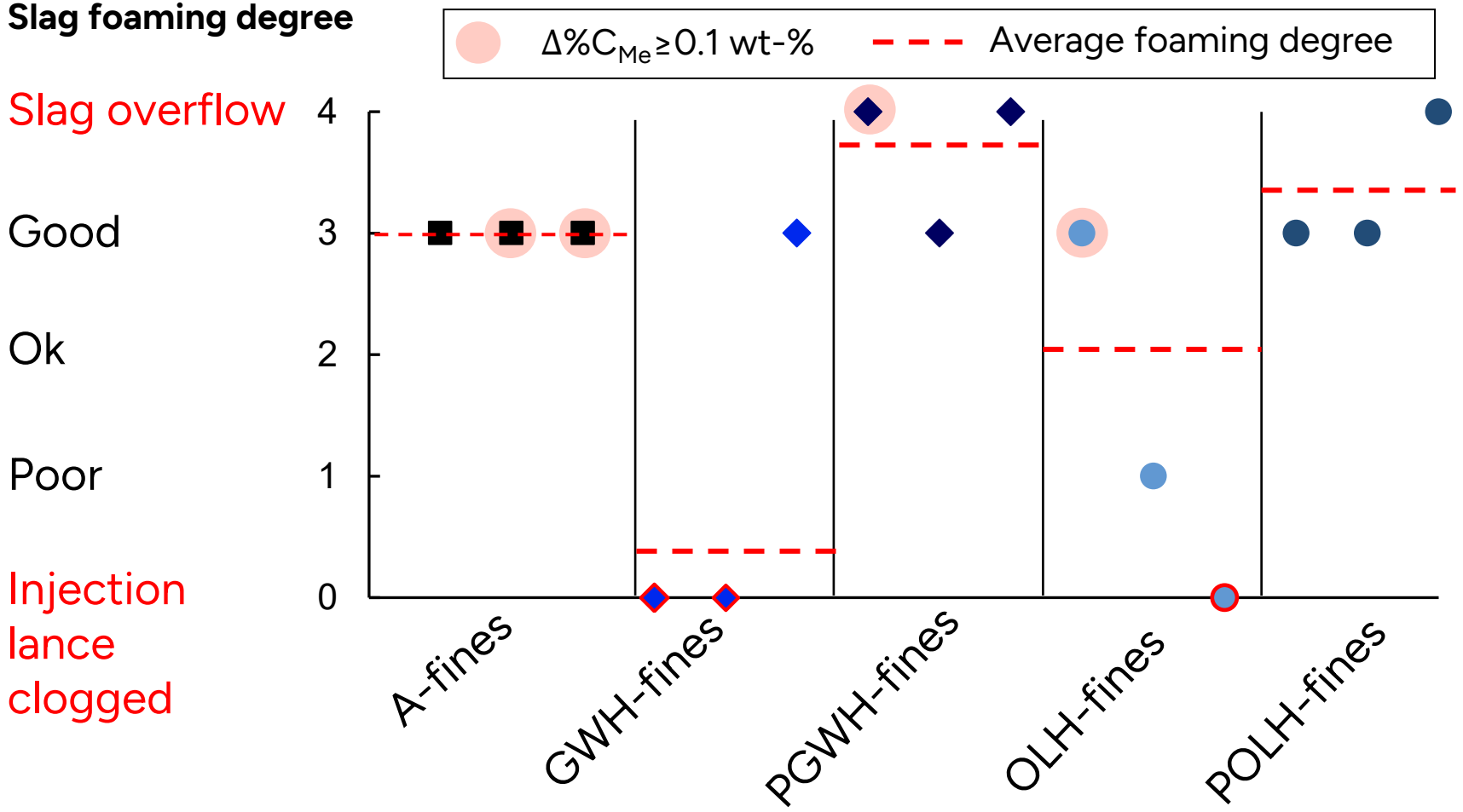
Level 4 – Slag ovreflow



Results – Stage 3 Slag foaming

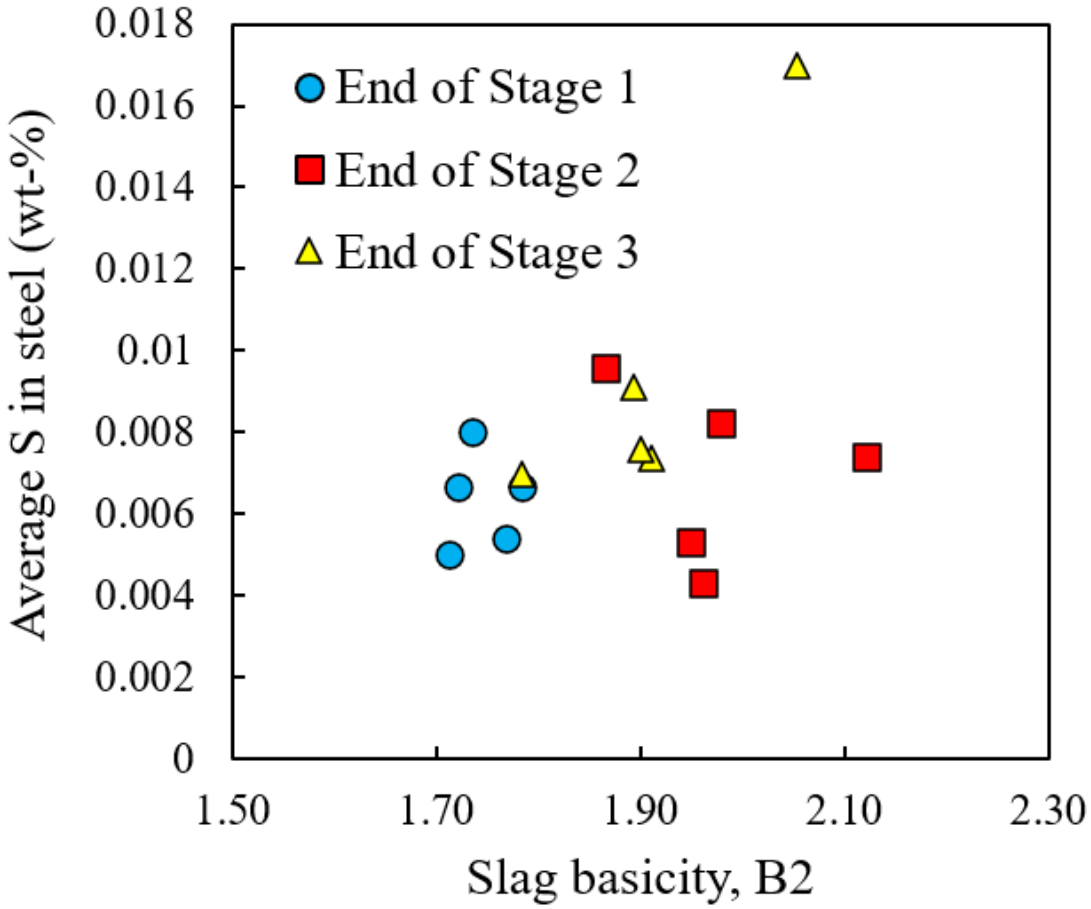
$\Delta\%C_{Me}=(\%C_{Me})_{before}-(\%C_{Me})_{after}$

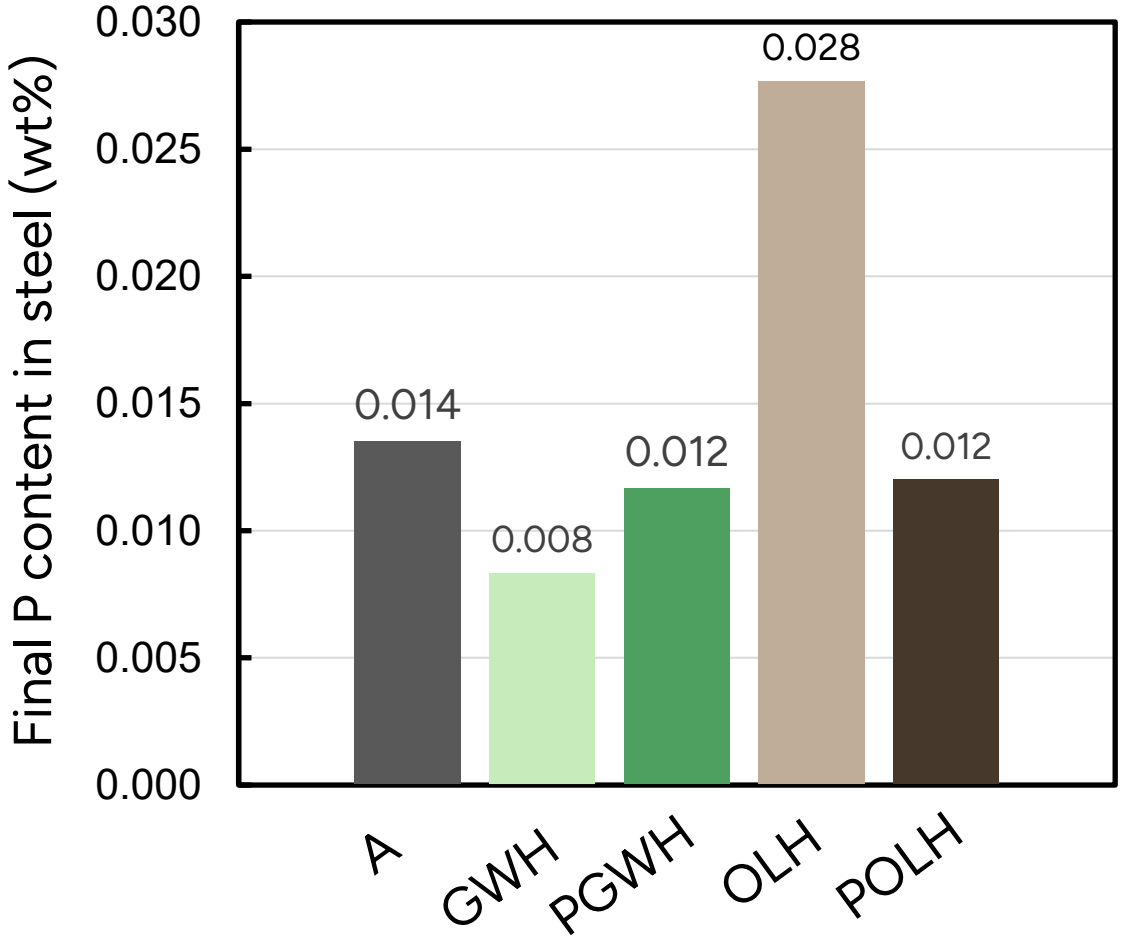
Slag foaming degree



Injection amount (kg/t-steel)	6-7	15-25	9-11	14-24	8-12

Results – Impact of impurities





Concluding discussions-Replacement ratio

Unit: Amount of alternative carbon material to replace 1 kg of anthracite

Carbon material	Based on FC content	Based on amount consumed during EAF trials			Impurity(S, P) transfer to steel
		Stage 1: Carburization	Stage 2: DRI feeding	Stage 3: Slag foaming	
Anthracite	1.0	1.0 (+++)	1.0 (++)	1.0 (++)	+
GWH	3.5	4.3 (+)	1.7 (+)	3.9 (+)	+
PGWH	1.6	1.9 (+)	1.4 (+)	1.5 (+++)	+
OLH	3.4	4.3 (++)	0.8 (+++)*	3.6 (+)	-
POLH	1.2	1.9 (++)	0.9 (+++)*	1.5 (+++)	+

*Less addition since anthracite and composite briquettes also added during this period.

Conclusions

1. Pristine and pyrolyzed hydrochar produced from **low-grade biomass (green waste, olive pomace)** were successfully applied in a **10 t EAF** for carburization, reduction, slag foaming - and produced steel quality comparable to using anthracite

2. Hydrochar could be added using **typical methods** for anthracite (top charging, injection)

3. Overall, **pyrolyzed hydrochar** showed better performance than **pristine hydrochar** where less amount could be used. However, pristine hydrochar is suitable for adding in self-reducing briquettes while partially functioning as a binder.

4. **Self-reducing composite briquettes** promoted effective reduction of FeO in the slag

Conact

This research was funded by **RFCS** under the **BioReSteel** project (N° 101112383).



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