STEEL24 MASTER

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6 - 10 Maggio 2024

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Cremona
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Production of hot hydrogen-rich syngas for the injection in the Blast Furnace

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Steelmaster
è una iniziativa sostenuta da
ESTEP Federacciai industriAll Arvedi European Commission

Project overview

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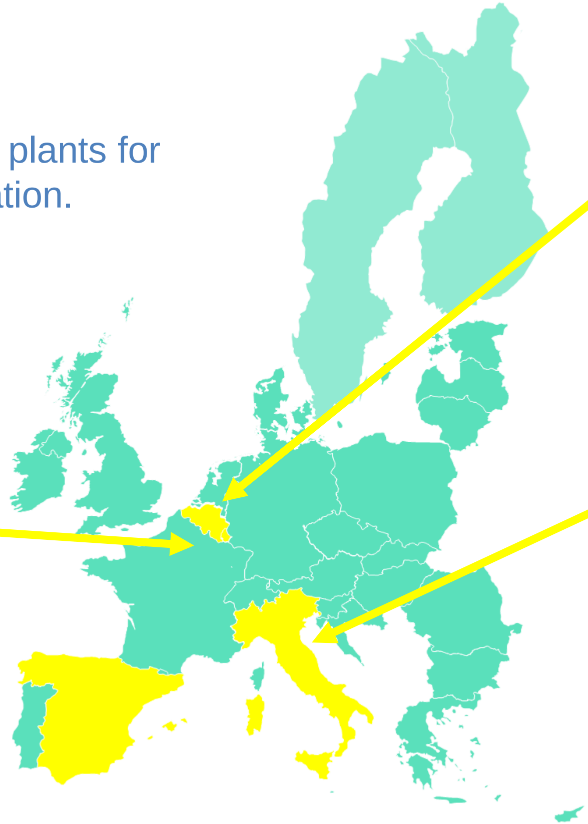
ProSynteg

Production of hot hydrogen-rich syngas in integrated plants for efficient injection in the blast furnace and CO_2 mitigation.

Call: *RFCS-2021*
Topic: RFCS-02-2021-PDP
Start date: 01/07/2022
End date: 31/12/2025
Budget: € 3.448.899,75

PAUL WURTH SMS group

ArcelorMittal



CRM GROUP

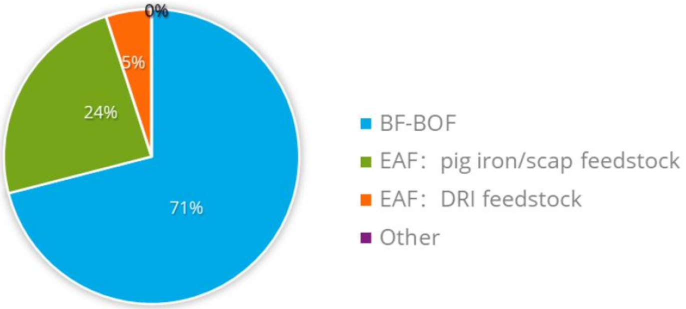
Acciaierie d'Italia

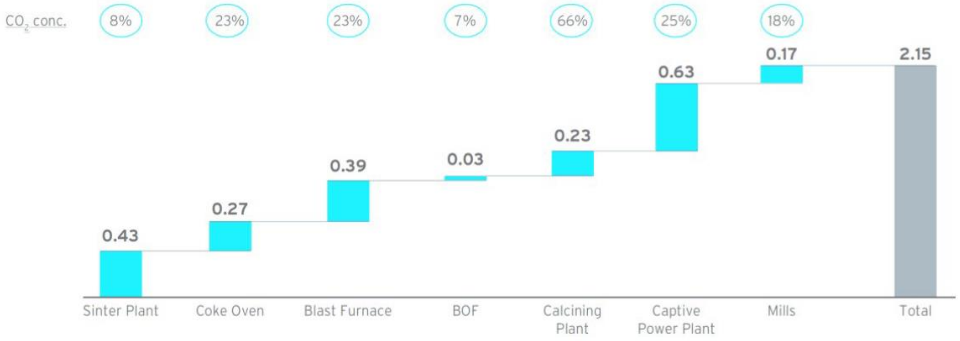
RINA

PAUL WURTH SMS group
ITALY – Third party

RINA

Introduction





70% of the world steel production is based on Blast Furnace – Basic Oxygen Furnace (BF-BOF) route, that has a strong impact on the CO_2 production.

1 tonne of crude steel → **2.15** tonnes of CO_2

Introduction

Main possible pathways to reduce CO2 emissions:

1. Utilization of Electric Arc Furnace (**EAF**) technology:
    I. limitations on the availability of scrap metal;
    II. limitations on the production of certain steel grades that require high purity.
2. Optimization of the BF-BOF process route:
    I. improving the efficiency and effectiveness of the BF process for the steel production.

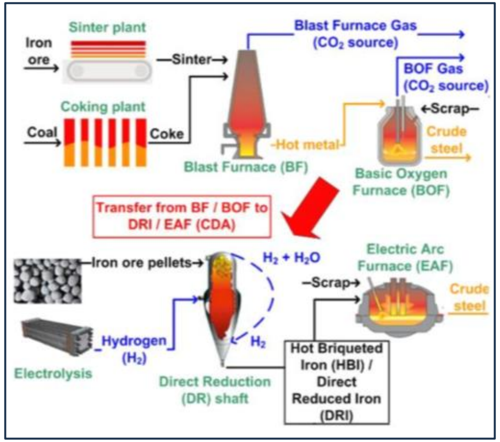
Areas of intervention

Areas of intervention on BF-BOF route.

Areas of intervention	Specific objectives
Carbon direct avoidance (**CDA**)	Enabling steel production through carbon direct avoidance (CDA) technologies at a demonstration scale
Smart carbon usage via carbon capture, utilization, and storage (**SCU-CCUS**)	Fostering smart carbon usage (SCU – Carbon capture) technologies in steelmaking routes at a demonstration scale, thus cutting CO2 emissions from burning fossil fuels (e.g., coal) in the existing steel production routes.
Smart carbon usage via process integration (**SCU-PI**)	Developing deployable technologies to improve energy and resource efficiency (SCU – Process Integration).

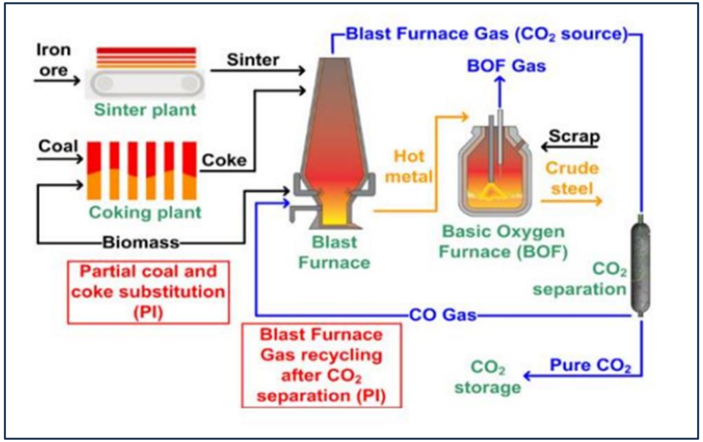
Areas of intervention

CDA



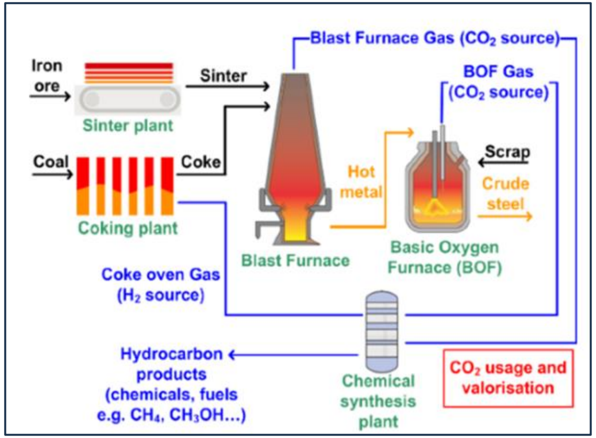
CDA includes technologies that avoid carbon emissions during steelmaking.

SCU-PI



PI allows reducing fossil fuel (coal, natural gas, etc.) used in both BF-BOF and EAF steel production.

SCU-CCUS



CCUS allows the utilization of the COG and CO2 produced for valuable products production.

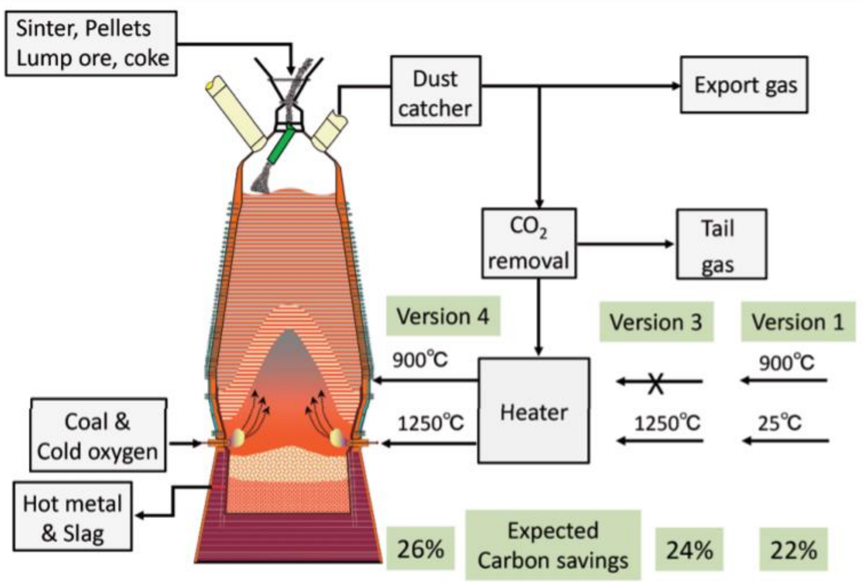
TGR-BF

TGR-BF

The main phases are:

- off-gases are taken from the top of the BF;
- dust removal;
- CO_2 removal;
- gas recirculation after heating.

TGR technology can separate CO2 from reducing gas and combine with CCUS technology to guarantee carbon emission reduction.



H2 injection to the Blast Furnace

The replacement of carbon with H2 as a reducing agent is expected to decrease CO2 emission.

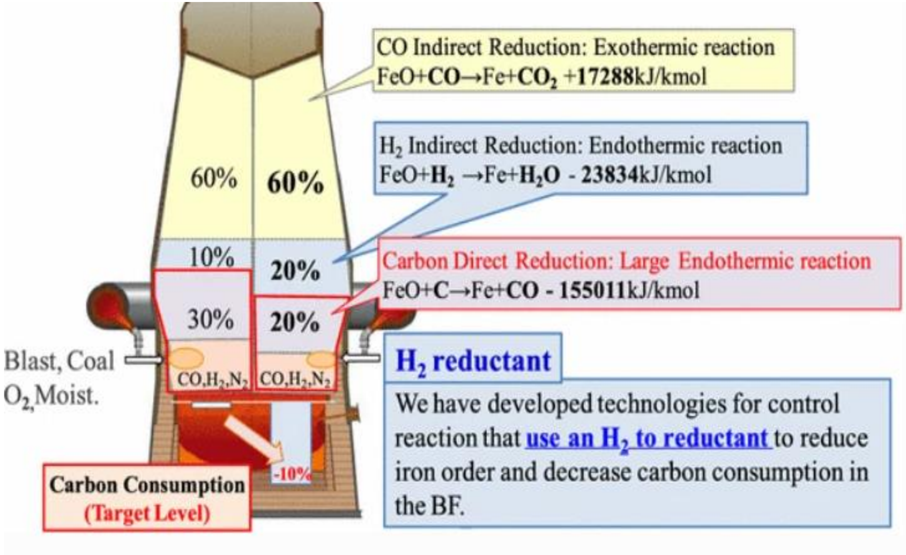
Contrariwise the utilization of H2 in BF deteriorates the process operation from the following issues:

1) H2 requires more energy to compensate the endothermic reaction heats.

$Fe_2O_3 + 3H_2 \rightarrow 2Fe + 3H_2O$ is 100 kJ (endoth.)

$Fe_2O_3 + 3CO \rightarrow 2Fe + 3CO_2$ is –23.5 kJ (exoth.).

2) Coke layer is thinned when the reducing agent is replaced by H2 . ($C + H_2O \rightarrow CO + H_2$) (endoth.)

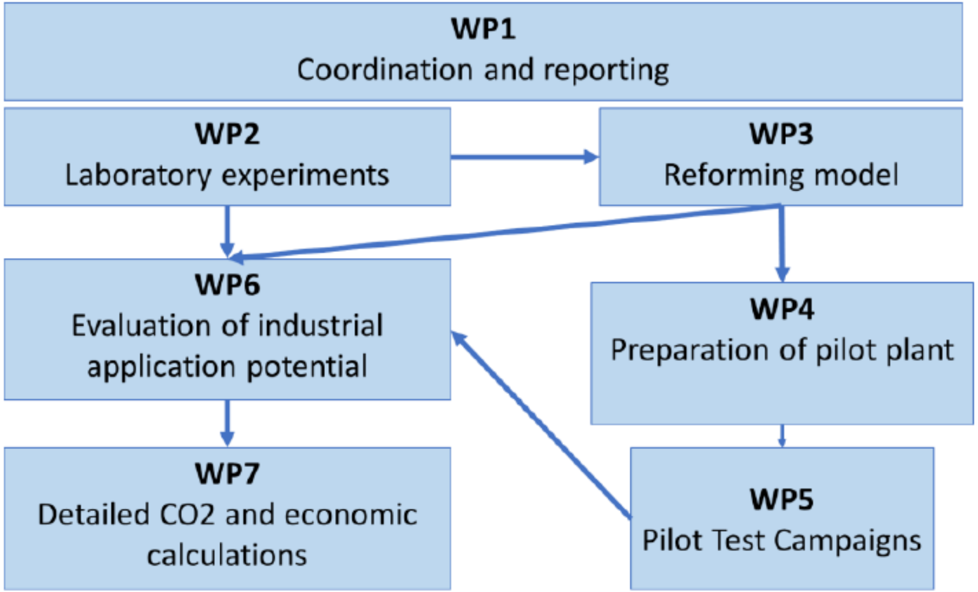


Problem addressed

Problem addressed by ProSynteg

In integrated steel plants **coke breeze** is used as a solid fuel in the ore/mineral mix of the sinter strand(s) but in the next future, due to **high environmental impact** of the sinter production, various steelmaking will be forced to close the sinter plants with the necessity to find an **alternative** of coke breeze **utilization**.

ProSynteg WP distribution



GANTT chart

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Work package	Work package title	Deliverables	1st year				2nd year				3rd year				4th year	
			I	II	III	IV	I	II	III	IV	I	II	III	IV	I	II
			2022	2022	2023	2023	2023	2023	2024	2024	2024	2024	2025	2025	2025	2025
			IIIQ	IVQ	IQ	IIQ	IIIQ	IVQ	IQ	IIQ	IIIQ	IVQ	IQ	IIQ	IIIQ	IVQ
WP 1	**Coordination and reporting**															
Task 1.1	Coordination meetings	**D1.1, D1.2, D1.3**														
Task 1.2	Administration and reporting															
Task 1.3	Dissemination															
WP 2	**Laboratory experiments**															
Task 2.1	Supply of coke breeze samples for lab experiments	**D2., D2.2, D2.3**														
Task 2.2	Production and supply of alternative carbon materials for lab experiments															
Task 2.3	Characterisation of carbon materials, including combustion and reactivity experiments															
Task 2.4	Small-scale combustion experiments on lab scale burner															
Task 2.5	Small-scale reforming experiments with various steelmaking offgas and hot CO2															
WP 3	**Reforming model**															
Task 3.1	Conception and set-up of a kinetic model of the reforming reactor	**D3.1, D3.2**														
Task 3.2	Validation of CFD simulation using data from test of burners															
Task 3.3	Calibration and fine-tuning of model parameters based on lab experimental results and pilot results															
WP 4	**Preparation of the pilot plant**															
Task 4.1	Detailed engineering	**D4.1**														
Task 4.2	Adaptation of the existing plant															
Task 4.3	Commissioning															
WP 5	**Pilot test campaigns**															
Task 5.1	Realisation of pilot campaigns	**D5.1**														
Task 5.2	Analysis of the results															
WP 6	**Evaluation of industrial application potential**															
Task 6.1	Flexibility of the process regarding raw materials	**D6.1, D6.2, D6.3, D6.4**														
Task 6.2	Calculation of selected industrial operating points by means of the tuned reforming model															
Task 6.3	Detailed calculation of the value in-use of the syngas at the BF and comparison with direct injection of COG in tuyeres															
Task 6.4	Safety issues at the BF linked to the new process, to gas injection and to the increases H2 content of the BF top gas															
Task 6.5	Alternative options for using the hot syngas in reheating furnaces or other combustion applications															
WP 7	**Detailed CO2 and economic calculations**															
Task 7.1	CO2 calculations and LCA on the main industrial options, including the injection of hot syngas in BF shaft	**D7.1, D7.2**														
Task 7.2	Economic calculations															

ProSynteg

RINA

ProSynteg main tasks

1. Material characterisation and small scale tests
2. Process modelling
3. Pilot tests campaigns and data collection
4. Impact evaluation on industrial scale economic feasibility of the process

Areas of intervention - ProSynteg

Main objectives

Utilization of the coke breeze calorific value to produce hot H2-rich syngas from dry-reforming of coke oven gas.

Process Integration (PI) is one of the main pathway dedicated to the process modifications of conventional steel plants processes.

- Gas injection in the BF has a potential of 15-20% total mitigation.

	Mitigation potential (% of average BF/BOF plant)
Use of biomass and spent-C streams at the BF	20-25%
Gas injection in the BF (including the energy required for preparing the gas)	15-20%
Use of some biomass and spent-C streams at the coke plant	5%
Actions at the Sinter plant	5%
Operation of heating applications using low-C fuel gas	5%
CCUS on steel plant gases	40%
	90-100%

Project concept

By combining COG with hot CO2, it is possible to thermally reform the methane (and higher hydrocarbons) contained in the COG according to the dry reforming reaction.

COG

	CH_4	C_2H_6	C_2H_4	C_6H_6	O_2	H_2	H_2O	CO	CO_2	N_2
%	22.6	0.8	1.7	1.2	0.4	45.6	1.6	4.8	2.5	18.8

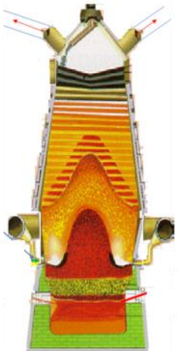
Coke breeze + O2 → **Combustion reactor**: C+O2 (T~3200 °C, P = 4-6 bar)

CO2 + heat → **Reforming reactor**: CH4 + CO2 ➔ 2 CO +2 H2, ΔH (1000°C) = +258.9 kJ/mol (T~2075 °C, P = 4-6 bar)

Flue gas

	%
H_2	43
CO	32.5
H_2O	6
CH_4	5
CO_2	2
Other	11.6

Syngas injection



Reduction of Coke rate and CO2 emissions.

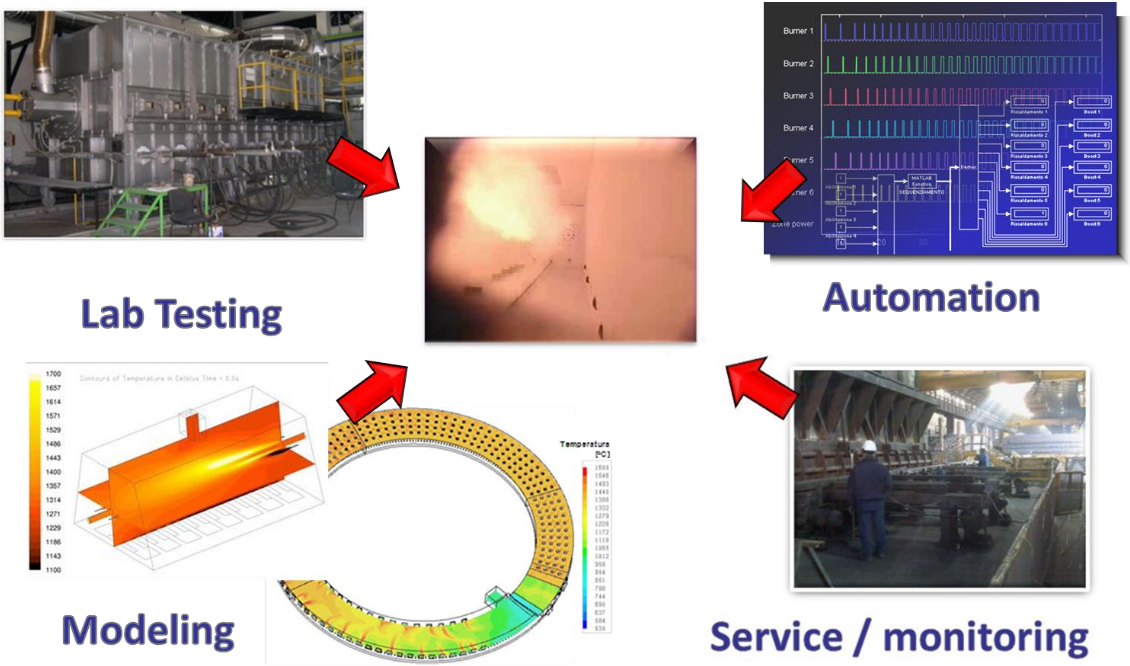
Main goal: H2-rich syngas with a **H2/CO ratio** (1.3 to 2) is 10 times higher than the hot decarbonated gas that is injected in the **BF shaft** in the TGR-BF process.

RINA-CSM activities

Activities carried out by RINA-CSM in the project.

RINA-CSM activities

RINA-CSM facilities



RINA-CSM activities

RINA-CSM facilities

Combustion station equipment – modular furnace (1 to 3 MW)

- Length (internal) [m]: 3 – 7.5
- Max syngas flow rate [kg/h]: 2000
- Max air flow rate [Nm3/h]: 3500
- Max working T [°C]: 1250

Continuous monitoring of:

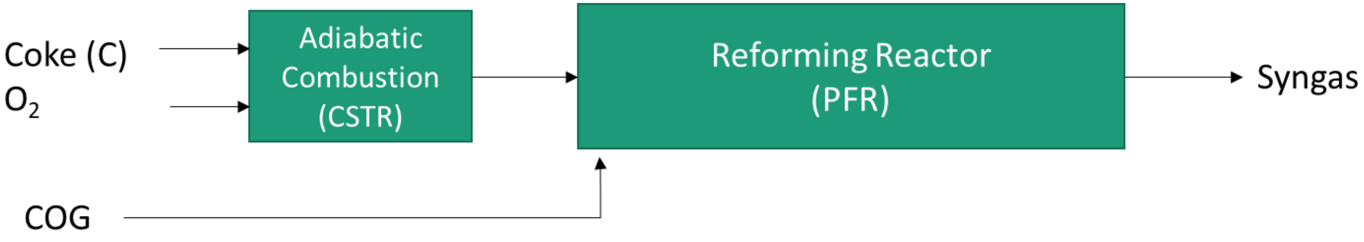
1. T profile along burner axis.
2. Polluttants.
3. Cooling system (furnace T control).

RINA-CSM activities

Reforming model and CFD simulation

<u>Kinetic model set-up</u>

1. A preliminary model (CSTR+PFR) has been developed during past activities, and it will be upgraded.
2. The model will be employed to analyze the influence of the reforming process parameters on the syngas characteristics.
3. Analysis will focus on the influence of process conditions, on syngas flowrate, temperature and composition as well as soot production.

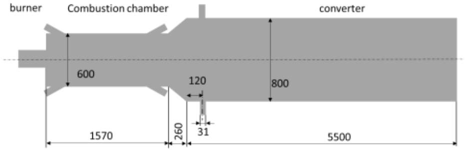


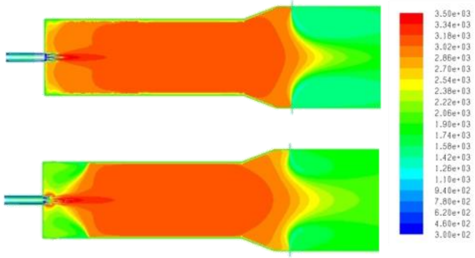
RINA-CSM activities

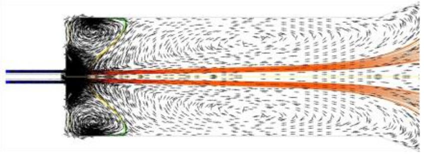
Reforming model and CFD simulation

<u>CFD simulation and model parameters fine tuning</u>

1. The aim of CFD activity is to supply information on the reactor geometry, gas injection system, in order to achieve the target characteristics of syngas.
2. Simulation will reproduce the test facilities and same experimental condition, to be compared with the industrial experimentation.





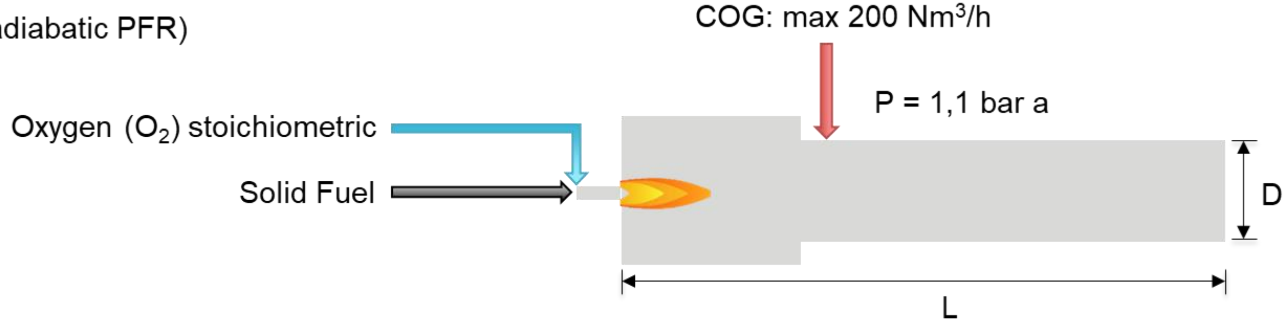


RINA-CSM activities

Reforming model

Model description

Simulation:
Flame (CSTR) + Reformer (1D adiabatic PFR)



Flame evaluation: termodynamic equilibrium, semiempirical data
Reformer evaluation: kinetic calculation, geometrical data
Kinetic scheme: Polimi 50

Constraints:

- ✓ $CH_4 < 5\%$
- ✓ $H_2O < 7\%$
- ✓ T < 1100-1300 °C
- ✓ $\frac{CO+H_2}{CO_2+H_2O} > 7$
- ✓ Soot: as low as possible

RINA-CSM activities

Reforming model

Materials

COG from updated analysis

COG Nov-2023	
Specie	% vol
CH_4	22.61
C_2H_6	0.81
C_2H_4	1.67
C_6H_6	1.23
O_2	0.42
H_2	45.61
H_2O	1.60
CO	4.77
CO_2	2.46
N_2	18.81

Current Coke Breeze Analysys

			m.s.r.
Moisture:	%	1,1	ISO-579
Chemical analysis (on dry basis)			
Volatiles:	%	0,63	ISO-562
Ash:	%	11,81	ISO-1171
Fixed carbon	%	87,56	ASTM-D3172-73
Sulphur:	%	0,72	ISO-351
Gross calorific value	Kcal/Kg	7048,6	
Full Ash Chemistry			ASTM D-4326
SiO2	%	47,71	
Al2O3	%	24,76	
Fe2O3	%	6,72	
TiO2	%	1,23	
CaO	%	6,51	
MgO	%	3,04	
Na2O	%	0,58	
K2O	%	1,91	
P2O5	%	0,17	

Size					m.s.r.
					ISO
+3	mm.	....	%	0,4	728
2/3	mm.	....	%	0,4	
1/2	mm.	....	%	1,1	
0,5/1	mm.	....	%	3,2	
0,2/0,5	mm.	....	%	20,6	
-0,2	mm.	....	%	74,3	

RINA-CSM activities

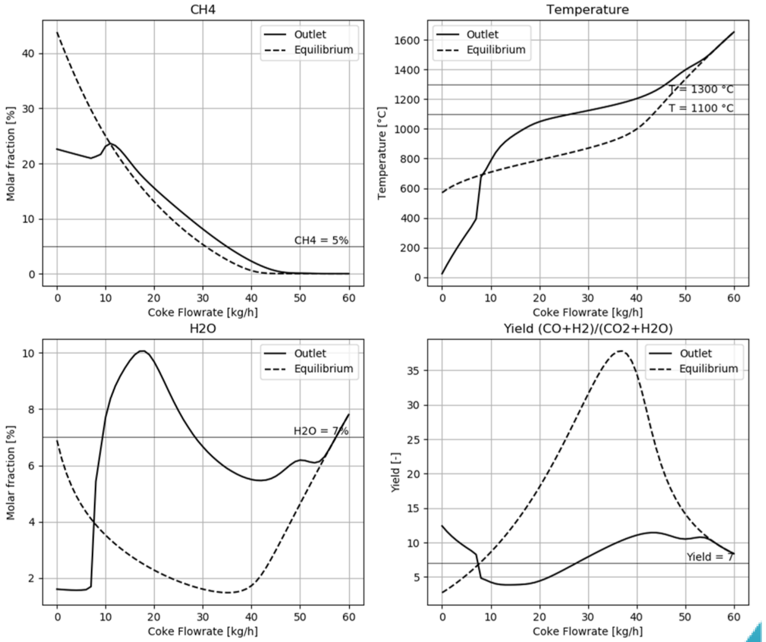
Reforming model

First Run

- Fuel: coke breeze
- O_2: stoichiometric
- COG: 200 Nm^3/h

COG Nov-2023				
Fcoke (kg/h)	CH4 (% vol)	H2O (% vol)	Tout (°C)	Yield (-)
30	8.10	6.66	1123	7.92
31	7.43	6.48	1130	8.29
32	6.76	6.31	1136	8.65
33	6.12	6.16	1144	9.01
34	5.50	6.02	1151	9.36
35	4.89	5.89	1158	9.69
36	4.32	5.79	1166	10.01
37	3.76	5.69	1175	10.31
38	3.23	5.61	1183	10.59
39	2.73	5.55	1193	10.84
40	2.26	5.50	1204	11.06
41	1.82	5.47	1215	11.24
42	1.43	5.46	1228	11.37
43	1.07	5.48	1242	11.44
44	0.76	5.53	1259	11.43
45	0.52	5.61	1278	11.34
46	0.33	5.73	1300	11.18
47	0.21	5.87	1324	10.96
48	0.14	6.02	1349	10.74
49	0.11	6.14	1374	10.57
50	0.09	6.19	1397	10.51

Figure of Merits



RINA-CSM activities

Reforming model

First Run

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✓ T < 1100-1300 °C
✓ $\frac{CO+H_2}{CO_2+H_2O} > 7$
✓ Soot: as low as possible

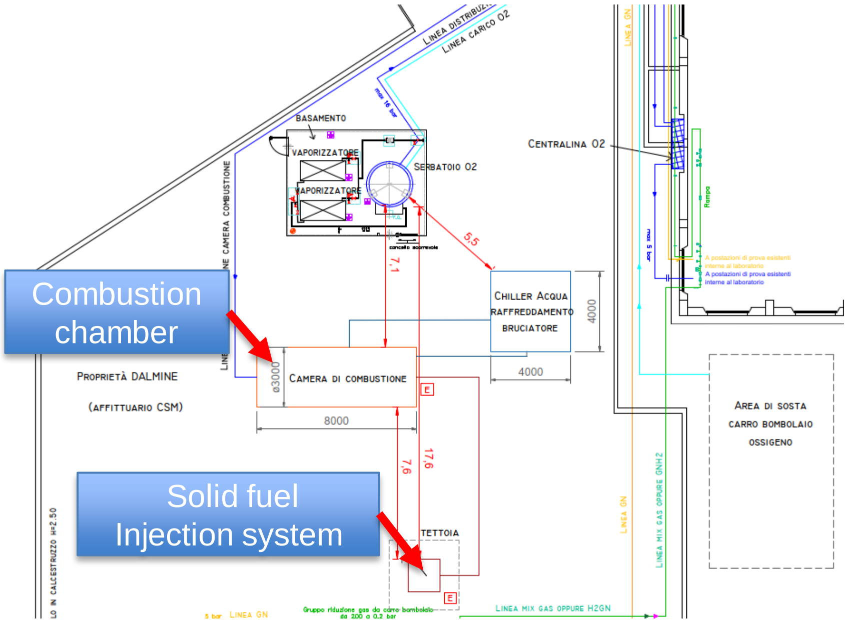
Results

- Feasible flowrate: between 34 and 47 kg/h
- Lower limits due to methane fraction
- Upper limit due to temperature
- Reforming reactions don't take place with low coke flowrate

RINA-CSM activities

Site preparation for experimental trials

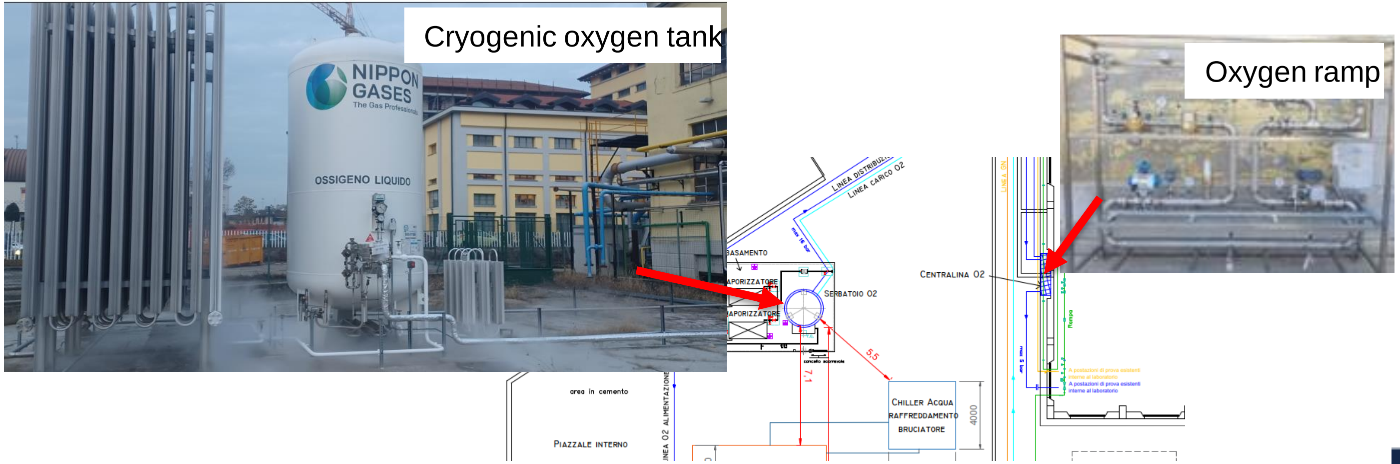
- Layout design for the new facilities needed (combustion chamber, coke breeze injection system, chiller, storage area).
- Authorization process (local firefighters department approval).



RINA-CSM activities

Site preparation for experimental trials

The system allows for regulating the flow of O2 based on the required quantity for combustion.

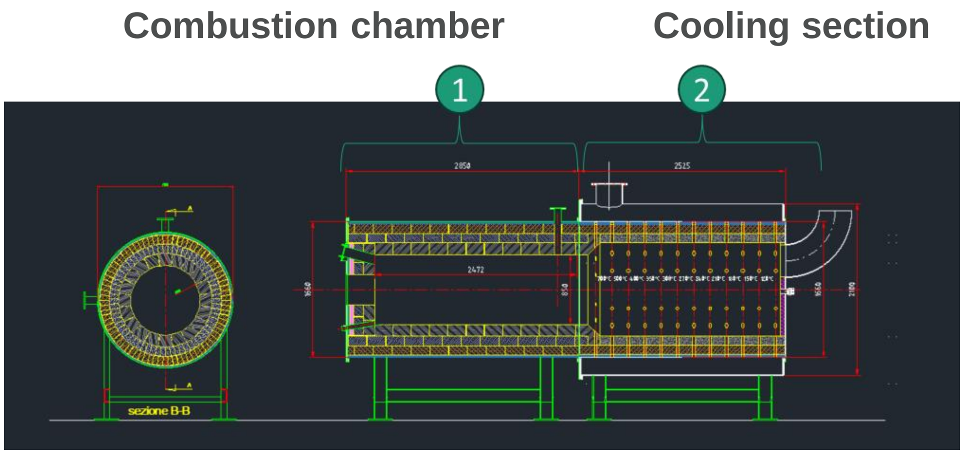


RINA-CSM activities

Combustion chamber design

Some characteristics of the combustion chamber.

- Thermal potential: 1000 kWt
- Internal diameter: 1000 mm
- Internal length: 3500 mm
- Flue gas outlet T: 1600 °C



The system will be equipped with:

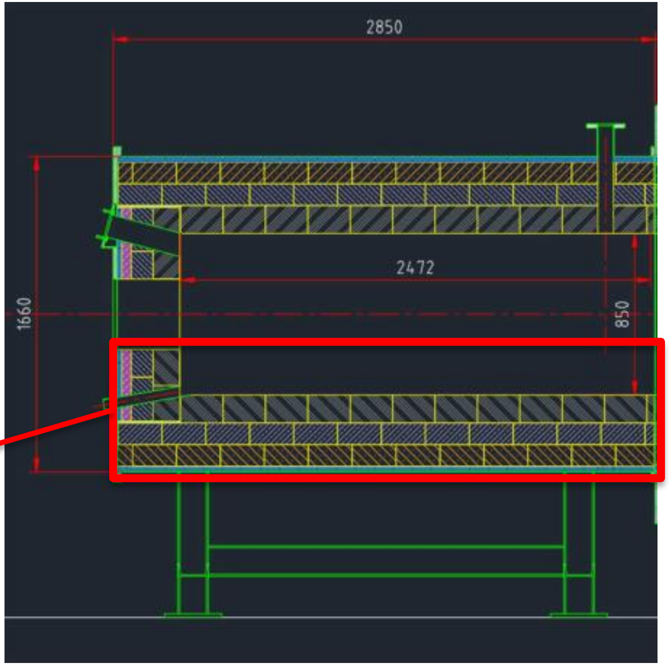
an auxiliary heating system, fuel and oxygen flow rate monitoring, temperature measurement by thermocouple and video recorder monitoring system.

RINA-CSM activities

Combustion chamber design

Main objective is to develop the flame fully and freely up to the maximum power condition to completely characterize the flame length and width up to maximum power.

	Type of material:	Thk [mm]	l [W/mk]
A	***Ultra cast HP***	150	1,560
B	***Brick ASTM 30***	115	0,650
C	***Brick ASTM 28***	115	0,320
D	***Microporous***	25	0,035
	Total thk.	**405**	



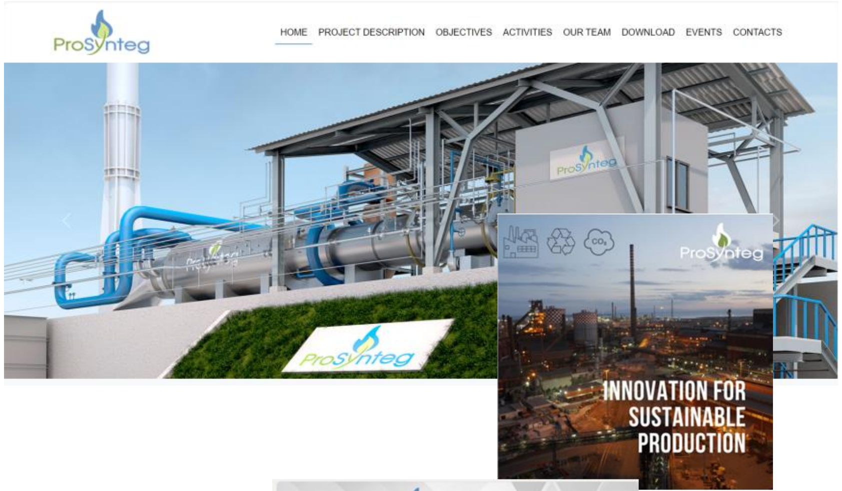
Refractory materials differ in density, compressive strength, and silica content.

Dissemination activities

Website and LinkedIn page

https://www.prosynteg.eu/

https://www.linkedin.com/company/prosynteg-rfcs-project/



Events

Conclusions

- Reforming model has been setup.
- The combustion chamber detailed design has been completed.
- Authorization process has been started.

Next activities

- CFD simulation will be performed after obtaining the burner data.
- Experimental trials to characterize the coke breeze burner (1 MW) provided by PW.
- Experimental trial results will be used to validate the CFD model.

Acknowledgments

This work was carried out with support from the **European Union's Research Fund for Coal and Steel** (RFCS) research program under the ongoing project: *Production of hot hydrogen-rich syngas in integrated plants for efficient injection in the blast furnace and CO2 mitigation – ProSynteg* - GA number: 101057965.

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