La decarbonizzazione dell'industria siderurgica
Roma - La Sapienza 20 Aprile 2023

SAPIENZA
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L’idrogeno nel ciclo di produzione dell’acciaio: le sfaccettature di una complessa ma necessaria evoluzione

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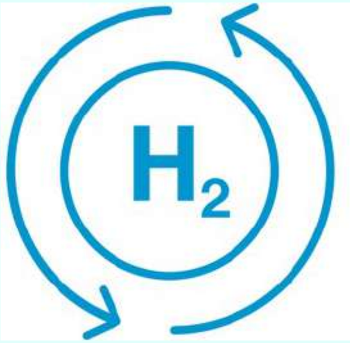
TOPICS

- H transition in steelmaking
- Evolution of iron feedstocks and effects on EAF sleelmaking
- Route to decarbonize heating operations in steelworks
- Safety

H transition in steelmaking

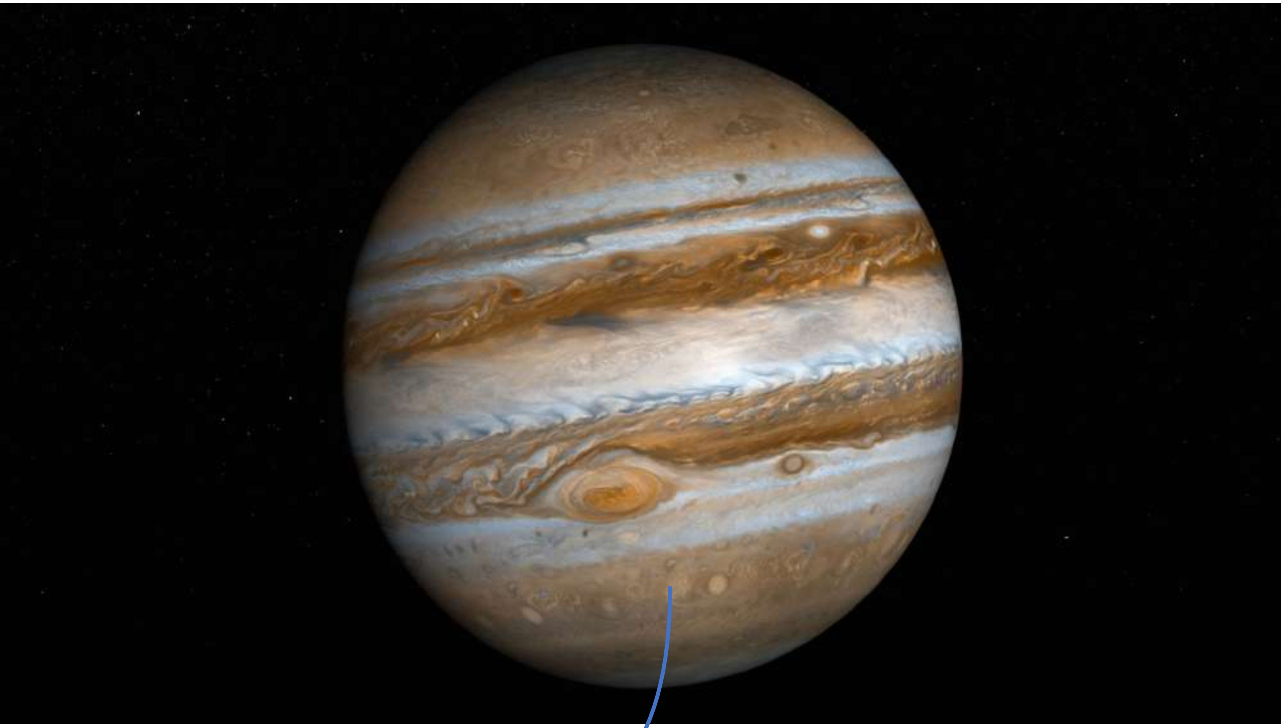
STEEL PRODUCTION accounts for **25% CO_2** emissions in European Industrial Panorama

REDUCE GREENHOUSE GAS EMISSIONS by minimum 50% and towards 55% by 2030, in a cost effective way.



HYDROGEN can be used as a fuel, an energy carrier or storage. Most importantly, it does not emit greenhouse gas and almost no air pollution when used.

Large-scale deployment of **CLEAN HYDROGEN** (produced by renewable energy sources) is key for the EU to achieve a higher climate ambition.

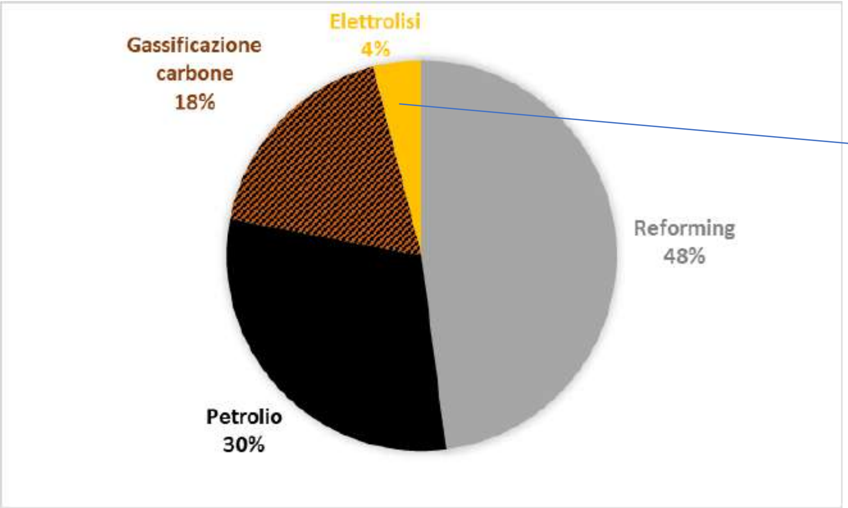


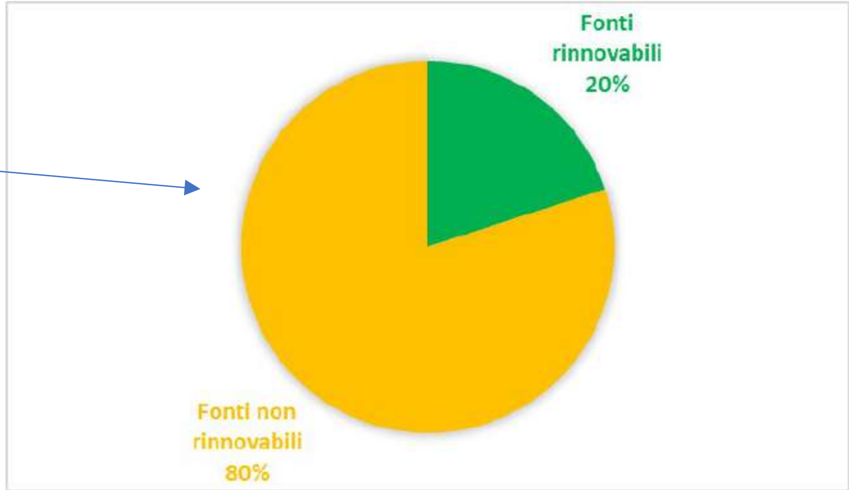
"L'eau est le grand réservoir, où la nature trouve la masse de carburant, qui se forme continuellement sous nos yeux, et la cellule et la végétation peuvent être sa grands moyens".

?

The 50 shades of hydrogen

Black: Hydrogen produced from Oil or Coal (with improved technologies some call it Brown…)
Brown: Hydrogen produced from biomass with old technologies
Gray: Hydrogen produced from methane (reforming) or from biomass with new technologies
Blue: Hydrogen produced from methane but with CO_2 sequestration
Turquoise: Hydrogen produced by the pyrolysis of methane obtaining carbon in the solid state (experimental technology)
Orange: Hydrogen produced by Nuclear Power (attention! In some classifications this is called purple or pink! And recently European Commission proposed new rules under which hydrogen produced with nuclear energy is to be considered green)
Yellow: Hydrogen produced from a mix of renewables and fossils (depends on the percentages….)
Green: Hydrogen produced by electrolysis using electricity generated from renewables





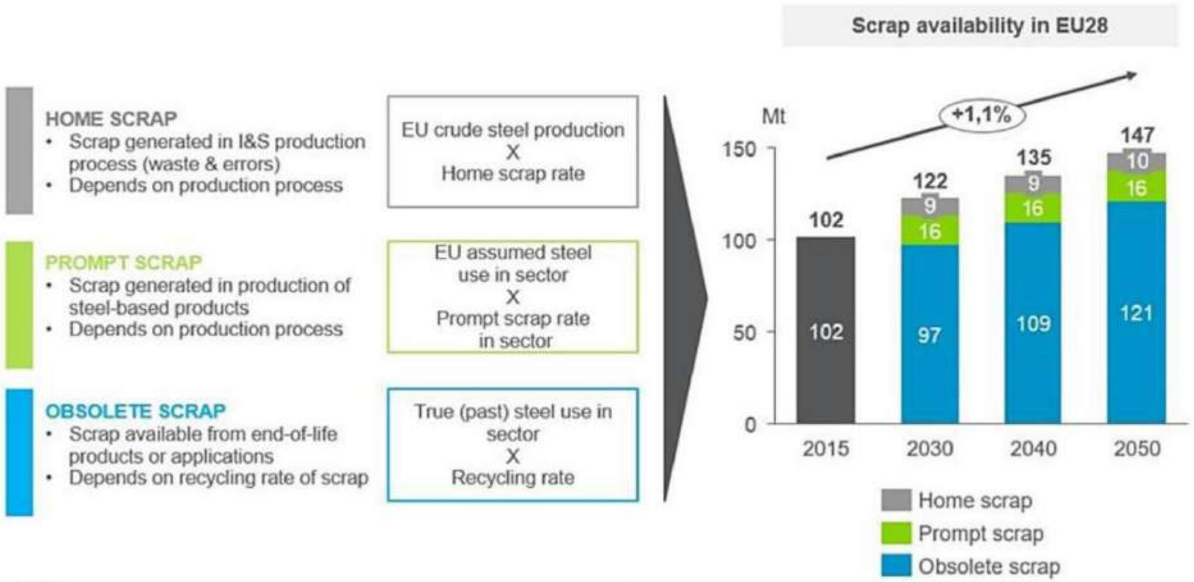
Evolution of iron feedstocks and effects on EAF sleelmaking

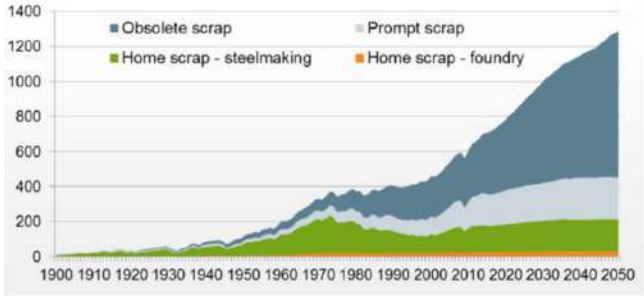
- The viability of both iron-ore (although in an improved c-lean way) and scrap production routes must be preserved, as they are both necessary to ensure the EU steel sector’s capacity of delivering high-quality steel grades using different raw materials.

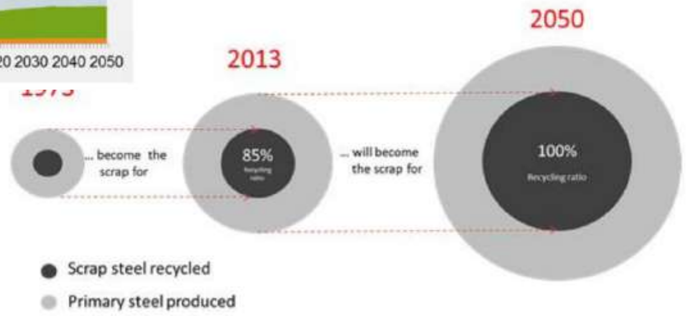
- It is necessary to consider that the availability of scrap at a certain point in time is defined by the past production and the ongoing recycling rate.

- Currently, the worldwide steel recycling rate is around 85%, since there are some low-quality scraps that are being reused

- Obsolete scrap characteristics are expected to drastically change and worse because of the increasing of the complexity and heterogeneity of available ferrous material (e.g. combination of steel with plastics and fibers, more complex joints, technical coatings, etc.) and of the repeated recycling and recycling rate.







ESTEP, Improve the EAF scrap route for a sustainable value chain in the EU Circular Economy scenario, 2021
EUROFER, "LOW CARBON ROADMAP - Pathways to a CO2-neutral European steel industry," EUROFER, 2019
ArcelorMittal, "Global corporate responsibility report 2014," 2014.
World Steel Association, "worldsteel," [Online]. Available: https://www.worldsteel.org/.
S. Hornby, et. Al., Impact of Hydrogen DRI on EAF Steelmaking, 2021, https://www.midrex.com/tech-article/impact-of-hydrogen-dri-on-eaf-steelmaking/

Evolution of iron feedstocks and effects on EAF steelmaking

Influence of different scrap elements over EAF process performance obtained through mass and thermal balances elaborated by ArcelorMittal and supported by different melting tests conducted in a 6 tm pilot EAF in France

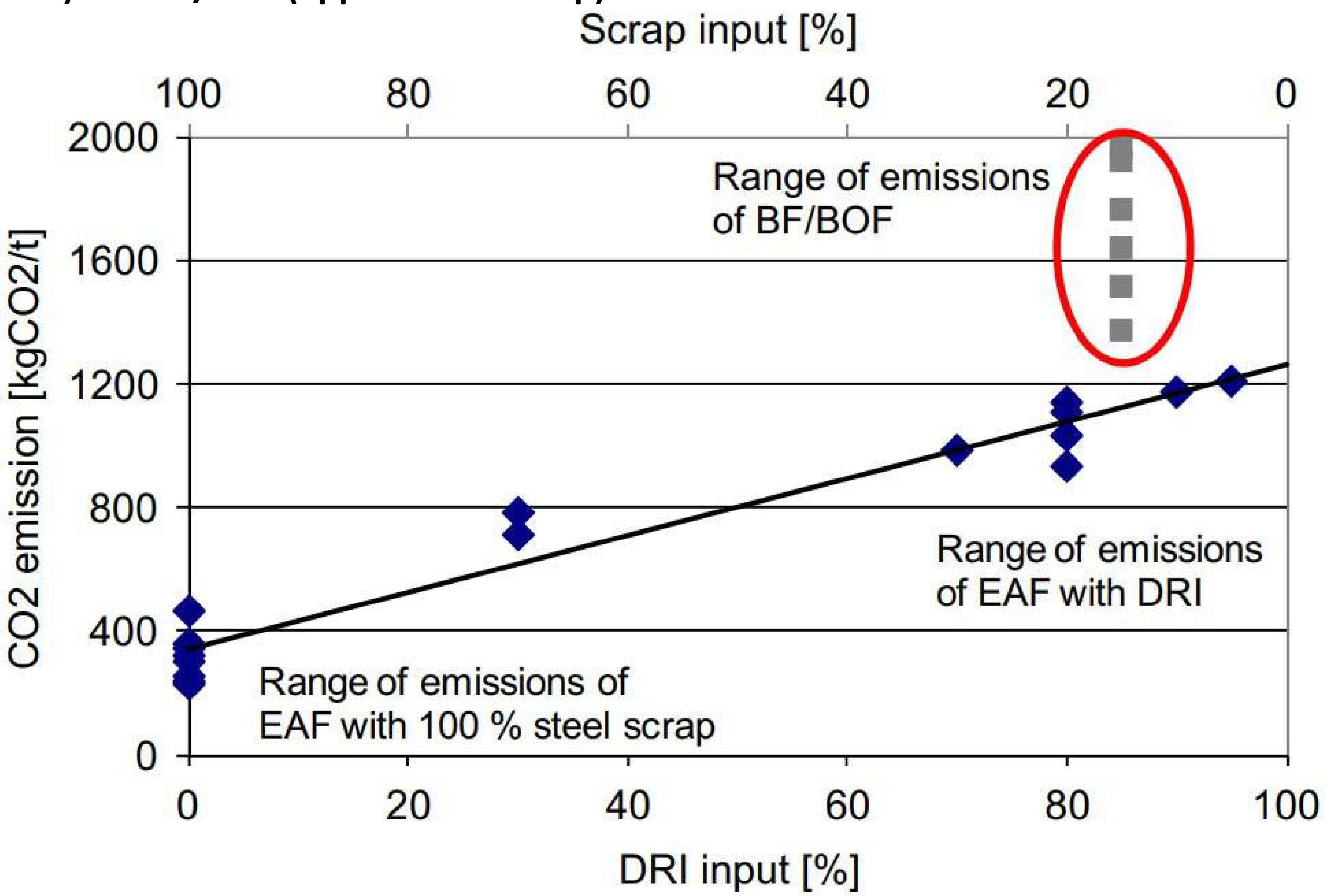
		Metallic yield	Energy (kWh/t scrap)	Carbon (kg/t scrap)	Burnt Lime (kg/t scrap)	Slag, Refr. (kg/t scrap)
% Fe + tramp elements	Scrap with 100% Fe					
% C	+1% C -1%Fe					
% Al	+1% Al -1%Fe					
% Si	+1% Si -1%Fe					
% H	+1% H -1%Fe					
% acid gangue	+1% acid qangue -1%Fe					
% basic gangue	+1% basic gangue -1%Fe					
% O on Fe	+1% O -1%Fe					
% H2O	+1% H2O -1%Fe					

- ➢ green colour represents positive influence and red colour represents negative influence on the process
- ➢ For metallic yield the partial substitution of Fe by any other element will always penalize the metallic performance → intense green colour represents low negative influence and the intense red colour represents big negative influence

A. Vicente Rojo, New methods for ferrous raw materials characterization in electric steelmaking, PhD Thesis, 2020

Evolution of iron feedstocks and effects on EAF sleelmaking

Specific CO_2 emission as function of DRI to scrap ratio for steel production routes in EAF (charged with scrap and DRI, 565 kgCO2/tDRI) and BF/BOF (approx. 15% scrap)

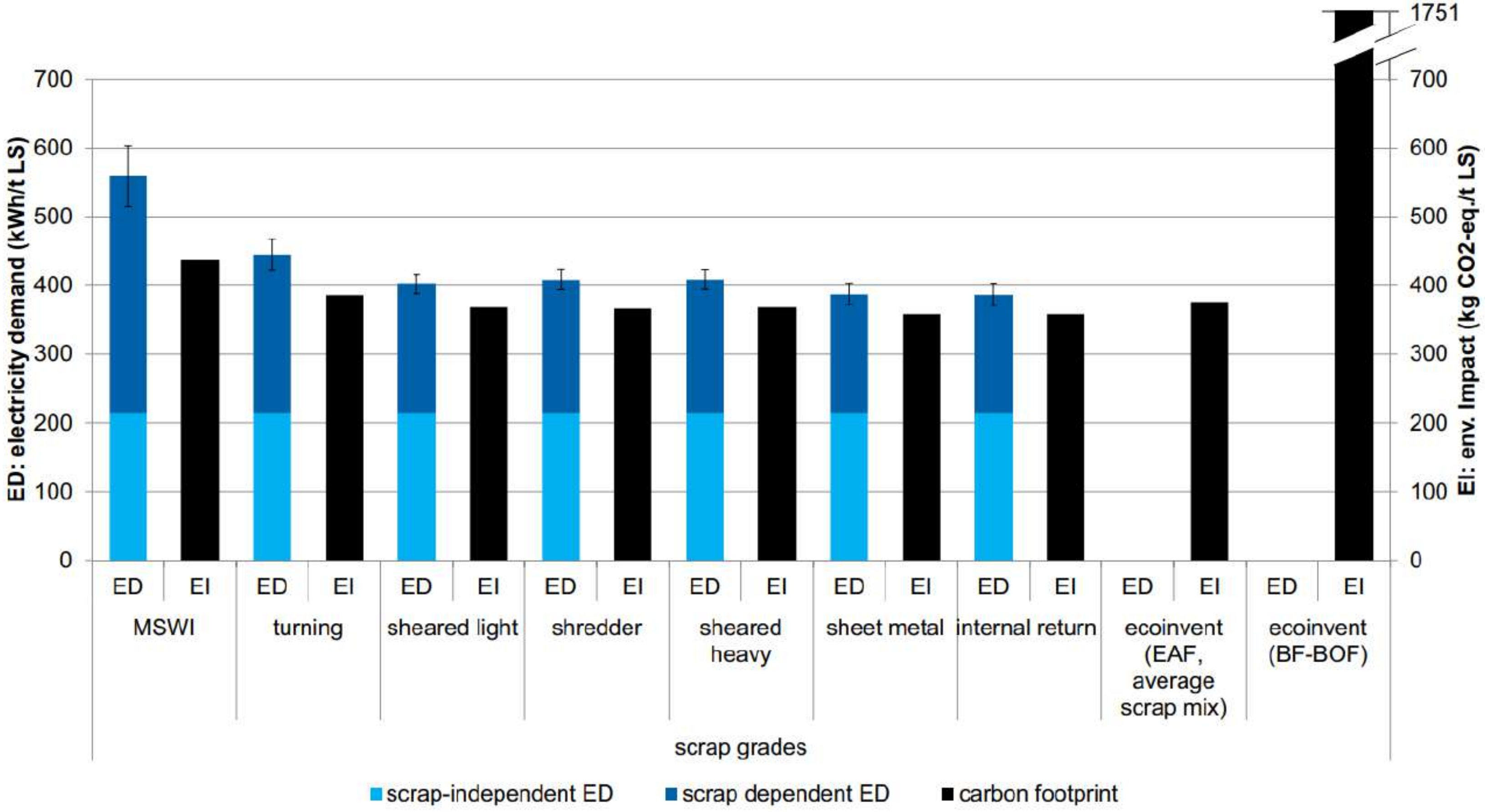


Kirschen, M., et al. (2011). Influence of direct reduced iron on the energy balance of the electric arc furnace in steel industry. *Energy*, *36*(10), 6146-6155.

Evolution of iron feedstocks and effects on EAF sleelmaking

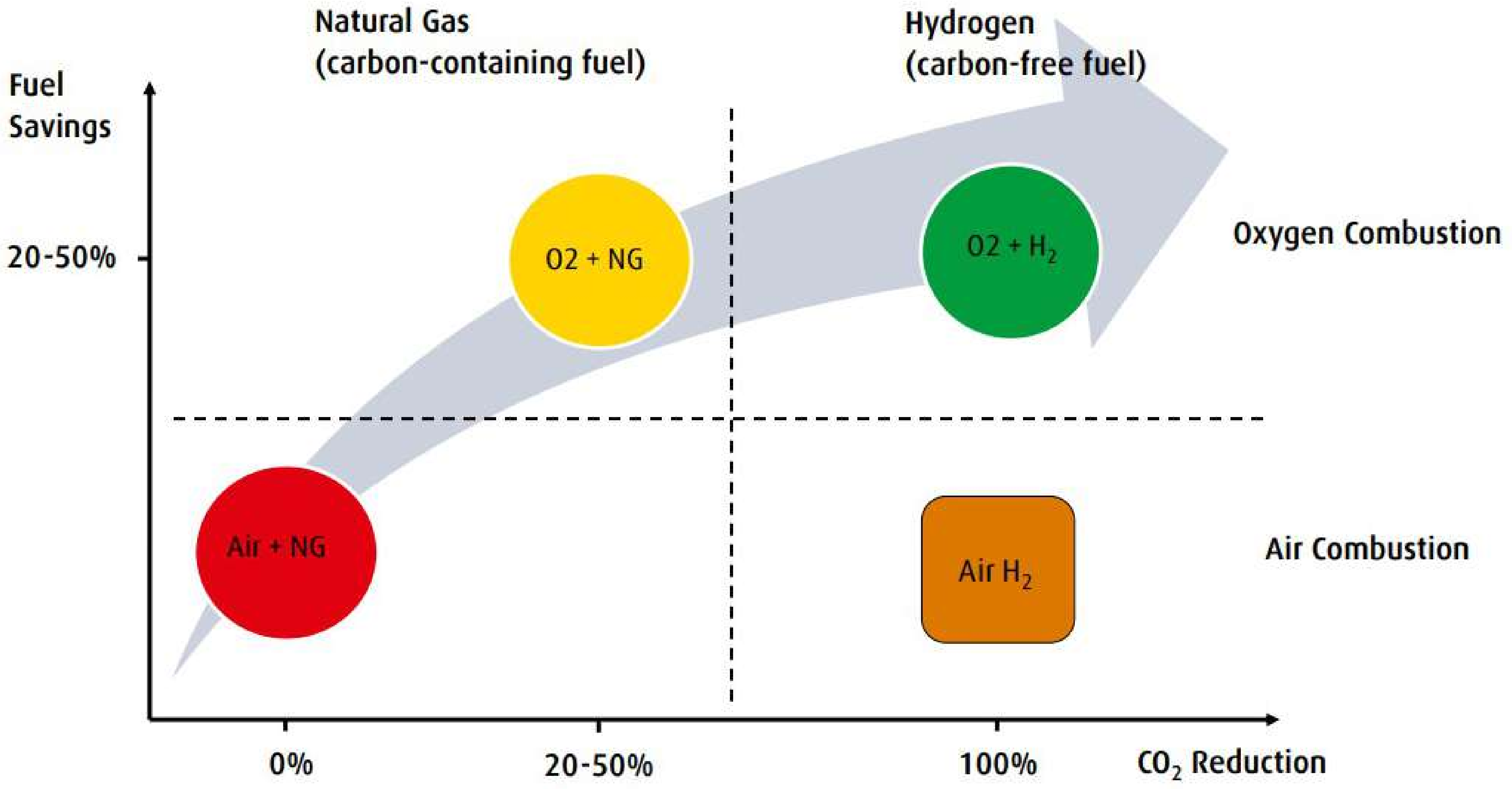
Electricity demand (ED) and environmental impacts (EI) in terms of climate change for the production of 1 tonne of steel from the investigated scrap qualities

- Electricity demand is strictly linked with scrap quality → specific electricity demand is up to 45% higher for low-quality scrap than for high-quality scrap



Haupt, M., et al. Influence of input-scrap quality on the environmental impact of secondary steel production. Journal of Industrial Ecology, 21(2), 391-401.

Route to decarbonize heating operations in steelworks



J. Von Schéele, Pathways Towards Full Use of Hydrogen as Reductant and Fuel, H_2 for Green Steel – 2nd International Conference, 30 Nov - 1 Dec, 2022 – Versailles (France)

Effects and technical challenges of the use of H_2 as fuel in EAF and reheating furnaces

- **Higher flame temperatures**
  - Potential NO_x increasing
- **6 times higher burning velocity of H_2 with respect natural gas**
- **3 times lower calorific value of H_2 with respect to natural gas**
- **Factor of four difference in the air requirement between H_2 and natural gas**
- **Change in the furnace temperature**
- **Change in furnace atmosphere and Flue gas composition**
  - High steam content
- **Changes in heat transfer**
  - Radiation/convection

Adaptation and optimization of high performance burners
- NG-H2 blend or pure H2 usage
- ensuring ignition and operation stability
- control NO_x
- Optimize flame shape, heat transfer and related profile

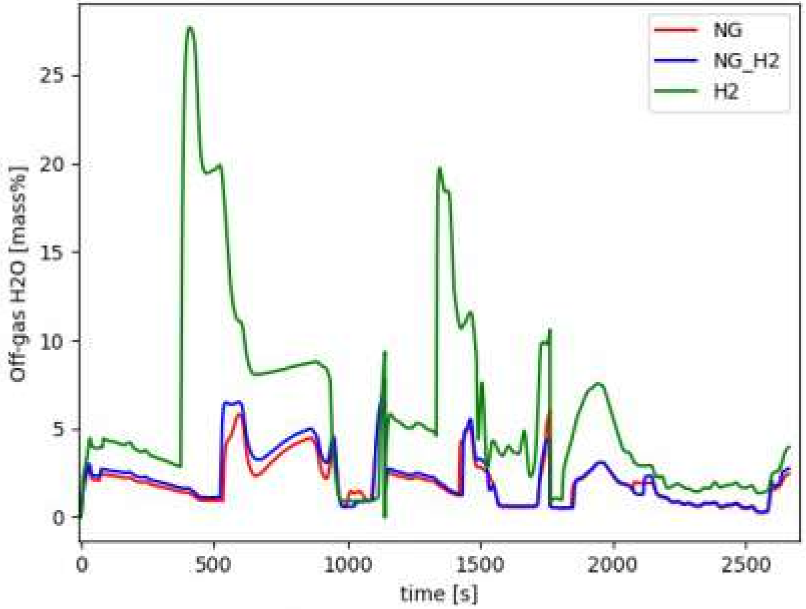
Investigating effects of new combustion phenomena and atmosphere
- process yield
- product
- Furnace refractories
- Flame radiation and energy efficiency

Solving safety issues
- leakage
- H_2 reactivity
- potential embrittlment

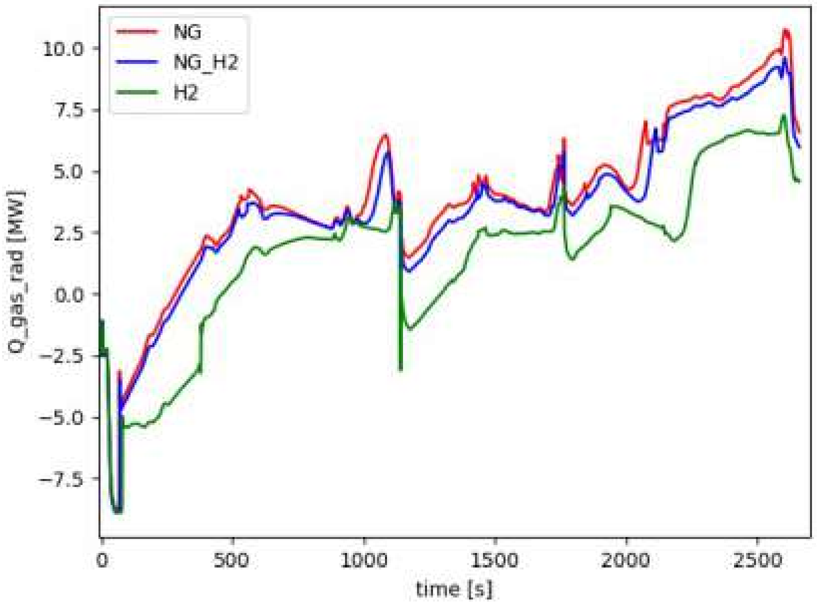
ESTEP, Improve the EAF scrap route for a sustainable value chain in the EU Circular Economy scenario, 2021
ESTEP, CLEAN STEEL PARTNERSHIP Strategic Research and Innovation Agenda (SRIA)

Burners research – Effects on EAF

RFCS funded DevH2forEAF project aims at designing, realizing and testing EAF burners able to work with NG/H2 mixtures (50%) up to 100% hydrogen.



Water content in the off-gas during one heat



Radiative heat transfer from the gas phase

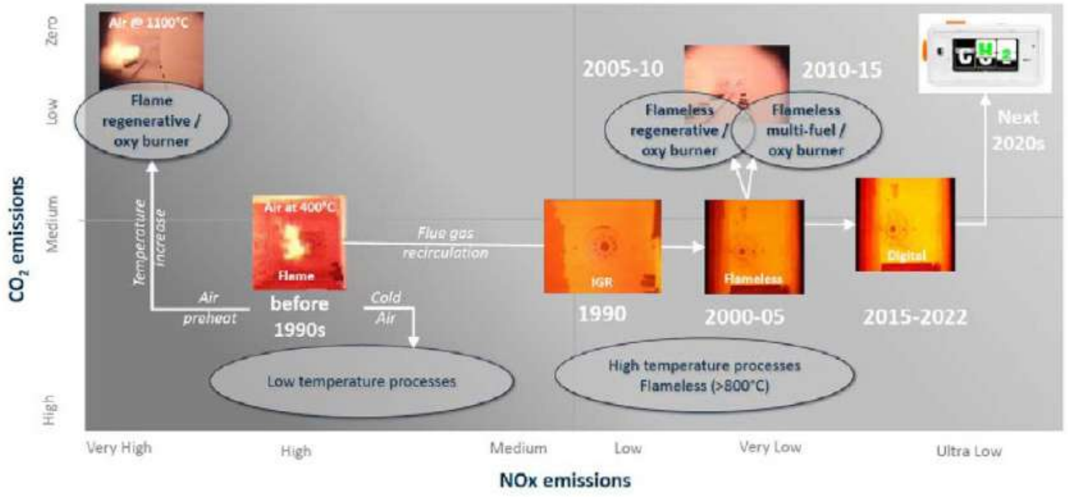
Preliminary results of dynamic EAF process simulation:

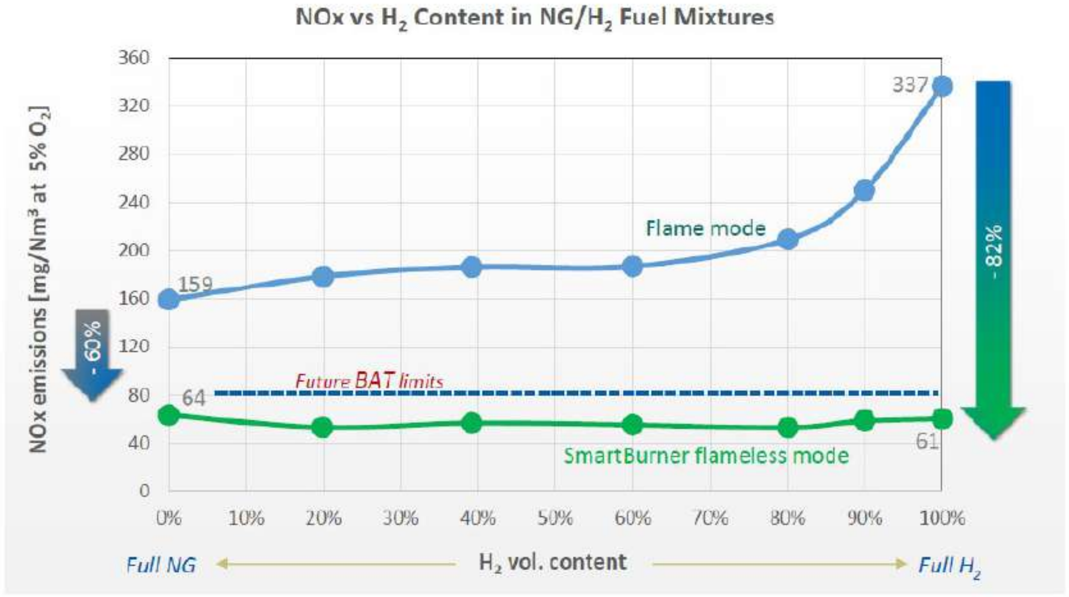
- changed composition of the furnace atmosphere → different radiation properties of CO2 and H2O
- reduced radiative heat transfer from the furnace freeboard to the scrap when using NG/H_2 blends or pure H_2 as fuel

T. Echterhof, Hydrogen use in EAF steelmaking and downstream processes , H_2 for Green Steel – 2nd International Conference, 30 Nov - 1 Dec, 2022 – Versailles (France)
https://www.devh2eaf.eu

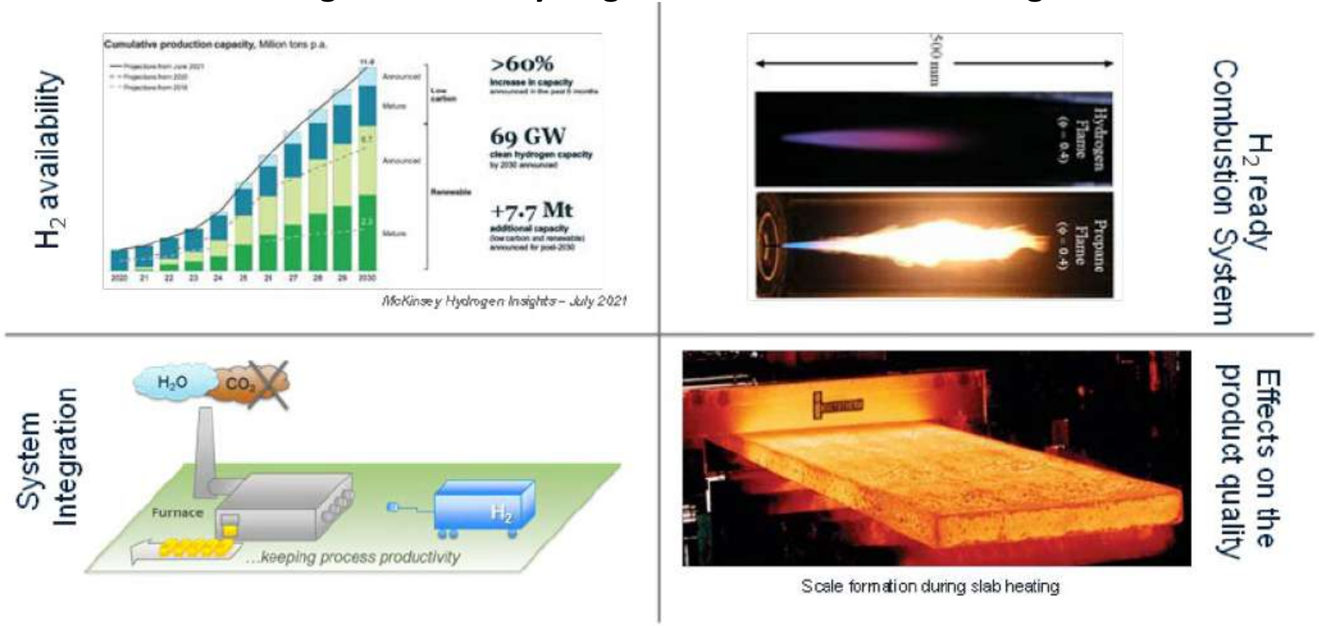
Burners research – NO_x emissions

Evolution of combustion technologies in terms of CO2 and NOx emissions





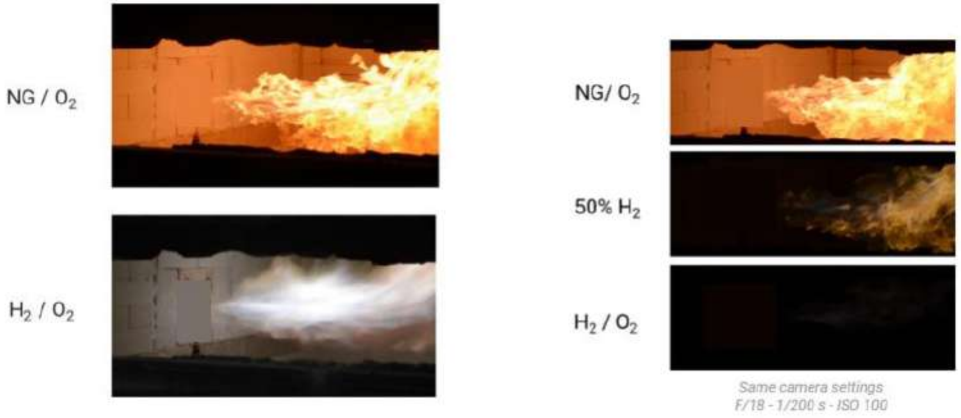
Enabling factors for hydrogen combustion in reheating furnaces

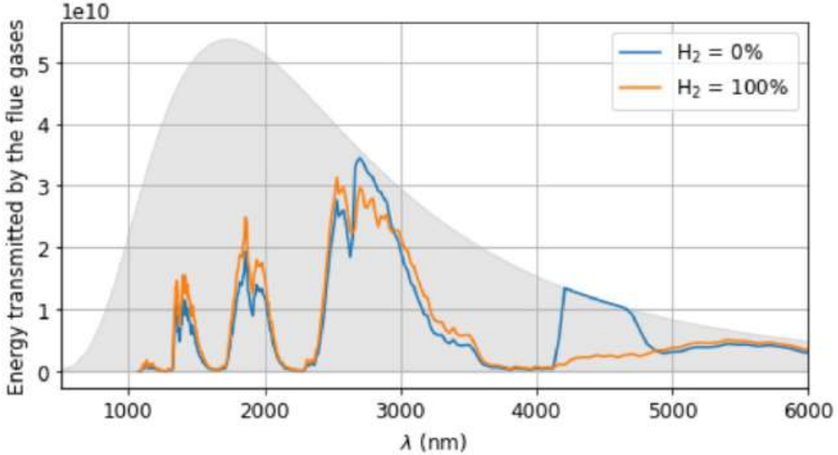


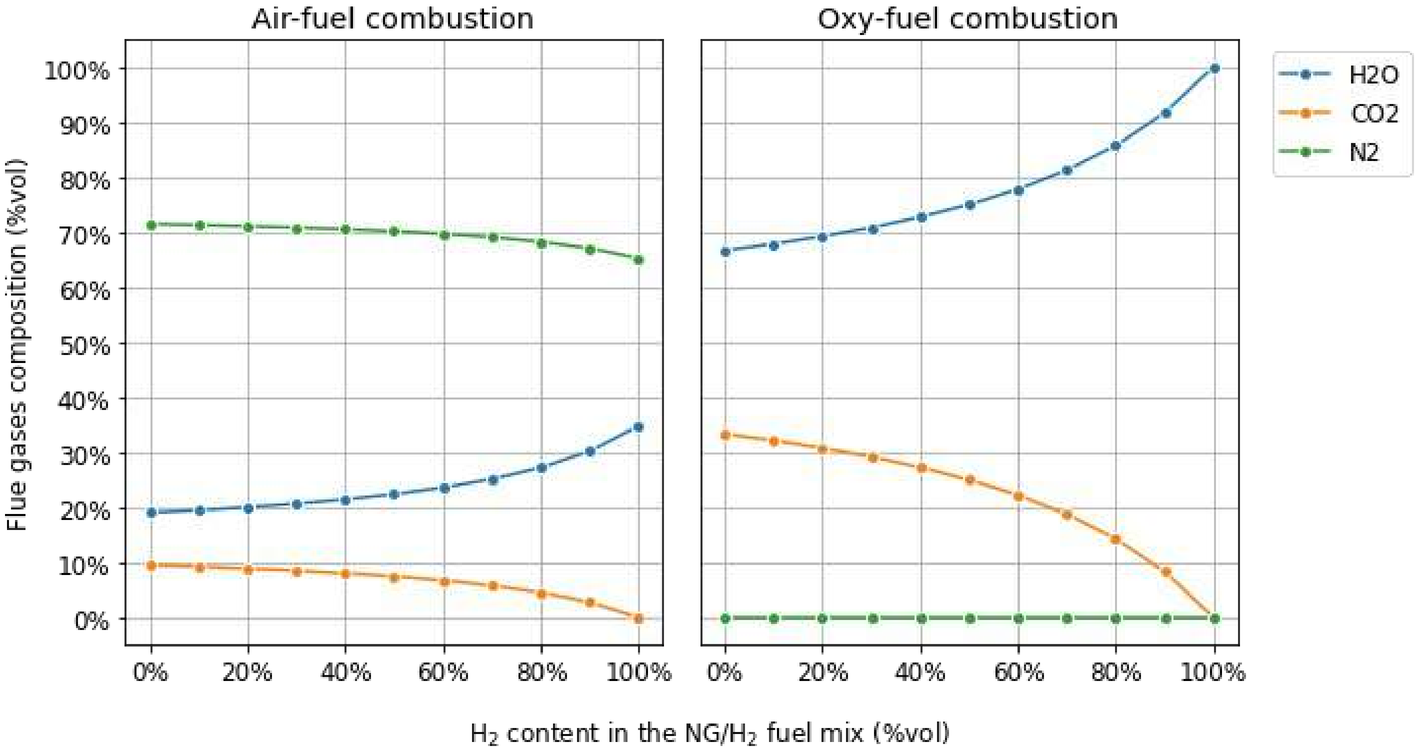
- In the flame regime, a relevant increase in NO_x emissions is verified for hydrogen contents above 60% vol.
- In the optimal flameless regime the level of NO_x emissions is always kept below 80 mg/Nm^3 at 5% of oxygen in dry flue gases.

A. Della Rocca et al., (2021), Rolling mill decarbonization: Tenova SmartBurners with 100% hydrogen. Matériaux & Techniques, 109(3-4), 309.

Burners research – CO_2 reduction, heat transfer and flue gas







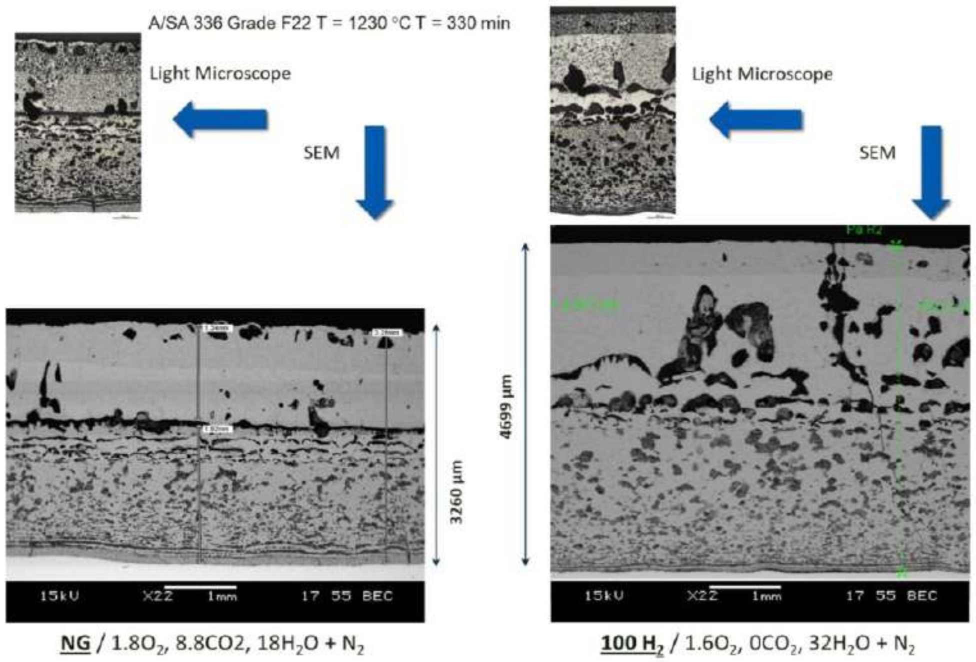
- ➢ Flame is not the only contributor to heat transfer
- ➢ Radiation through walls and flue gases provide the most energy transfer
- ➢ Most of the energy is transfered in the infrared

J. Caudal et al., Oxy-hydrogen combustion for energy-intensive industrial processes – 2nd International Conference, 30 Nov - 1 Dec, 2022 – Versailles (France)

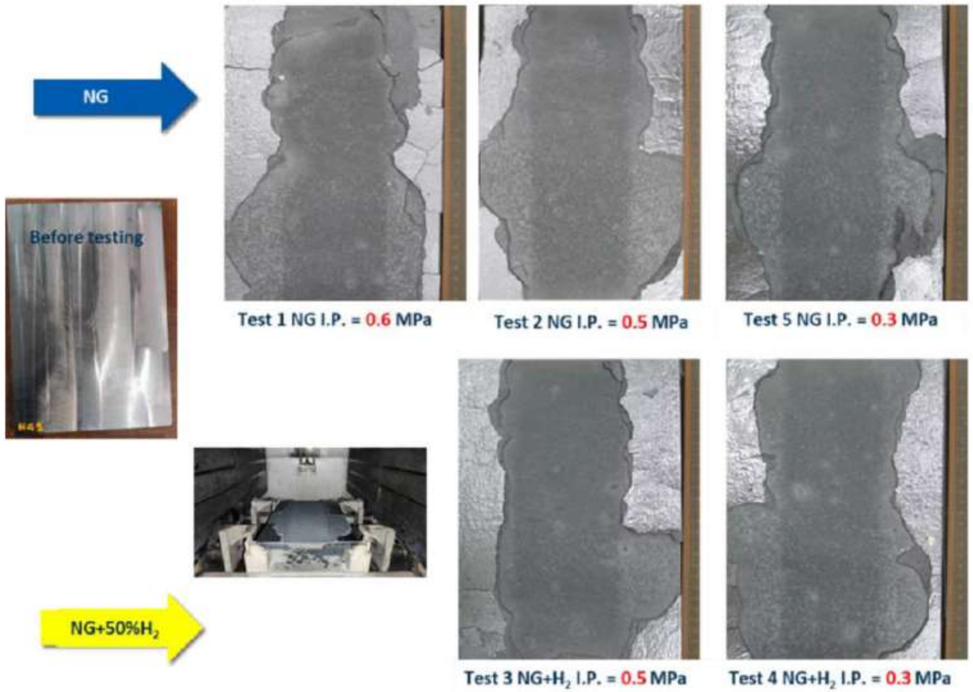
P. Rivière et al., Statistical Narrow-Band and Absorption Distribution Function models for radiative transfer in combustion applications involving CO2-H2O-CO-CH4-soot mixtures, 2011

Effects on product in reheating furnaces – Scale growth

Metallographic investigation on A/SA 336 Grade F22V



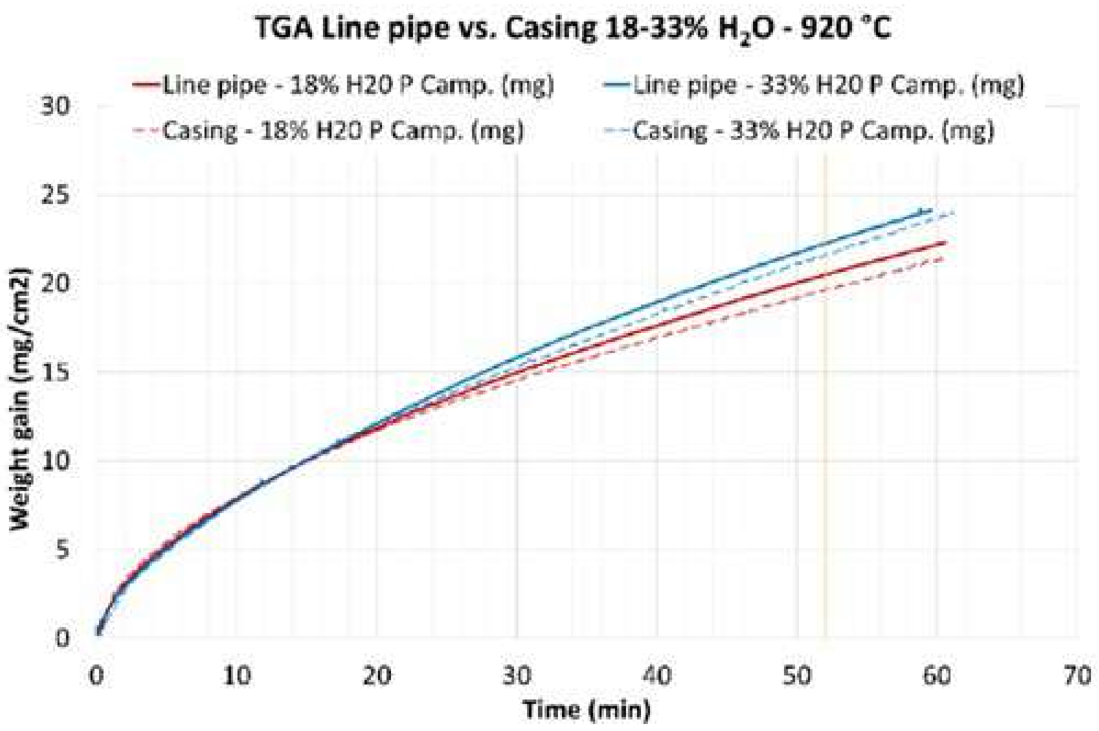
Visual aspect of sample after descaling test (A/SA 336 Grade F22V)

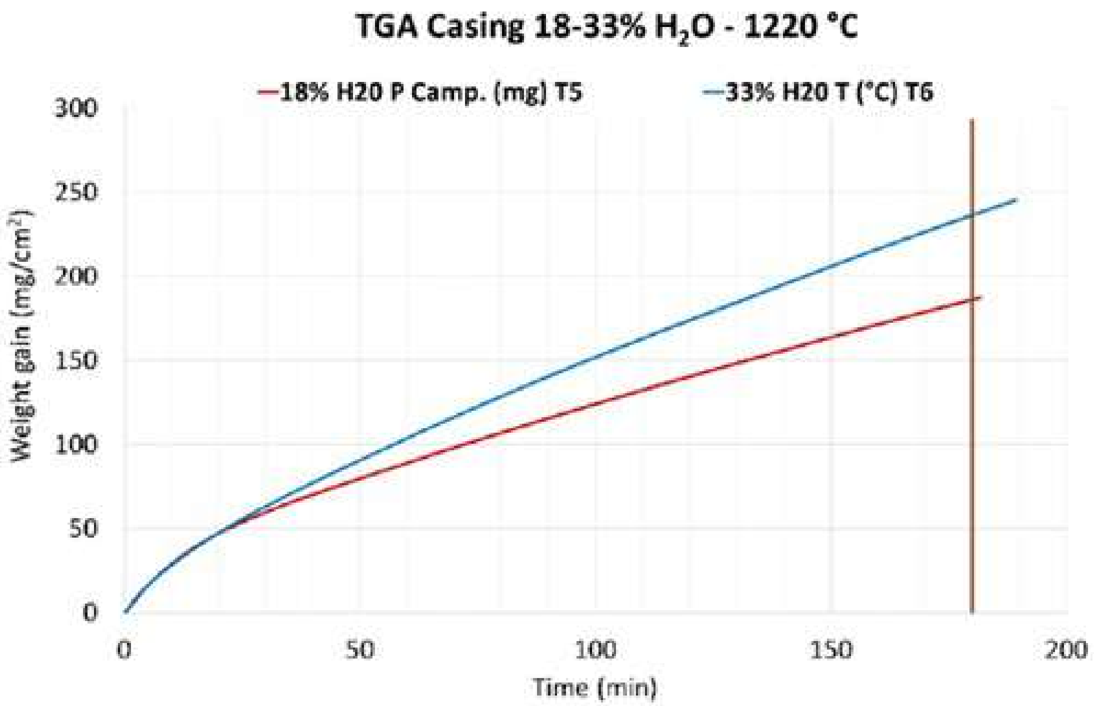


- The scale growth was up to 44% in thickness in case of reheating at 1230 °C with combustion of 100%H2 (3260 vs. 4700mm), the scale seams was more porose but with similar interface to the one obtained by the combustion of only NG.
- the material had the same descaling susceptibility using an atmosphere deriving form 50%H2–50%NG in comparison to NG

Luzzo, I., et al., (2021). Feasibility study for the utilization of natural gas and hydrogen blends on industrial furnaces. Matériaux & Techniques, 109(3-4), 306

Effects on product in reheating furnaces – Scale growth

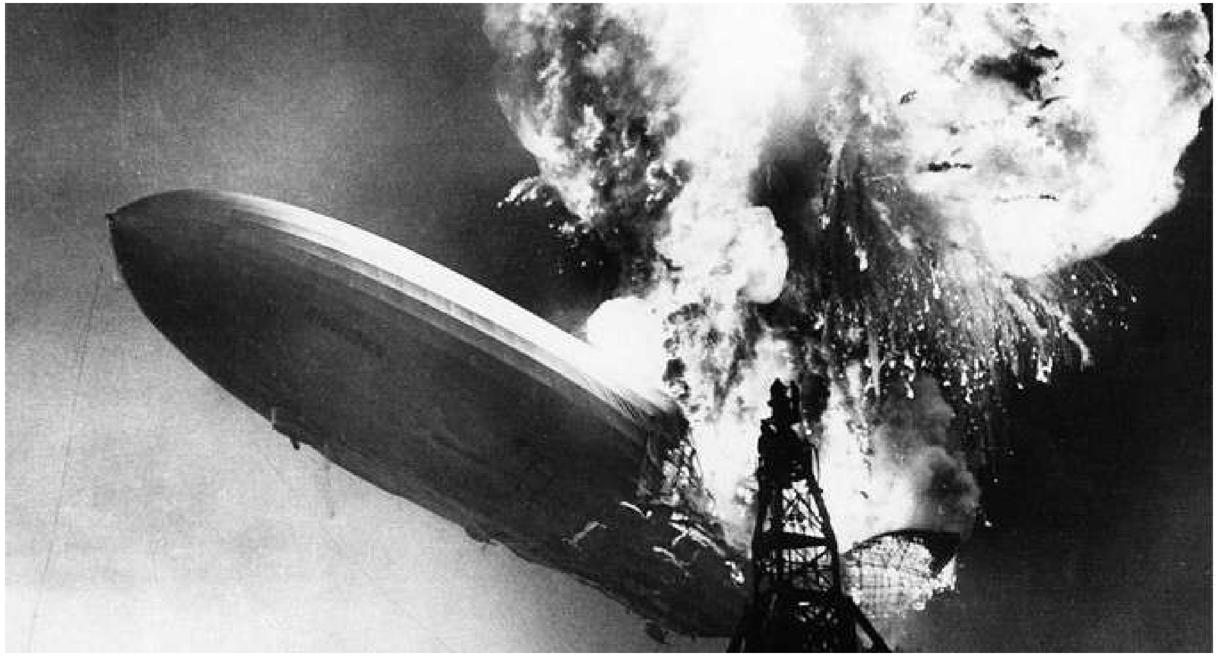




- in case of heating at 920 °C with 100% H_2, the increase in scale growth is up to 10% (line pipe steel +8%, casing steel +10
- in case of re-heating at 1230 °C with H_2, the increase is about 16% (only casing) at high temperatures, the phenomenon begins to become more important.

Cirilli, F., Jochler, G., Mosconi, M., & Praolini, F. (2021). Effects of H2 combustion on scale growth and steel surface quality in reheating furnaces. Matériaux & Techniques, 109(3-4), 302.

Safety




“L’universo è fatto
principalmente da
idrogeno
e ignoranza”
Tratto da John Dobson: A Sidewalk Astronomer
Sideralmente
sideralmente_stellaria - osservatorio sideralmente