ESTEP SPRING DISSEMINATION EVENT

17-18 FEBRUARY 2026 - BRUSSELS (BELGIUM)

HYDRA project: an open experimental platform paving the way for DR-EAF route hydrogen-based for carbon neutral steel production

Update on project results

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Introduction

The steel industry is at a critical point, where the need for sustainability intersects with the demand for innovation.

Hydrogen as reducing agent and energy vector contributes to mitigate CO2 emissions and also environmental impacts in primary and downstream stages, offering a compelling path toward sustainable steel production.

In this scenario, HYDRA, a six-year project launched by RINA-CSM and supported by the European Commission, aims to make a mark. It focuses not only on the technical development of hydrogen-based steel production but also on addressing the critical infrastructure requirements for hydrogen production, transport, and distribution. This holistic approach ensures that hydrogen can be scaled up effectively, driving long-term sustainability in steel manufacturing.

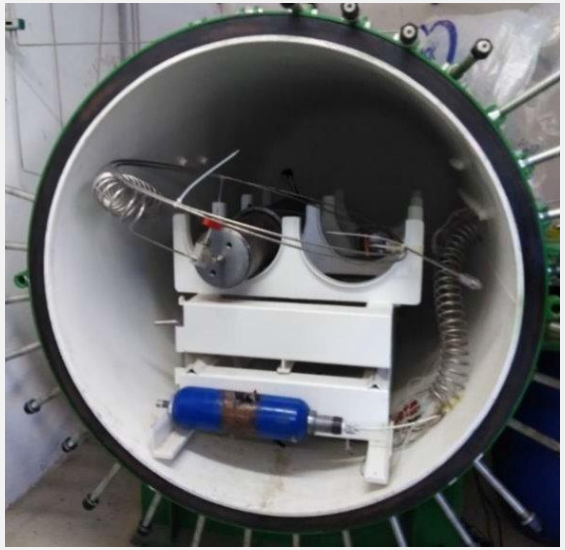
The pilot plants, that are the core of the project, will serve as a real-world demonstration of this transformative breakthrough technology.

The installation of EAF has been completed and the first heat carried out. The DRP installation is at final step commissioning will start end of February/March.

Project description

WP1 (***Development of green hydrogen use in iron and steelmaking'***) **is aimed to:**

- to define the guidelines and procedure for a safe and reliable use of H_2 within the industrial steelmaking plants
- to give confidence to the steelmakers about the feasibility of introducing H_2 in the industrial steelmaking process
- to evaluate the impact of H_2 percentage in a CH_4/H_2 blended mixture on the industrial steelmaking plant (targeting 100% H_2)
- to make deeper knowledge and to upgrade the standards and regulation framework for the design and realization of dedicated hydrogen components in the steel making plant, with the HSE related issues.
- To provide training support (training HUB)



Project description

WP2 is focused on the **Direct Reduction process** in a pilot plant.

The pilot plant has been designed to investigate phenomena governing the Direct Reduction process, simulating in a reliable scale what occurrs in industrial plants

DRP tower of about 30 m height

100 kg/h DRI produced (about 2 t per day)

Gas input by wagon tank (slot for four wagon tanks foreseen)

Gas treament line equipped with CO_2 capture

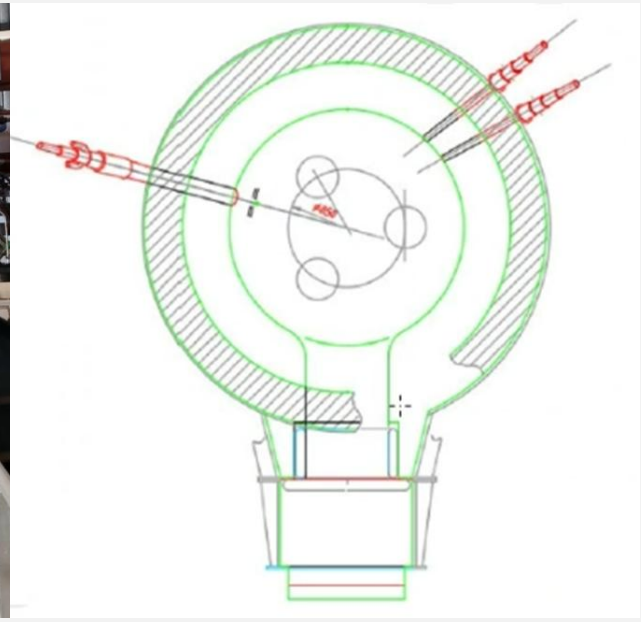
NG injection in the lower part of the furnace

Project description

WP3 is focused on the DRI melting will be investigate with a state- of-the-art electrical furnace pilot plant, of capacity of 7 t/heat.

Main characteristics of the furnace are:

- 7 t capacity, with 4 m^3 internal volume
- AC three electrodes
- Scrap and DRI charge
- Continuous charging of DRI
- Injection of solid materials (additive, coal, alternative carbonaceous materials)
- KT lance working as Hydrogen burner or Oxygen injector
- Furnace shell refractory insulated



Project description

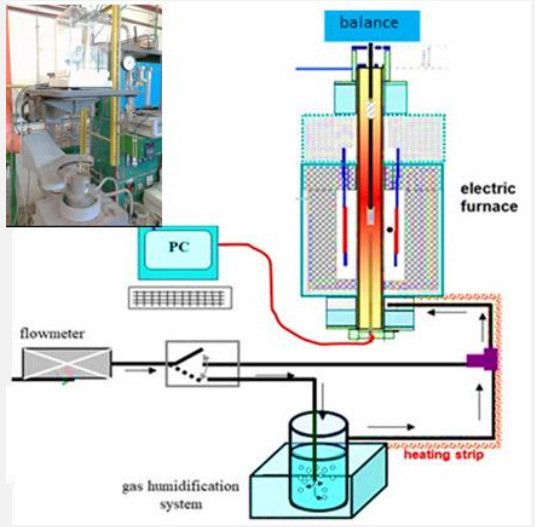
WP4 is focused on the use of hydrogen in furnaces for re-heating and treatment of the steel

This stream of activities uses the already existing facilities (experimental combustion station in Dalmine and high temperature labs in Rome

The aim of WP4 is to support the diffusion of the technology and investigating the effect of H_2 combustion both on the products quality and performance/life of the plant components

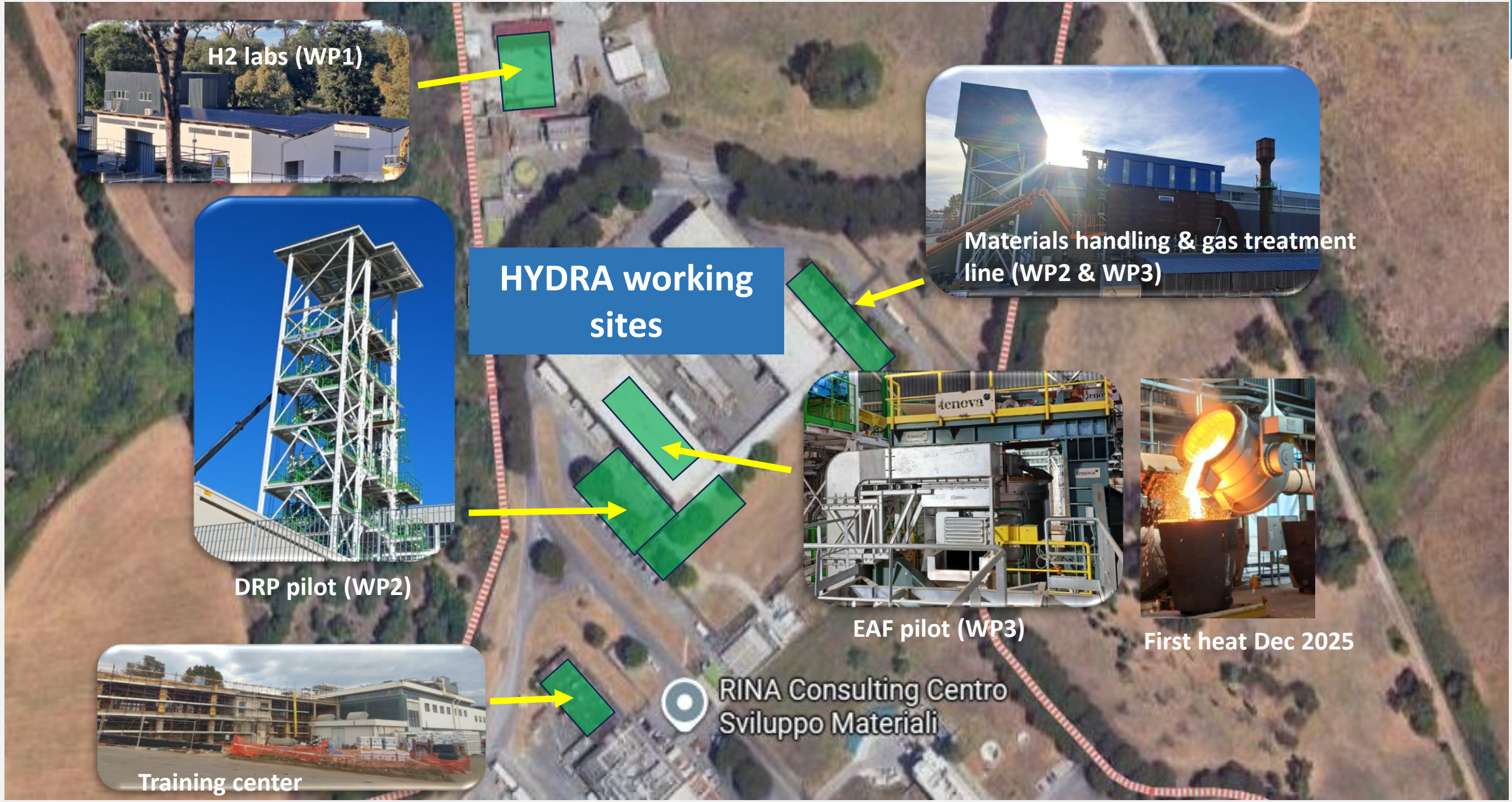

Combustion station


Horizontal furnace for annealing simulation



TGA to simulate steel oxidation

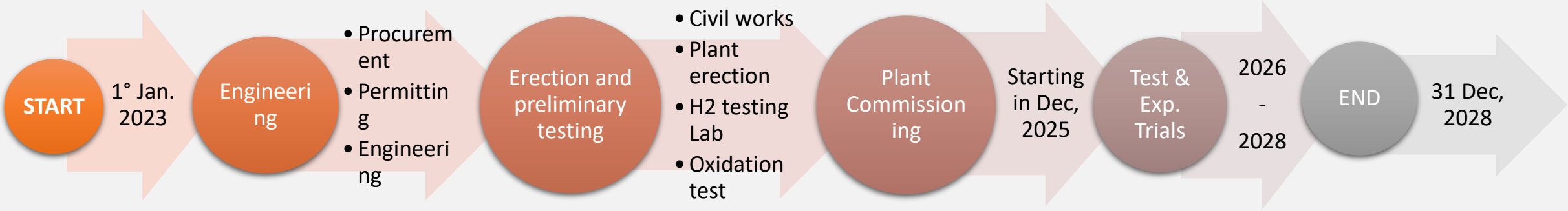
Project description



HYDRA – Project timing

Project officially started on the 1° January 2023 and will last six years

- All the facilities will be completed between end of 2025 and beginning 2026
- The first heat with pilot EAF carried out in December 2025
- Commissioning of DRP will start in March 2026
- Full operativity of the whole experimental platform June 2026
- Kinetic and combustion studies carried out
- Model improvement (DRP and EAF) ongoing



First results

- Kinetic studies of pellets reduction
- Impact of hydrogen combustion atmosphere on steel oxidation, descaling and annealing
- Hydrogen utilization in downstream: compatibility and limits of existing plant configurations, burner testing and scenario analysis
- Cooperation with Universities: Graduate and PhD thesis ongoing (two graduate thesis completed, one ongoing)
- Engagement with other EU projects to enable cross-project synergies and spillover effects
- Interaction with industrial partners

Kinetic of reduction of iron ore pellets

- Tests with two different grades
- Temperatures tested: 800°C and 1000°C
- Three hydrogen flow rates (velocity) tested: 50 Nl/h, 120 Nl/h, 200 Nl/h
- Three gas atmospheres tested: pure H_2, pure CO, H_2/CO in a ratio 3/1 (simulating CH_4 steam reforming)
- Chemical compostion and iron speciation measured before and after tests
- SEM analysis to investigate sample morphology and porosity evolution

Kinetic of reduction of iron ore pellets

Materials

Low Grade Pellets (LG)

Chemical Component	(%)
P_2O_5	<0.05
SiO_2	4.97
Al_2O_3	0.64
CaO	0.77
MnO	0.08
MgO	1.04
Na_2O	0.4
K_2O	0.06

Chemical Component	
Fe_{tot}	64.3
Fe_{met}	<0.5
Fe^{+2}	<0.5
Fe^{+3}	~63.0

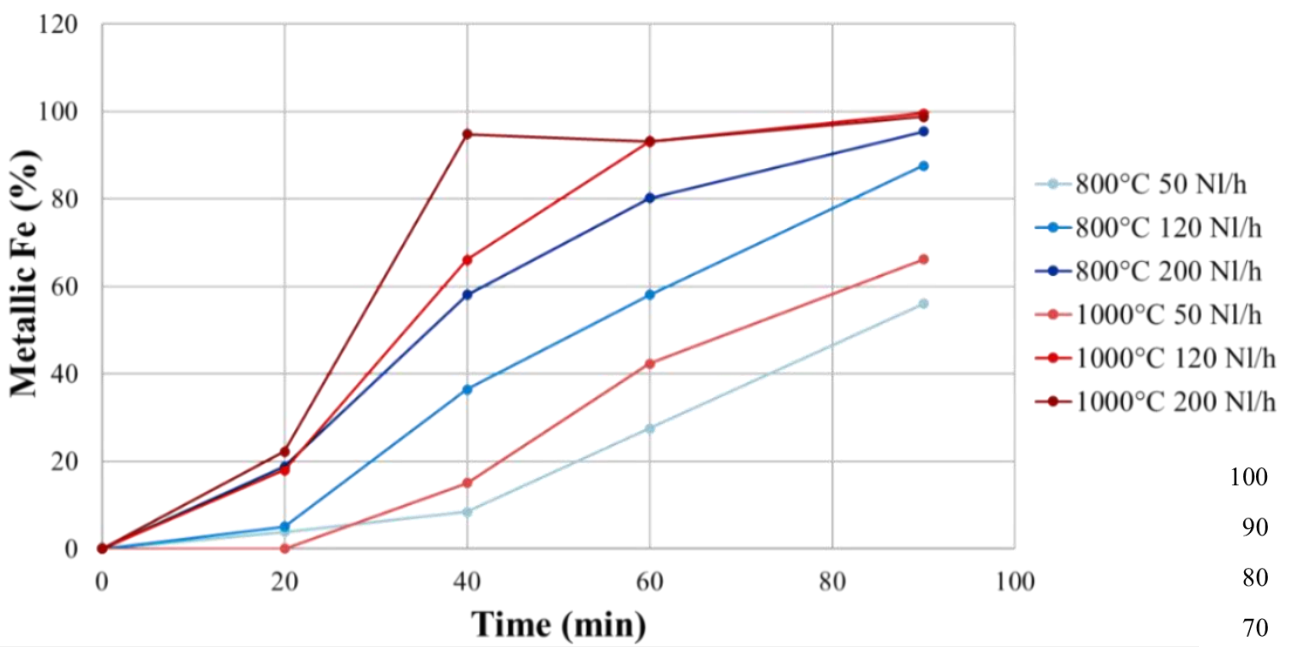
High Grade Pellets (HG)

Chemical Component	(%)
P_2O_5	0.15
SiO_2	1.71
Al_2O_3	0.5
CaO	1.14
MnO	0.1
MgO	0.42
Na_2O	<0.1
TiO_2	0.05

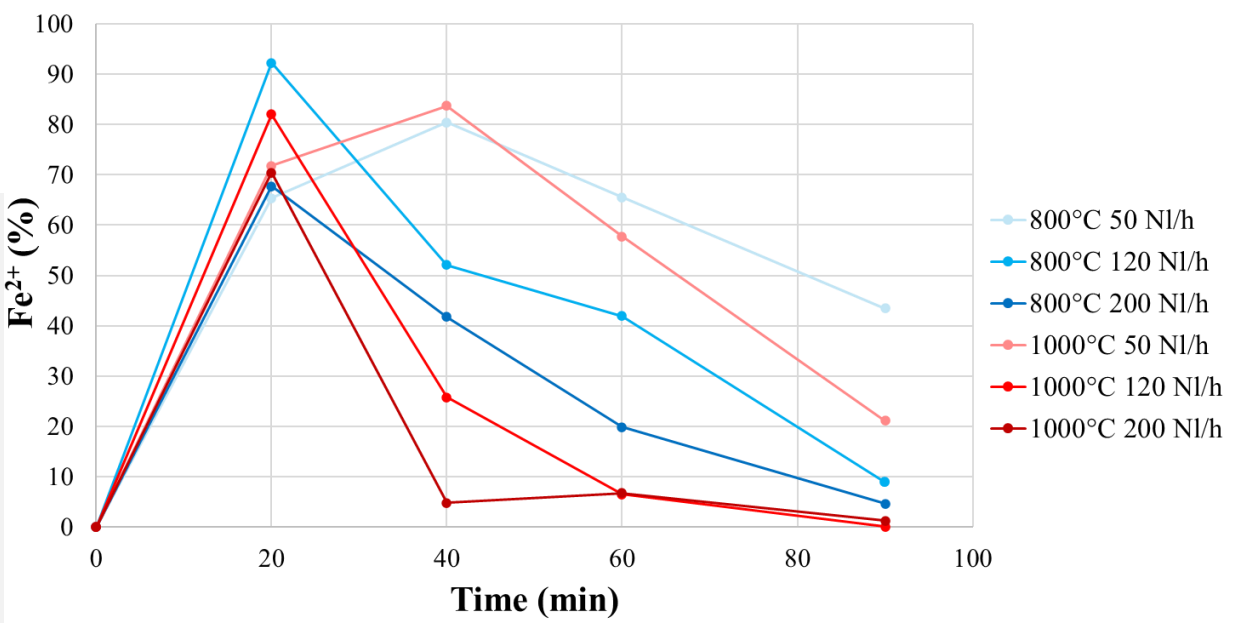
Chemical Component	
Fe_{tot}	67.0
Fe_{met}	-
Fe^{+2}	0.1
Fe^{+3}	66.9

Kinetic of reduction of iron ore pellets

- Low grade vs high grade (tests in pure H2)



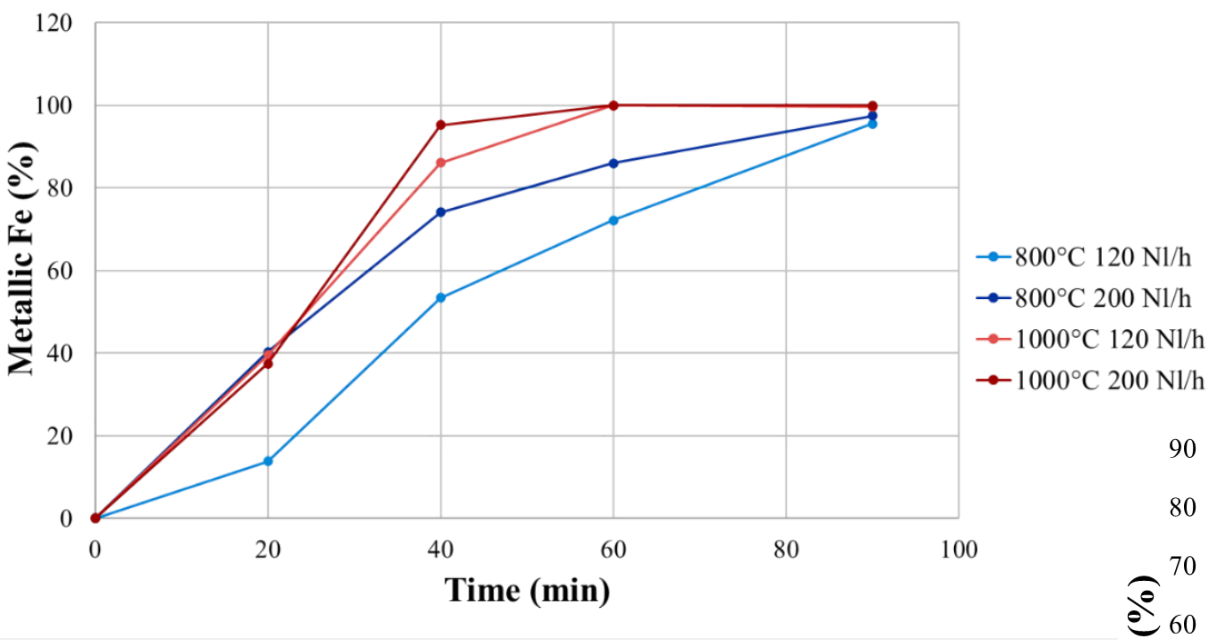
- Evolution of Fe and Fe^{2+} as a function of time for low grade pellets



- Significant effect of temperature and gas velocity

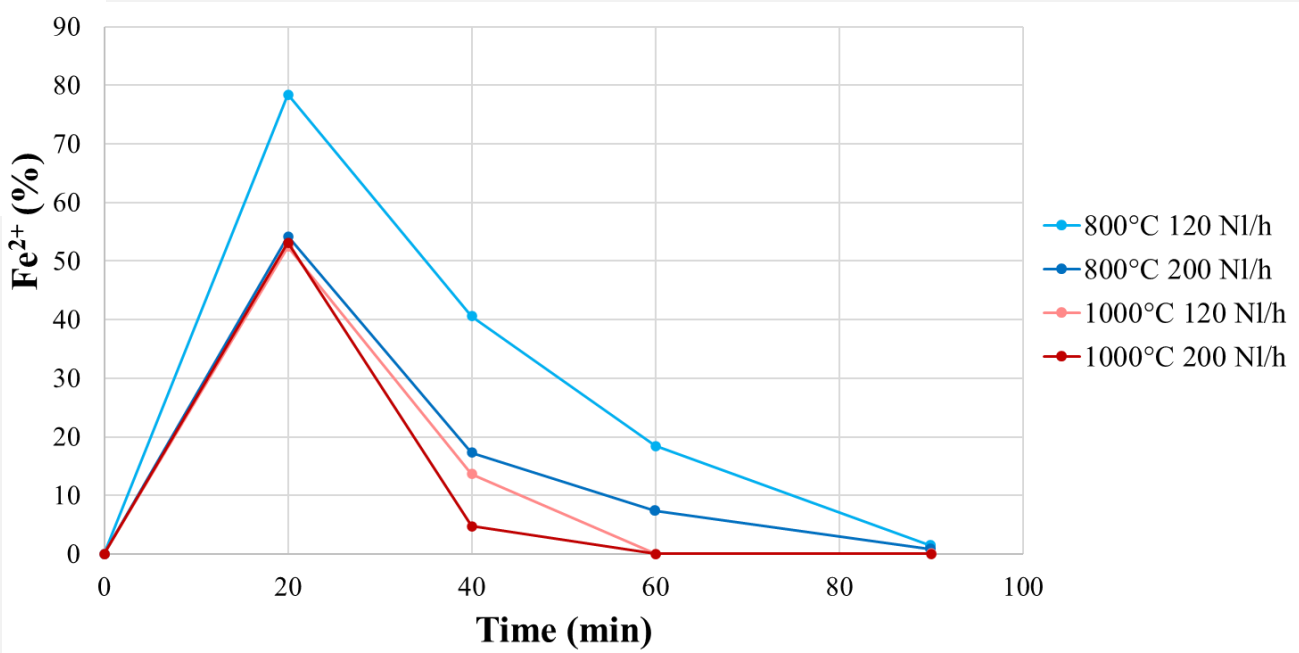
Kinetic of reduction of iron ore pellets

- Low grade vs high grade (tests in pure H2)



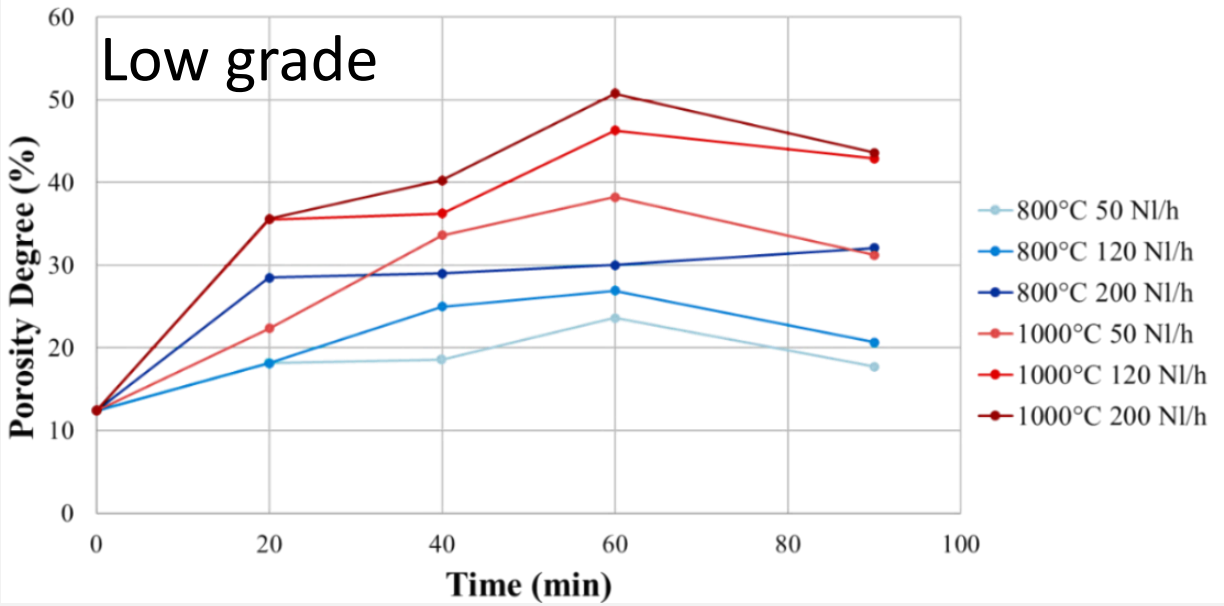
- Confirmed the effect of temperature and gas velocity
- Smaller dispersion of data respect low grade pellets

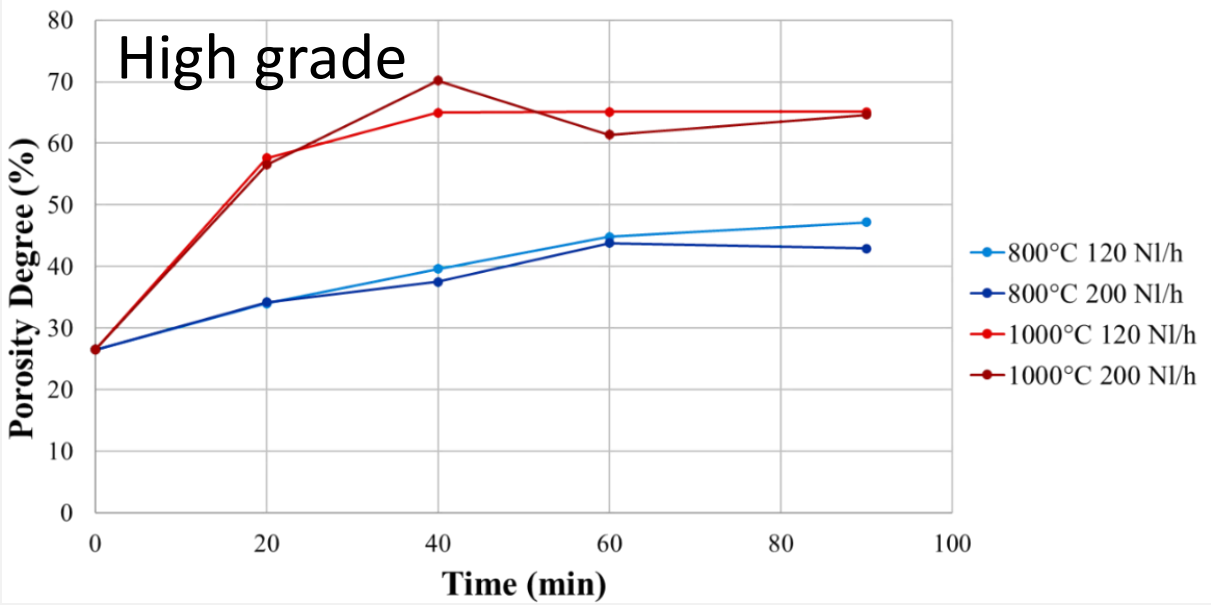
- Evolution of Fe and Fe^{2+} as a function of time for high grade pellets



Kinetic of reduction of iron ore pellets

- Low grade vs high grade (tests in pure H2): evolution of porosity





Porosity increases due to loss of oxygen. This is beneficial for the progression of the reduction reaction since it ensures an increase in the specific surface area

HG pellets showed higher average porosity increase respect LG. This is coherent with the higher gangue content of LG pellets which intrinsically decreases the amount of reducible iron

Values obtained with image analysis. Deeper analysis with other techniques (as Micro CT) planned

Kinetic of reduction of iron ore pellets

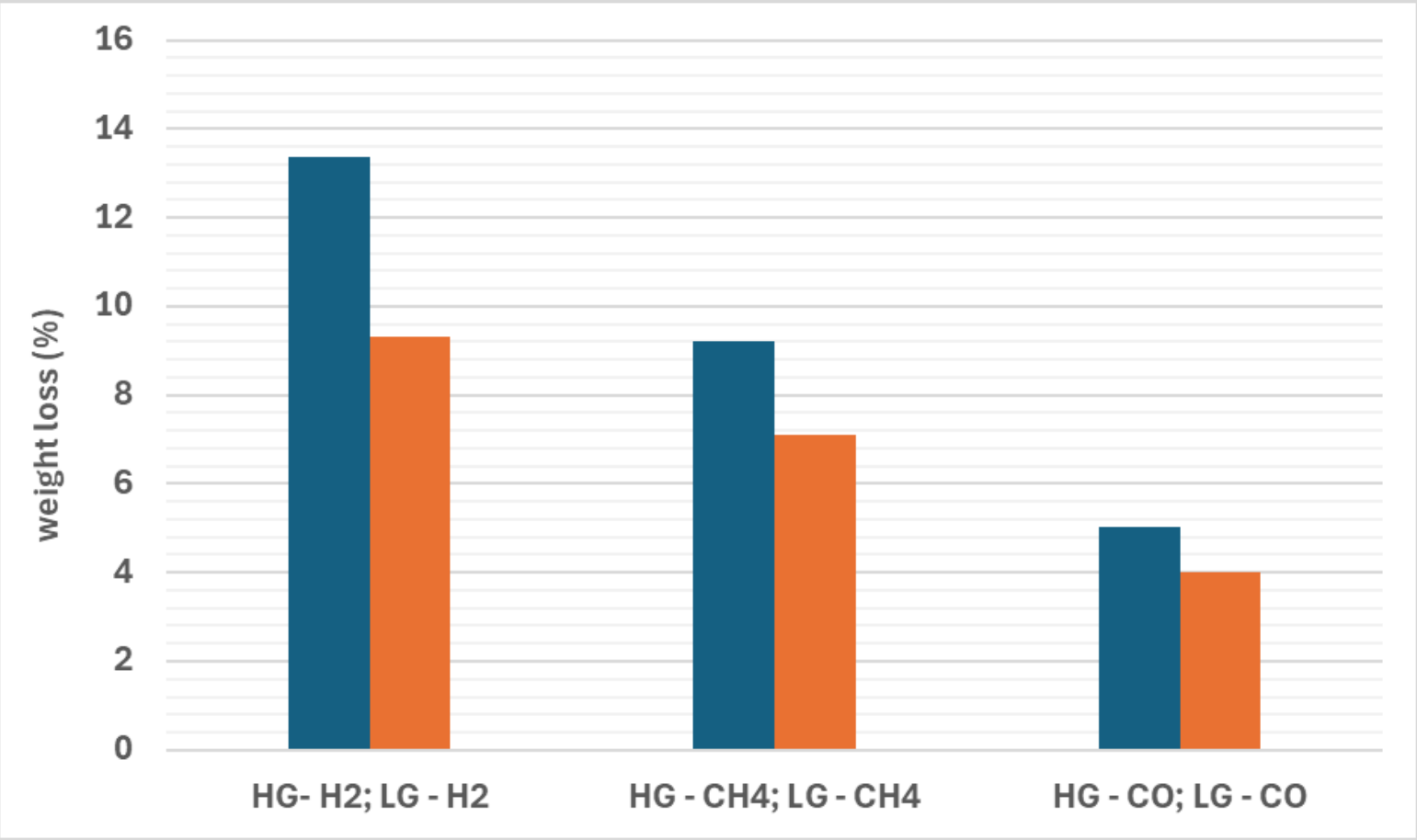
- Compare the reduction kinetic of CO vs H2
- Thre reducing species used: H_2, CO and CH_4 (simulated with H2/CO ratio 3:1)

- Sample heated at 1000°C in inert atmosphere
- After temperature stabilization switch to reducing atmosphere
- Tests duration 2 hours
- Tests repeated with low and high grades

Due to safety costrains of the lab, CO could not be used as pure gas but diluted with inert one. The same dilution applied to H2 and CO/H_2

These results have comparative value and are not directly comparable with tests carried out with pure H_2

Kinetic of reduction of iron ore pellets



Confirmed highest reaction kinetic of HG respect LG

H_2 reduction rate faster then CH_4 (H_2/CO 3:1 ratio)

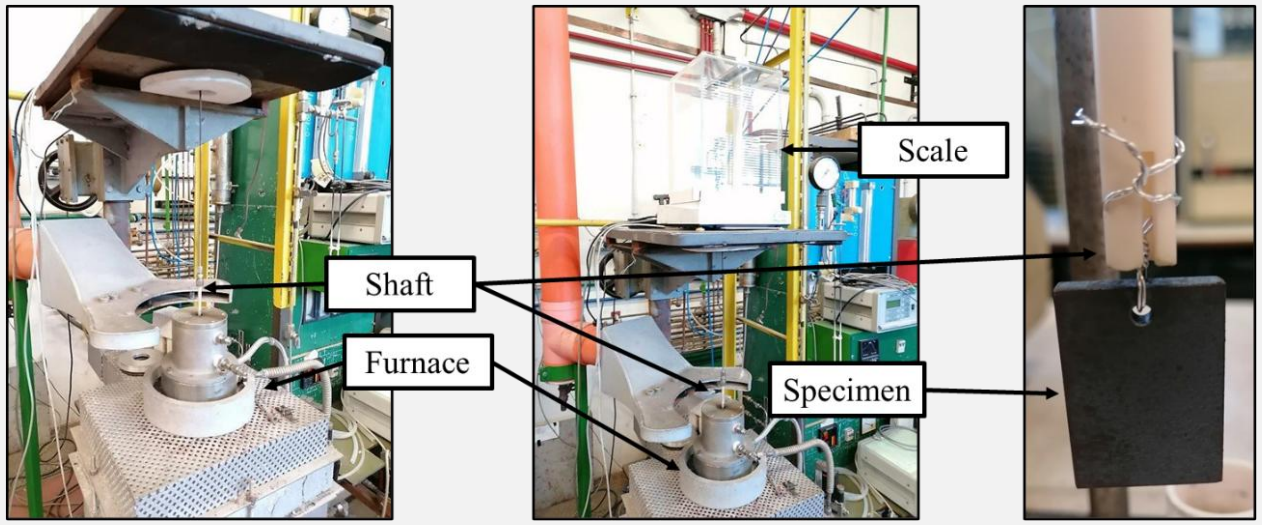
Kinetic of reduction of iron ore pellets: general conclusions

- Temperature: the optimal range is in between 800°-1200°C. High operating temperatures are necessary from a thermodynamic perspective to sustain the endothermic reaction of reduction and from the kinetic perspective to promote diffusion phenomena. At 1000°C of degree, with proper gas flow rate the best compromise seems to be obtained
- The first step of reduction from Fe^{3+} to Fe^{2+} is in general rapid and the limiting step is from Fe^{2+} to metallic Fe
- hydrogen flow: as expected, the higher the H2 flow is, the higher the reaction velocity
- Comparative tests of reducing blends of H2 versus CH4 (3H2/1CO) and CO showed a kinetic of reduction H2>CH4>CO

Steel oxidation and scale removal under hydrogen combustion atmosphere

Oxidation tests were performed on 13 different steel grades. In particular, three carbon steel grades were provided by Gruppo Pittini, four steel grades were provided by Acciaierie Venete, four steel grades were provided by Ori Martin and two stainless steel grades were provided by AST

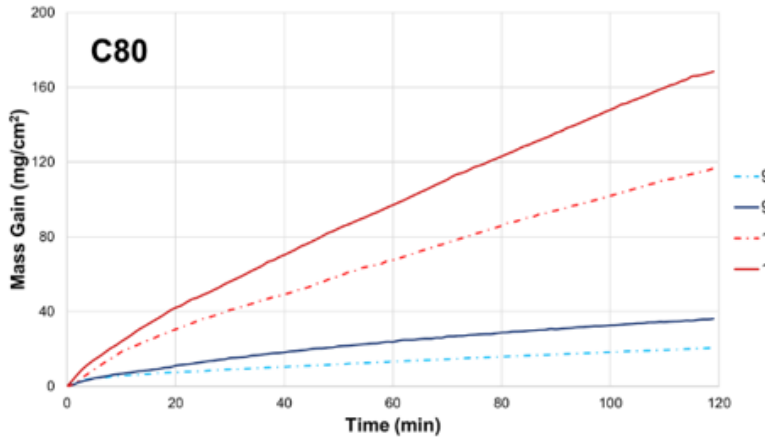
Oxidation tests were performed in isothermal conditions in lab furnace, The steel specimen was connected with an Al2O3 refractory shaft using the 3 mm hole created on its short side and a Pt wire and connected to a balance characterized by a precision of 1 mg

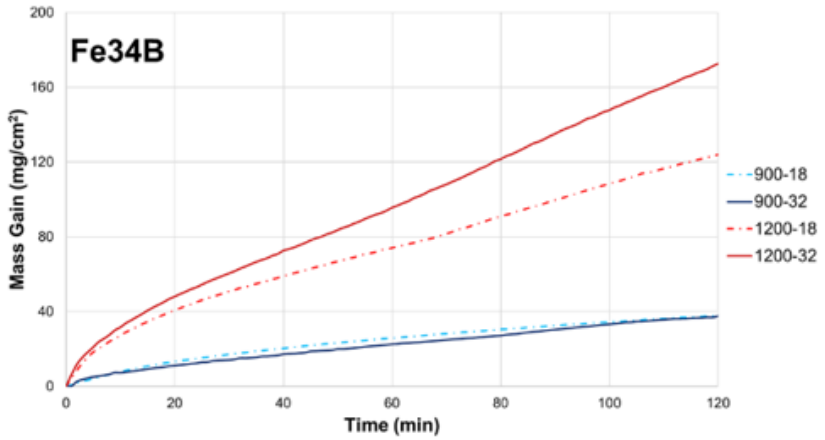


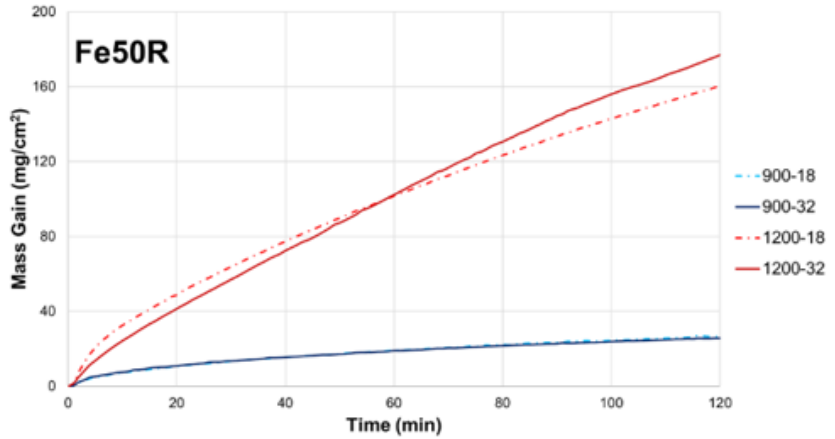
Temperature (°C)	Holding Time (h)	Atmosphere			
		N_2 (%)	CO_2 (%)	O_2 (%)	Moisture (%)
900	2	71	9	2	18
900	2	66	-	2	32
1200	2	71	9	2	18
1200	2	66	-	2	32

Steel oxidation and scale removal under hydrogen combustion atmosphere – example with carbon steels

Significant effect for carbon steels at 1200°C, while almost negiglible at 900°C



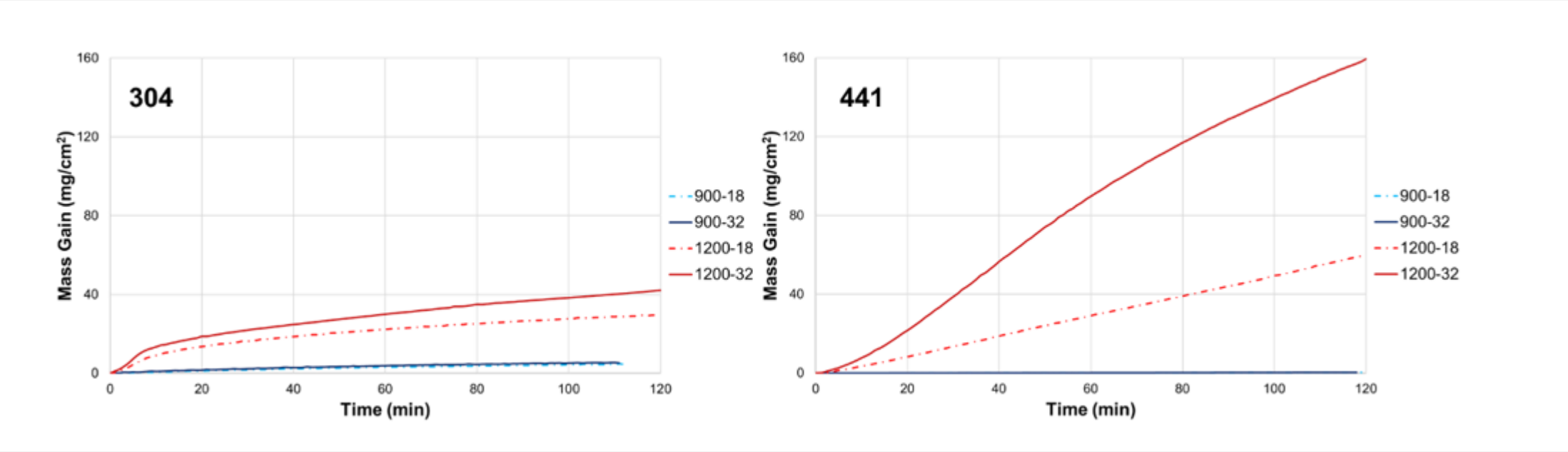




	C80	Fe34B	Fe50R
C	0.78 – 0.82	max. 0.05	0.17 – 0.19
Si	0.15 – 0.30	max. 0.10	0.10 – 0.15
Mn	0.60 – 0.80	max. 0.35	0.65 – .75
P	0.020	0.025	0.025
S	0.025	0.025	0.04
Cr	0.20	-	0.30

Steel oxidation and scale removal under hydrogen combustion atmosphere – example with austenitic and ferritic stainless steels

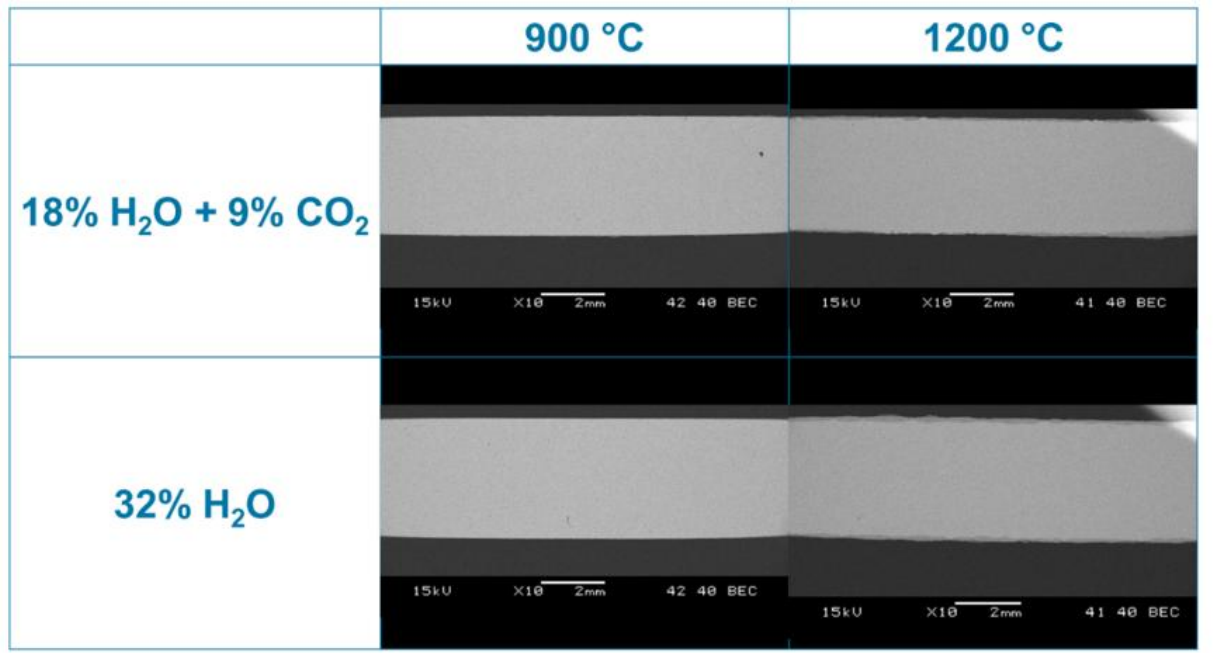
304 austenitic grade is characterized by a much higher resistance to oxidation than 441 ferritic grade especially at 1200 °C



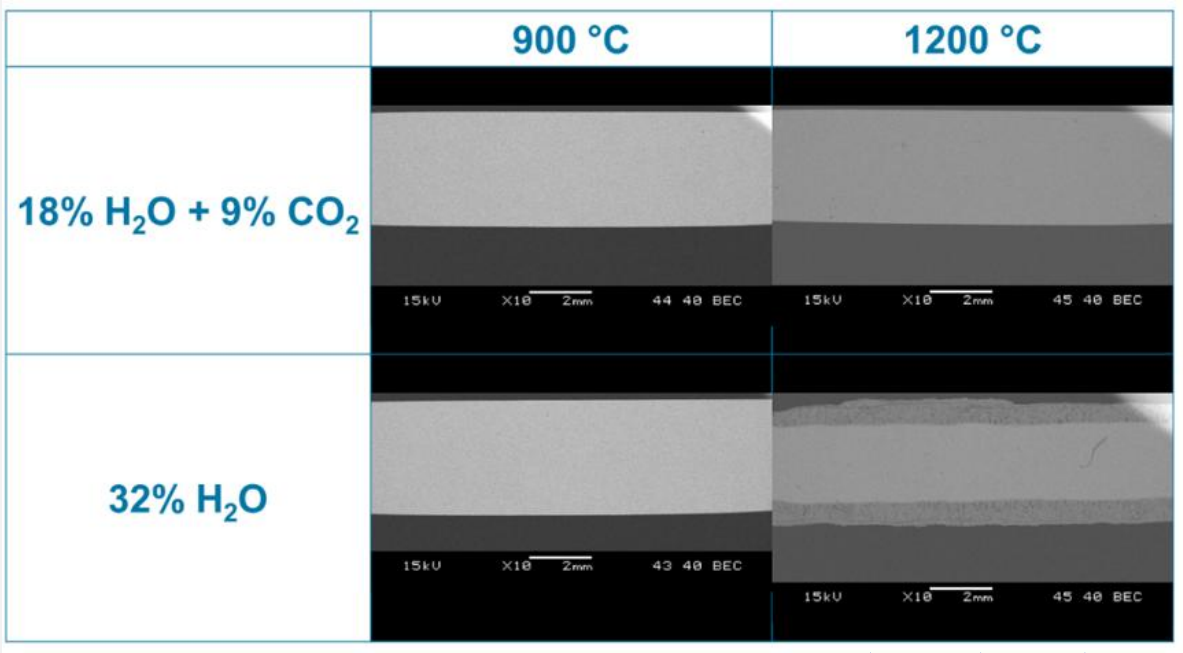
This difference is due to the austenitic nature of 304 which entails a 9.015 % of Ni in the alloy against the 0.255 % in the ferritic 441. Once the protective chromia layer becomes unstable due to the rapid volatilization the scale becomes richer in Fe and also in Ni in the case of 304 which is more noble than Fe and provides better oxidation resistance

Steel oxidation and scale removal under hydrogen combustion atmosphere

304



441



Scale growth is observed for 441 grade at 1200 °C in hydrogen atmosphere due to the combined effect of:

- high Cr mobility and diffusion resulting from the high operating temperature
- higher water vapor concentration which promote chromia volatilization and finally the low content on noble Ni

Steel oxidation and scale removal under hydrogen combustion atmosphere

Temperature has a significant influence on the oxidation behavior of all steel grades. A strong increase in oxidation phenomena and scale growth was observed for increasing temperatures regardless of the combustion atmosphere.

The oxidizing atmosphere proved to be another fundamental variable affecting steel oxidation response with the one simulating hydrogen combustion determining a greater increase in scale mass; the effect on scale kinetic growth depend on steel composition.

Si increases carbon steel oxidation resistance through the formation of silicon oxides and olivine. This effect remains active until heating temperature exceeds the melting point of iron olivine which can range from 1205 °C for pure fayalite, to higher values for iron olivine with higher forsterite content or to lower values around 1178°C (eutectic with FeO).

Higher Ni content in the steel grade proved to be beneficial for the oxidation resistance since Ni is more noble than Fe. Higher Ni amounts are also responsible for a more complex descaling of the steel.

Significant influence is exerted by Cr, with different impact in 304 and 441. This must be ascribed to chromia forming $CrO_2(OH)_2$, i.e., chromium (VI) oxyhydroxide, which is extremely volatile when high water vapor contents are present in the atmosphere.

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