Hydrogen as a Fuel for Industrial Processes: Lessons Learned from application cases

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Background

In order to limit global warming to 1.5 degrees Celsius – a threshold the Intergovernmental Panel for Climate Change (IPCC) suggests is safe – **carbon neutrality by mid-21st century** is essential

In December 2019, the European Commission presented the European Green Deal, its flagship plan that aims to make Europe climate neutral by 2050

Carbon neutrality means having a balance between emitting carbon and absorbing carbon from the atmosphere in **carbon sinks**

The energy sector is the source of around three-quarters of greenhouse gas emissions today

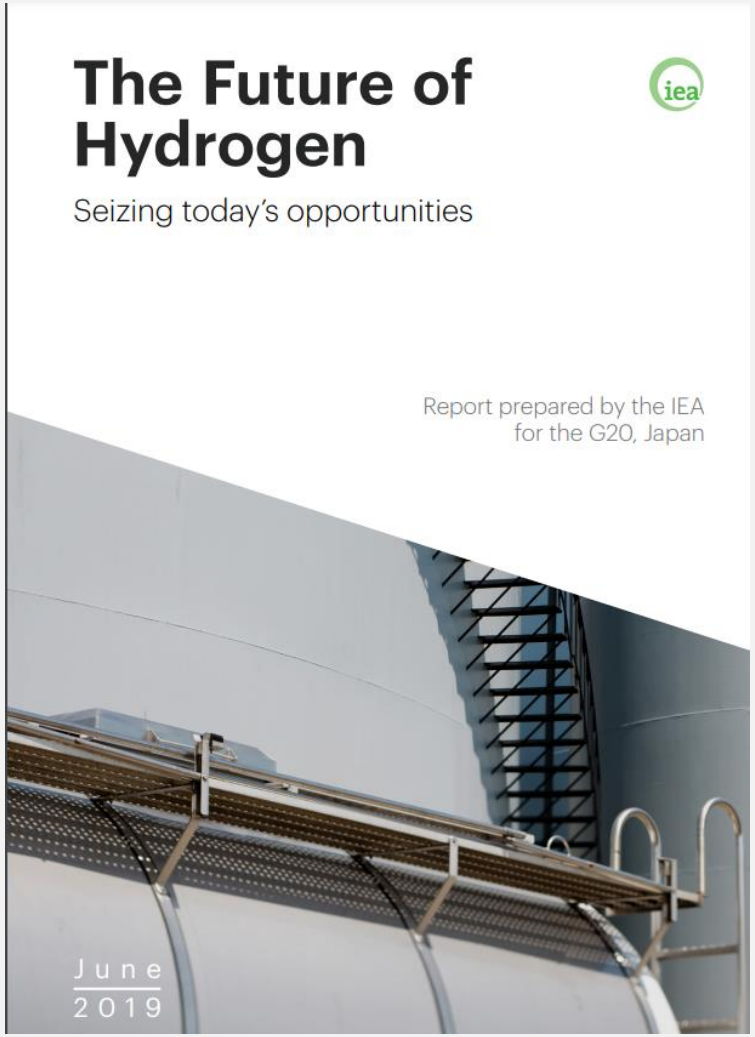
Background

Hydrogen can help tackle various critical energy challenges. It offers ways to decarbonise a range of sectors – including long-haul transport, chemicals, and iron and steel – where it is proving difficult to meaningfully reduce emissions.

Hydrogen is versatile. Technologies already available today enable hydrogen to produce, store, move and use energy in different ways

Hydrogen can enable renewables to provide an even greater contribution. It has the potential to help with variable output from renewables, like solar photovoltaics (PV) and wind

Hydrogen can be used much more widely. Today, hydrogen is used mostly in oil refining and for the production of fertilisers. It could be adopted in sectors where it is almost completely absent at the moment as power generation.



Content of the presentation

For most industrial processes, combustion plays a very important and very often irreplaceable role
But how can combustion become environmentally sustainable?

The following reported case studies deal about:

1. Results with purposely developed high performance burners, 100% hydrogen ready

2. Results about utilization of hydrogen in burners designed for natural gas utilization: steel & food case studies

3. An outlook on ongoing Horizon project HyTecHeat

Short description of Rina Group and Experimental Combustion Facility is given in what follows

RINA GROUP

We are more than 5,300 people around the world, committed to simplify complexities with a focus on energy transition, ESG and digitalization.

In 2000, we inherited a legacy from one of the world's first ship classification registers (Registro Italiano Navale) and turned it into a “business-to-society" company that helps clients stay ahead of changes and grow sustainably

.

We specialise in testing, inspection, certification and engineering solutions across a wide range of markets including, among others, marine, energy and mobility, real estate and infrastructure, space and defence, industry 4.0.

5,300
colleagues

200
offices worldwide

70
countries

Our people

More than **90 nationalities**

32%	**>70%**	**43**
women	educated to degree level	average age

Experimental Station for Combustion Studies

Modular furnace

Descaler simulator

TYPES OF COMBUSTIONS SYSTEM

- BURNERS:
  - High Speed,
  - Side and Roof
  - Air Preheated,
  - Regenerative,
  - Recuperative,
  - Flameless
- CERAMIC REGENERATORS

High temperature surfaces conditioning and descaling

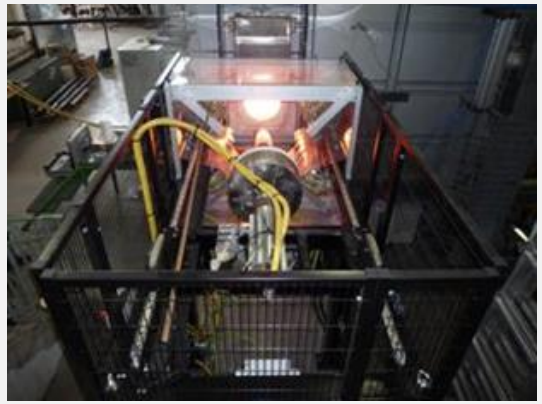
- Surface oxidizing under controlled atmosphere (from any fuel) and temperature (up to 1300 °C)
- High pressure water descaling (up to 400 bar)
- Nozzle Geometry flexibility
- Metallographic characterization
- Descaling map for the industrial setup optimization
- Overlap effect
- Double descaling

Combustion chamber for small burner

Thermal Fatigue & Quenching Machine

Thermal Fatigue & Quenching

- Flexible system: air - water or air / water spraying nebulization
- Temperature heating furnace: up to 1300 °C
- Sample temperature monitoring (thermocouples and infrared camera)
- Automatic repetition of test (fatigue tests)



1. Results with purposely developed high performance burners, 100% hydrogen ready

Performances of Hydrogen ready burners (steel reheating furnaces) developed by SMS-Group, CFD analysis and experimental trials

Irene Luzzo, Rina consulting Centro Sviluppo Materiali S.p.A, Dalmine (BG)

Pietro della Putta, SMS –Group, Tarcento (UD)

SMSZEROFLAME HY2 Hydrogen Hybrid

1. Results with purposely developed high performance burners, 100% hydrogen ready:
Use of hydrogen in bruciatori SMS-Group, trials on pilot plant

SMS Group has started a research program to develop a burner able to use both natural gas and hydrogen minimizing NOx emissions

The start point is the SMS ZeroFlame burner, a natural gas flameless burner that allows overcoming some criticises linked to the traditional flameless burners actually in the market as:

- Possibility of supplying an overboost
- Increasing of turn down
- Modulation of the flame length according to the geometry of the combustion chamber

Without increasing the NOx emissions respect to a flameless burner

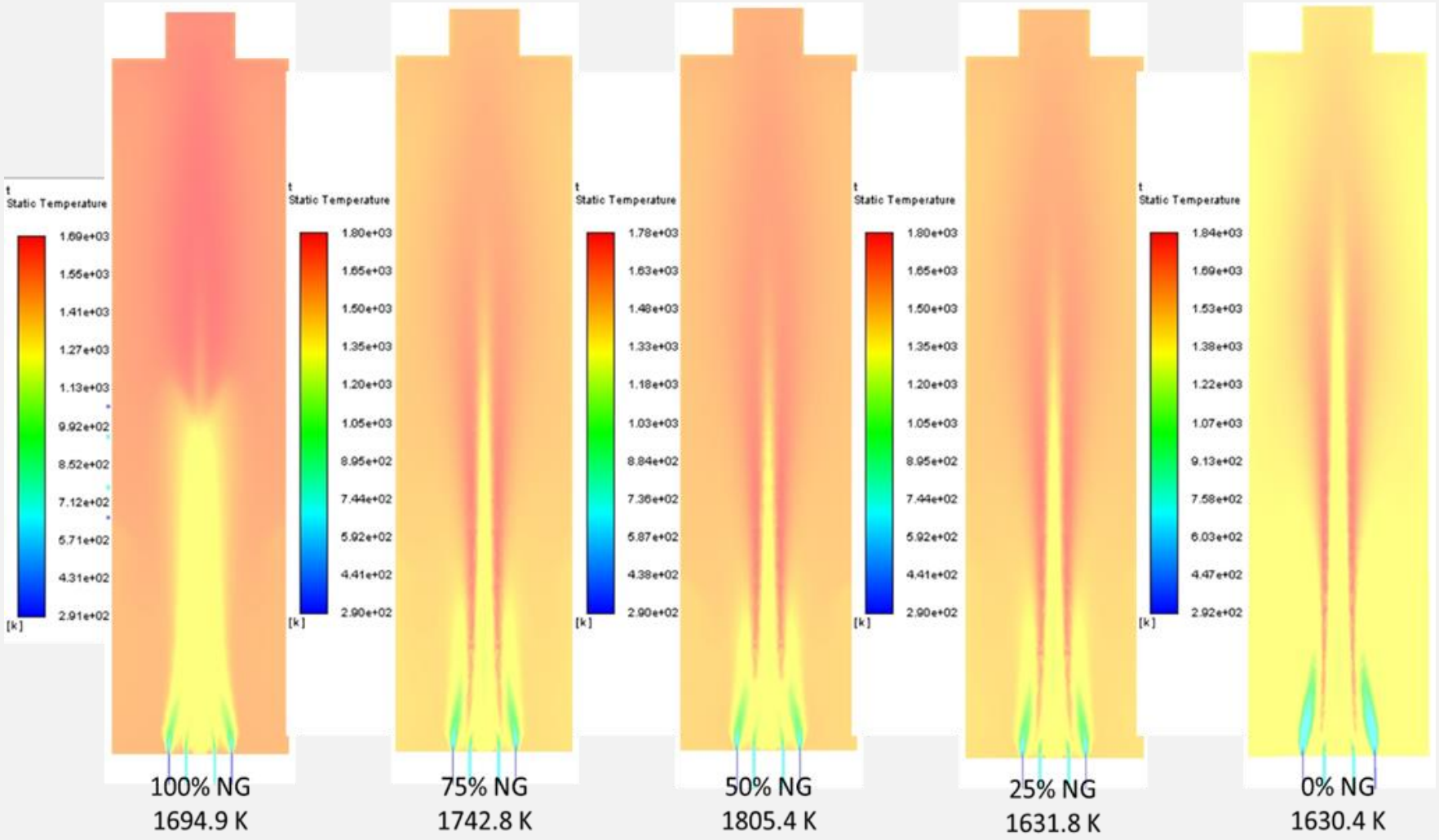
The ZEROFLAME HY2, as ZEROFLAME, was developed by two steps:

1. Modelling approach based on CFD analysis of the burner, to be able to verify the combustion process and identify any improvements/modifications to be applied to the burner: analysis a 2 MW burner and definition of scale to realize burners having different size.

2. Realization of the 1 MW prototype burner according to the results of CFD analysis and test in an experimental furnace to assess its performances. 1 MW size is developed by using scale criteria developed in CFD activity to verify their feasibility

1. Results with purposely developed high performance burners, 100% hydrogen ready

Use of hydrogen in bruciatori SMS-Group, trials on pilot plant



As expected, the presence of hydrogen strongly modifies the flame shape and the thermal field.

- Anticipation of the flame ignition with H_2 presence.
- not monotonic trend of the temperature increase: Max @ 50% vol of H_2 in NG at around 100 K

1. Results with purposely developed high performance burners, 100% hydrogen ready

Use of hydrogen in bruciatori SMS-Group, trials on pilot plant

Experimental conditions

Furnace chamber: 2 x 2 x 6 m

Zeroflame Burner HY2

- Rating: 1,0 MW
- Fuel: From 100%vol NG to 100%vol H_2
- Air temperature: 450 - 520 °C
- Furnace temperature: 1150 – 1250 °C
- O_2 in flue gas: 1 – 2 – 3% dry vol.
- Turn down: up to 40%
- Furnace pressure: 17 – 20 Pa
- Flow rate, pressure and temperature monitoring and recording
- Continuous video monitoring

The burner has been tested in flame and flameless mode

1. Results with purposely developed high performance burners, 100% hydrogen ready

Use of hydrogen in bruciatori SMS-Group, trials on pilot plant

No significant difference between flames produced by NG and H_2.

Flames poorly visible, the combustion is steady without pressure oscillations.

No soot or CO are detected

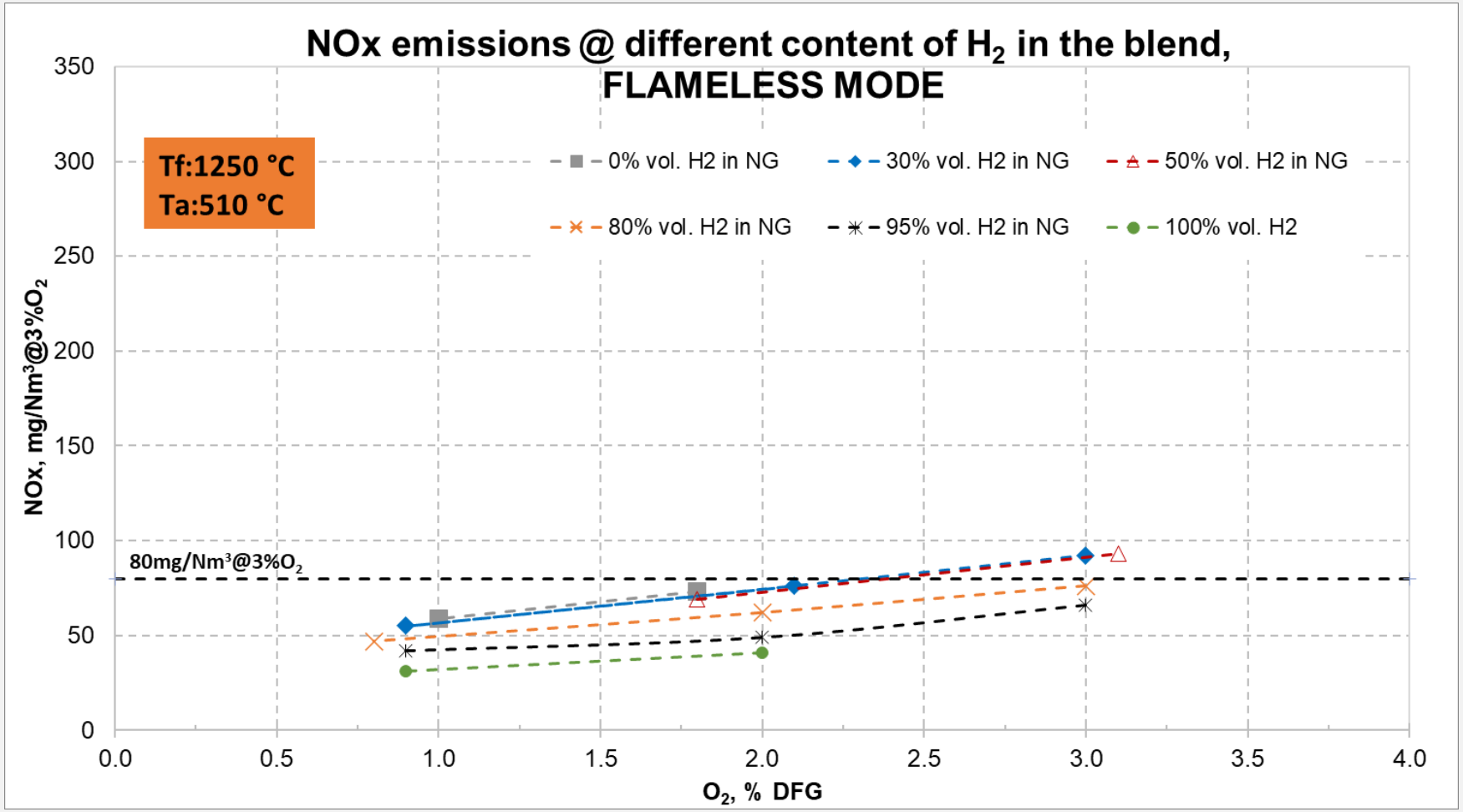
Flame - NG

Flame – H_2

1. Results with purposely developed high performance burners, 100% hydrogen ready

Use of hydrogen in bruciatori SMS-Group, trials on pilot plant

In flameless mode NOx emissions depend on the concentration of hydrogen in mixture, but variation occurs in a narrow range that is almost always below 80 mg/Nm^3@3%O_2.



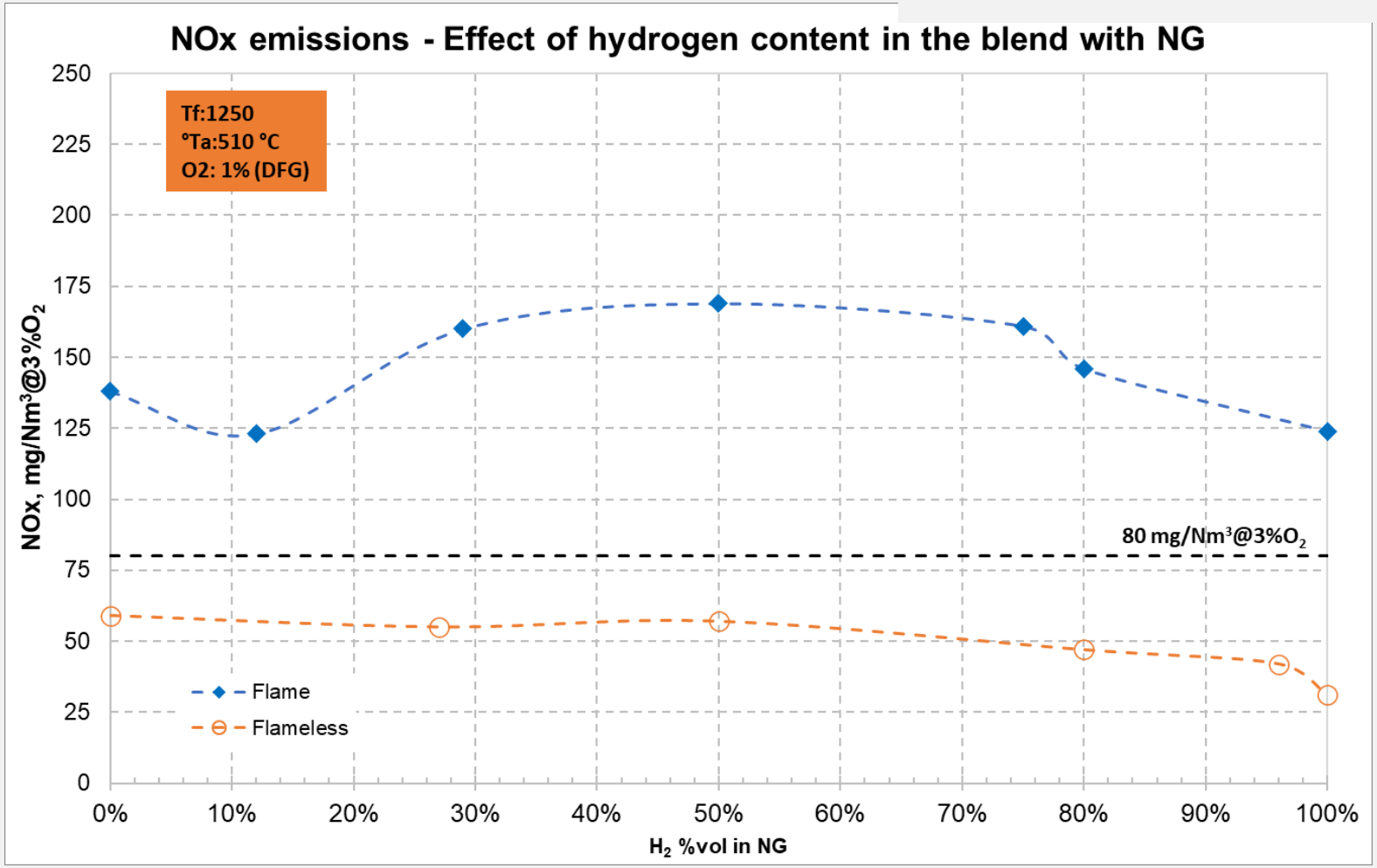
1. Results with purposely developed high performance burners, 100% hydrogen ready

Use of hydrogen in bruciatori SMS-Group, trials on pilot plant

NOx evolution- H_2 effect in the fuels

The effect of the variation of concentration of hydrogen in mixture is clearly visible in flame mode, while in flameless mode it exists but smoothed.

In all configuration, emissions at 100% of hydrogen are lower that that with 100% of natural gas



SMSZEROFLAME HY² Hydrogen Hybrid

General conclusions

- SMS Group has developed the SMS-ZeroFlameHY2 burner, that can work with pure natural gas or mixtures NG-H_2 with NOx emissions lower than 80 mg/Nm^3@3%O_2 at high furnace temperature (1250 °C) and combustion air temperature (520 °C)

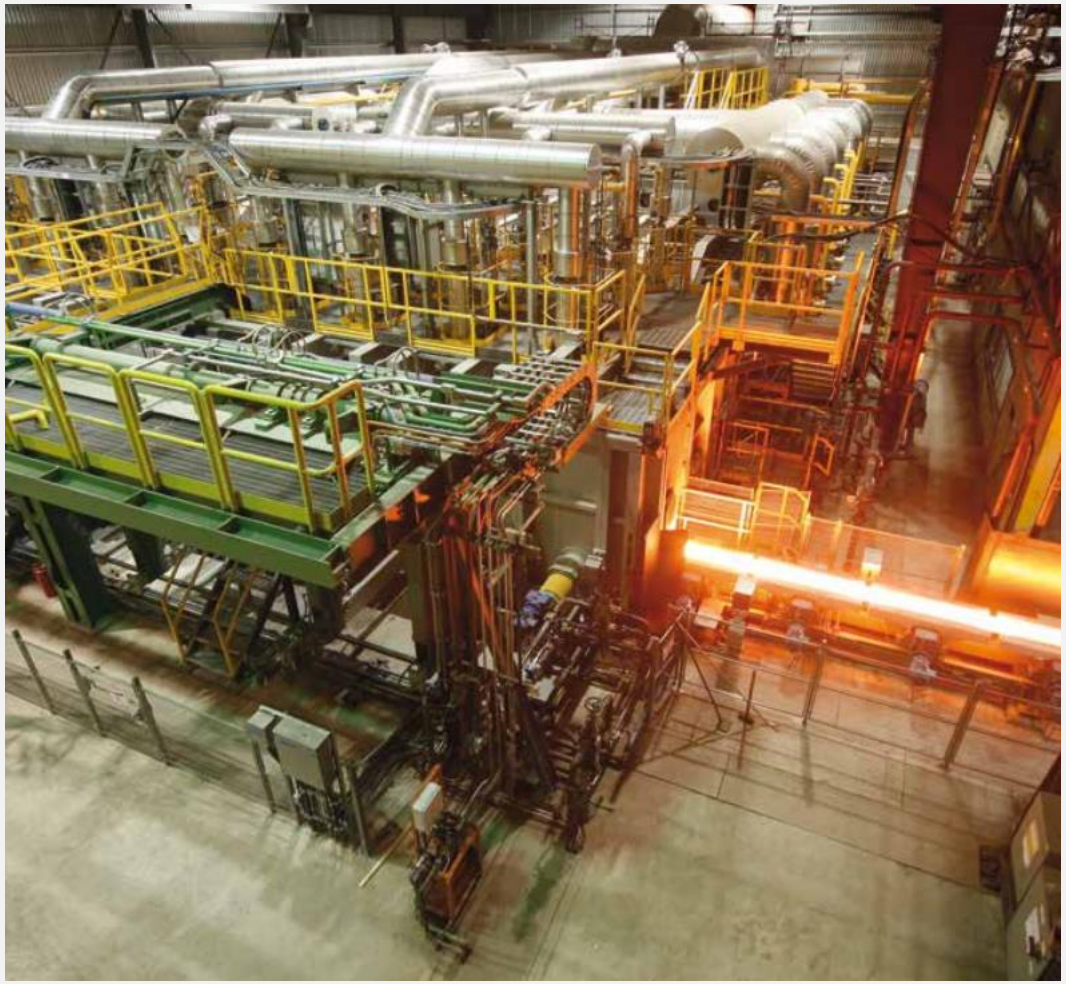
- The feasibility was demonstrated by CFD analysis and experimental test with 100% of H_2
- In FLAME MODE, NOx emissions increases around 10% in flame mode from 100% vol NG to 100% vol H_2 and for a maximum of 23% with 50NG%-50%H_2

- In FLAMELESS MODE, NOx emissions are around 59 mg/Nm^3@3%O_2 in NG and remain quite stable up to 50% vol H_2 in NG, then decrease to 32 mg/Nm^3@3%O_2 with 100% H_2

2-Results about utilization of hydrogen in burners designed for natural gas utilization: steel & food case studies

Steel case: characterization of side burners of reheating furnace

Hydrogen utilization in a combustion system originally designed for natural gas burning and maximum 15% hydrogen



Irene Luzzo, Rina Consulting Centro Sviluppo Materiali

Michele Bendotti, Andrea Venturi, Forni Industriali Bendotti

2-Results about utilization of hydrogen in burners designed for natural gas utilization: steel & food case studies

Introduction and scope of activity

The scope of this activity is to test 1,5 MW side burners provided by Bendotti with blends NG/H_2 up to 100% Hydrogen

The burners are already designed to work with 15% Hydrogen

The scope is to perform tests at higher H_2 percentage and evaluate the effect on combustion, varying the rate of the burner, air preheating and the furnace temperature

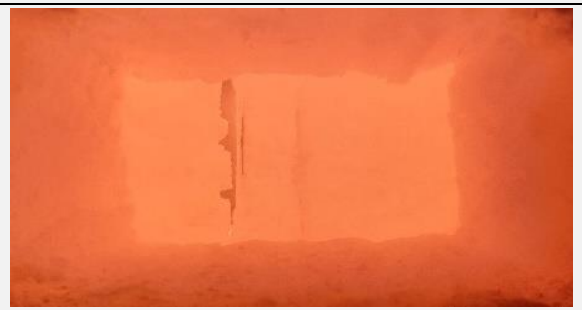
2-Results about utilization of hydrogen in burners designed for natural gas utilization: steel & food case studies

Experimental set up & conditons

- Furnace temperature: 1100 and 1200 °C
- Preheated air temperature: 400 e 500 °C
- O2 in furnace (DFG): 0.5%, 1%, 3%, 5%
- Blends: 100% vol of NG and 15%vol H2 in NG; further tests with 40, 80, 100% vol H2
- Combustion mode: Flame mode
- Fuel Lance: Standard and inner diameter of 40 mm
- Comburent air: piping for maximum 2500 Nm3/h flow rate
- Air preheating: maximum temperature 550 °C
- Flue gas suction: by stack positioned on tail module, pressure furnace controlled by valve
- Cooling system: by cooling lances
- Safety system
  - Ignition and flame detection: pilot burner ZMI25 Elster, UV sensor
  - At the burner, during working: pressure switch installed on the air pipeline, immediately before the burner inlet

2-Results about utilization of hydrogen in burners designed for natural gas utilization: steel & food case studies

Visual aspect

Standard fuel Lance - T: 1200 °C-Ta: 400 °C-100%Rate (1.5 MW) - 0.5%O_2 in flue gas (DFG)		
15% vol H_2 in NG	40% vol H_2 in NG	100% vol H_2
		
		

Visual aspect of flame at 1200 °C varying the fuel composition- standard fuel lance

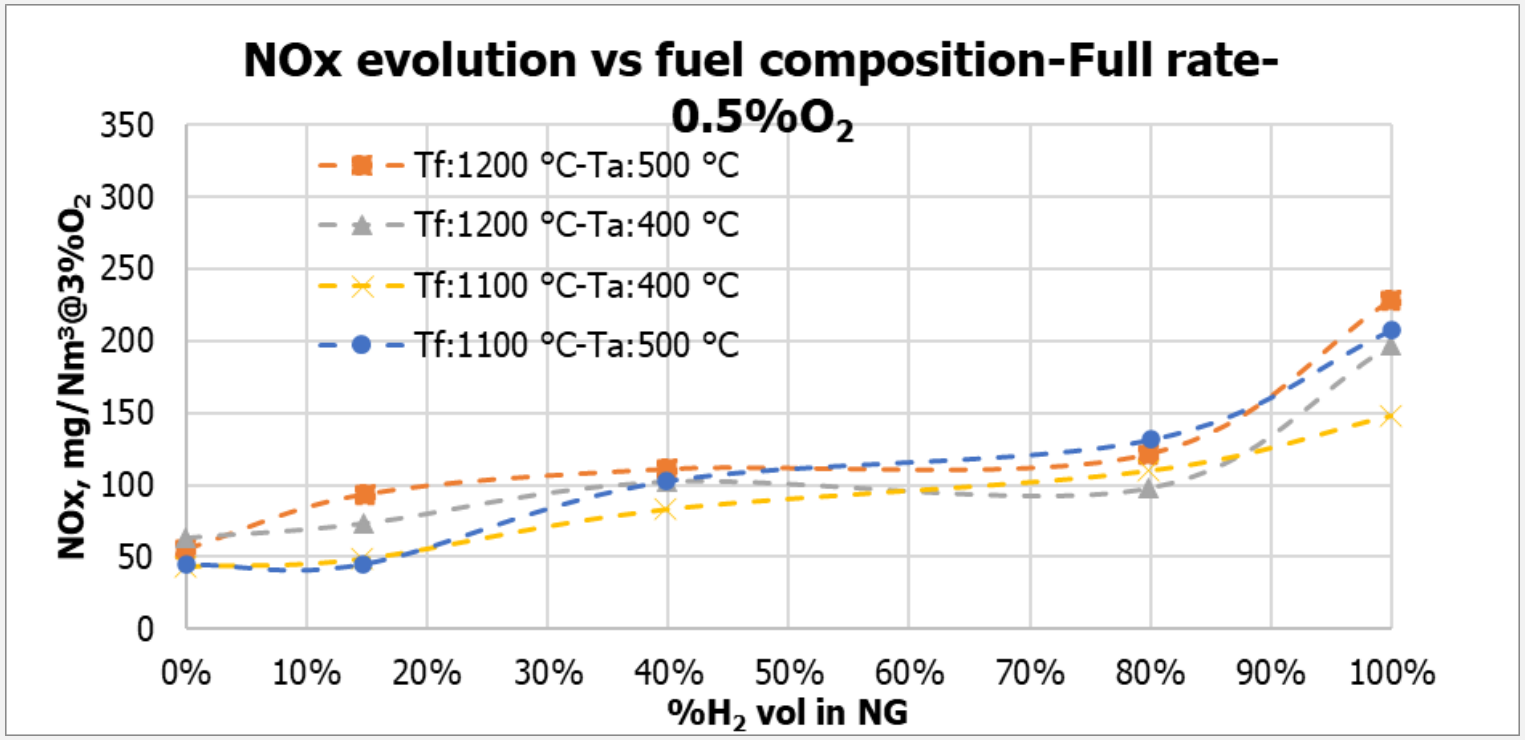
At 1200 °C in the furnace the flame is not evident for 100% and 80% of rate (1500 and 1200 kW) and becomes visible at 800 kW

The burner works on all selected conditions including the conditions tested for 100% vol of hydrogen

Above the 40%vol of hydrogen in NG the backwarded flame ignition position determines a local increase of temperature on diffuser refractory in correspondences of the outlet of air inner loops.

Characterization of side burners of reheating furnace

Effect fuel composition and rate of burner on the NOx emission



NOx Vs H_2 concentration in the blends- standard fuel lance and type n°2

The introduction of the hydrogen in the fuel determines an increase up to 30% of NOx emissions with 15%vol of H_2 in NG (94 vs 63 mg/Nm^3@3%O_2). With 100% vol of hydrogen, the increase is to 3-4 times the value achieved with 100% vol NG.

2-Results about utilization of hydrogen in burners designed for natural gas utilization: steel & food case studies

Main Conclusions

- The burner can work with NG and 15%vol H2 in NG with NOx emissions below 100 mg/Nm3@3%O2. The maximum increase of NOx emissions is 30 mg/Nm3@3%O2 respect to the emissions with natural Gas under the highest furnace and air temperature (0.5%O2 in flue gas).
- The burner was test also with the 40% and 100%vol of H2 in NG; Nox emissions and flame stability acceptable up to 40% of H2 in the blend
- at the 80% of the rate (1.2 MW) the emissions are quite similar to ones at 1.5 MW
- at 50% of rate (800 kW) the NOx emissions increases but remain below 120 mg/Nm3@3%O2 (0.5%O2 in flue gas)

2-Results about utilization of hydrogen in burners designed for natural gas utilization: steel & food case studies

Food Company

Specific testing campaigns has been carried out on industrial bakery

The bakery is currently heated by NG burning

Tests have been carried out characterizing one burners in the Rina Combustion facility

Satisfactory results obtained with 30% of Hydrogen utilization (volume percentage)

The impact on the bakery products is ongoing from the Company

No delivery of quantitative results disclosed by the Company

3 An outlook on ongoing Horizon project HyTecHeat

Reheating processes in steel production totally rely on NG burning as thermal source

The massive usage of hydrogen in steel industry, as envisioned in the Carbon Direct Avoidance pathway of the ESTEP/EUROFER masterplan, requires a transformation of entire steelmaking process from liquid production process (UPSTREAM) to the rolling and finishing line (DOWNSTREAM)

Co-funded by
the European Union

HyTecHeat

3 An outlook on ongoing Horizon project HyTecHeat

Expected results & Impacts

- Decarbonization roadmap requires net zero target at 2050, with intermediate target of 55% reduction at 2030
- Steel reheating processes (downstream) are common to both integral and EAF route and consumes 50 Nm3/t of Natural Gas
- H_2 is currently rarely used in Steelmaking; all aspects related to safety and permitting must be faced in real industrial demonstrators

3 An outlook on ongoing Horizon project HyTecHeat

Legal name	Country
RINA CONSULTING - CENTRO SVILUPPO MATERIALI SPA	IT
TENOVA SPA	IT
NUNKI STEEL SPA	IT
TATA STEEL NEDERLAND TECHNOLOGY BV	NL
SWERIM AB	SE
SSAB EMEA AB	SE
LINDE SVERIGE AB	SE
ARCELORMITTAL MAIZIERES RESEARCH SA	FR
SNAM S.P.A.	IT
INDUSTRIE DE NORA SPA-IDN	IT
DALMINE SPA	IT

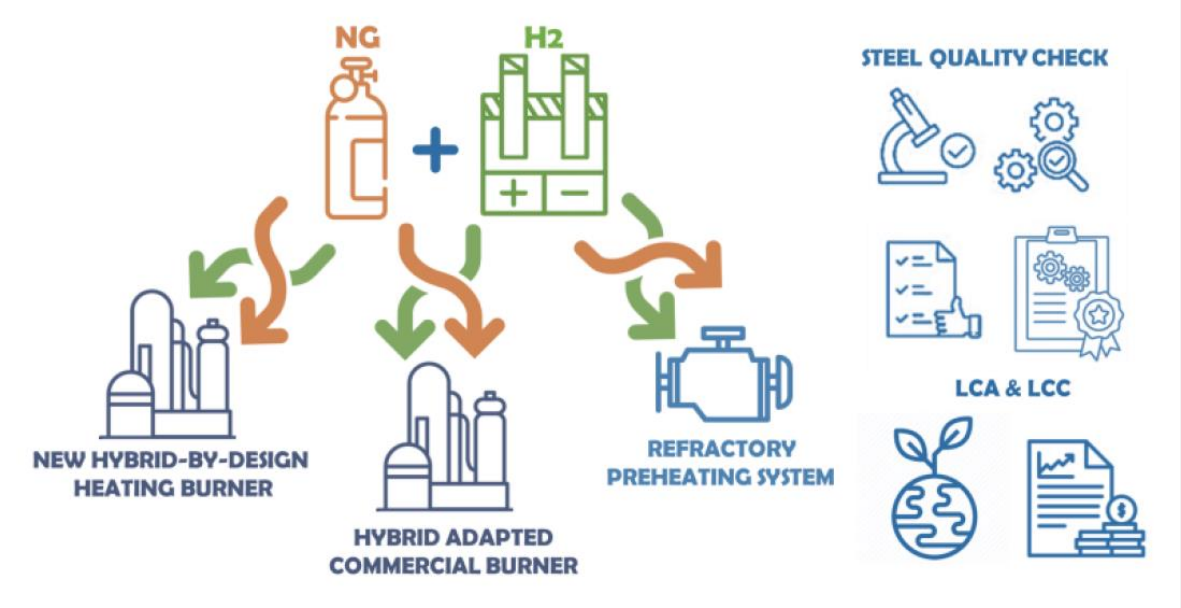
Eleven partners from four different European countries

3 An outlook on ongoing Horizon project HyTecHeat

Three different democases are envisioned:

1) **TENOVA democase**: a hybrid by-design burner will be applied and tested in order to evaluate performances

2) **TATA steel democase**: a burner currently fully-NG will be adapted to evaluate the limit up to which the current systems can be pushed to work in hybrid heating gas atmospheres without reducing system performance

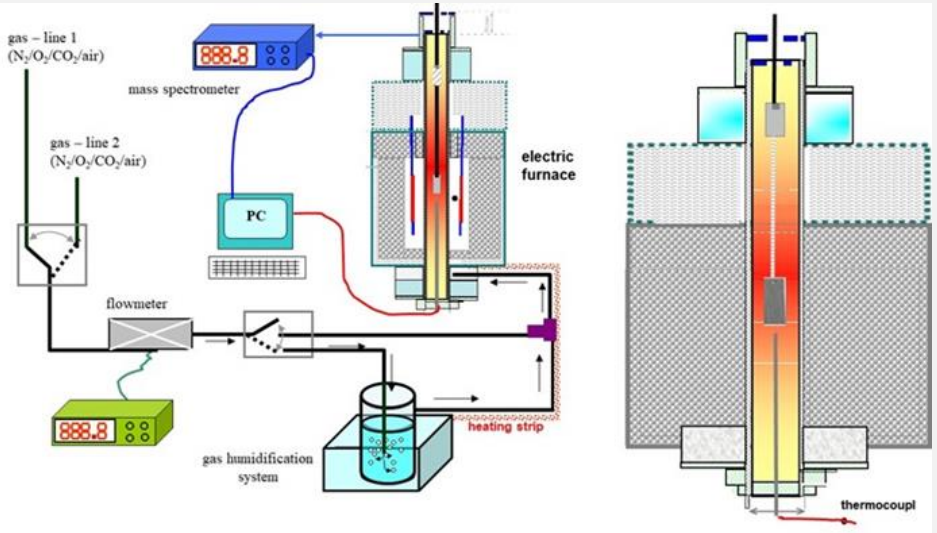


3) **Nunki Steel democase:** the effect of hybrid heating system will be evaluated on the quality of the refractory in pre-heating systems

3 An outlook on ongoing Horizon project HyTecHeat

STEEL QUALITY EVALUATION: THE BRIDGE TO TRL 8

The assessment of the relationship among thermal gradient, steel grades and composition of combustion atmosphere on on surface quality will be carried out with purposely designed experimental activities.



Thermogravimetric apparatus furnace

descaling

Expected results & Impacts

- Identification of quality issues for carbon and stainless steels as a function of NG/H_2 substitution ratio
- Realization of industrial demo cases on air and oxygen combustion, assessing multifuel burner able to work with 100% H_2 and current systems able to work in the range 20-50% (potentially 100%) H_2
- Results can be applied to each steel production facility
- Market increase for RES installations and electrolysers utilizations
- Improved social acceptance of steel factory
- Saving of CO_2 in downstream processes in the range up to 25 Mt / year

For more info:

Thank you for your attention

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