Dissemination of the heating technology research results for emission minimization and process optimization towards todays fossil-free heating agenda

RFCS-2021

Grant agreement No 101057930

Roadmap

Deliverable 5.3

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Dissemination level: Public

Version 2.0

Published 2023-10-25

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1 Introduction

The objective of this deliverable is to define based on the analysis of surface quality and furnace integrity possible roadmaps to assure the production of high-quality steel grades in Europe with a minimum on CO2 emission.

Roadmaps have been defined regarding the project structure for:

- ”Heating and burner technology”
- ”Modelling and control (level 2) of entire furnaces”
- ”Sensors and control (level 1), standards, regulations”
- ”Materials in the furnace and product quality”
- ”Heat transfer, heat recovery, productivity economy

A first proposal has been discussed at the ESTAD 2023 workshop with specialists around the table to possible new roadmaps and related concerns.

An updated proposal has been presented during a final open webinar on December 14, 2023.

The final presentation with corrections of roadmap is presented in Annex 1.

2 Global focus of the roadmap for future research

Global focus of the roadmap for future research is reducing CO2 emissions by 35% by 2030, and of achieving carbon-neutral steelmaking by 2050. The global roadmap of one of the major steel producers, ArcelorMittal, is presented below. The main focus regarding reheating furnaces is the sourcing of clean electricity (Key D). At this moment mainly studies and industrial trials are being performed. Industrial changes are expected after 2030 in order to be carbon neutral by 2050.

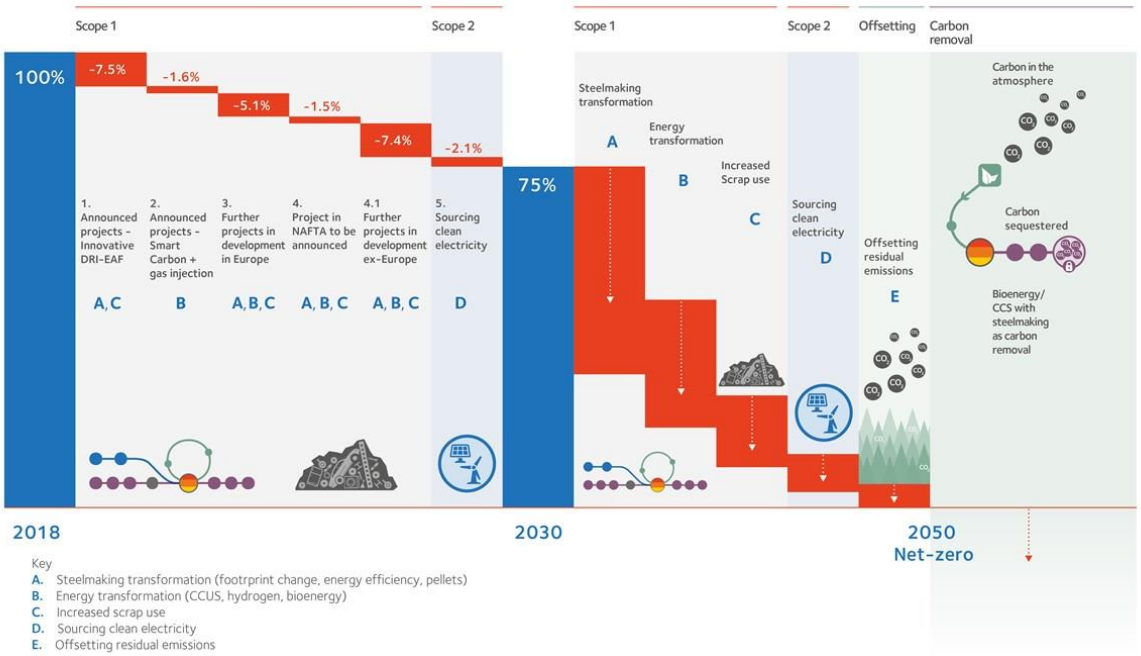

Figure 1 : Decarbonization of the steel industry

To achieve the net-zero target in 2050 the project DISSHEAT has defined several research needs in the field of:

- ”Heating and burner technology”
- ”Modelling and control (level 2) of entire furnaces”
- ”Sensors and control (level 1), standards, regulations”
- ”Materials in the furnace and product quality”
- ”Heat transfer, heat recovery, productivity economy

The results will be presented in the following paragraphs.

3 Heating and burner technology

Technology impact and integration research will focus on:

a. Burner technology:
   - ➢ Combustion heating with fuel flexible burners for future fuels, such as hydrogen, biofuels and ammoniac. The use of different oxidizers, air, OEC (Oxygen Enhanced Combustion), oxy-fuel and 100% O_2. And regarding NO_X-emissions, flameless or ultra LowNO_x burners. (Figure 2)

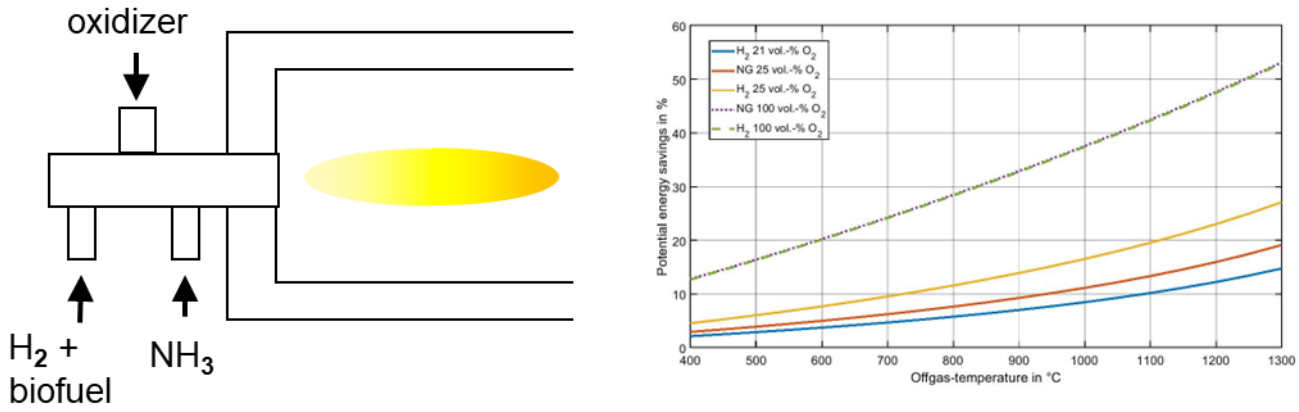

Figure 2 : Fuel flexible burner - Impact of oxidizers

   - ➢ The impact of burner technology on product heating regarding flame temperature and shape, and the radiative heat transfer of combustion gases (H_2O)

b. Efficient heating with new technologies by heat recovery from exhaust to preheat:
   - ➢ Oxidizers, future fuels or mixtures with exhaust
   - ➢ Products in the dark zone with off gas from new fuels, hybrid and combinations.

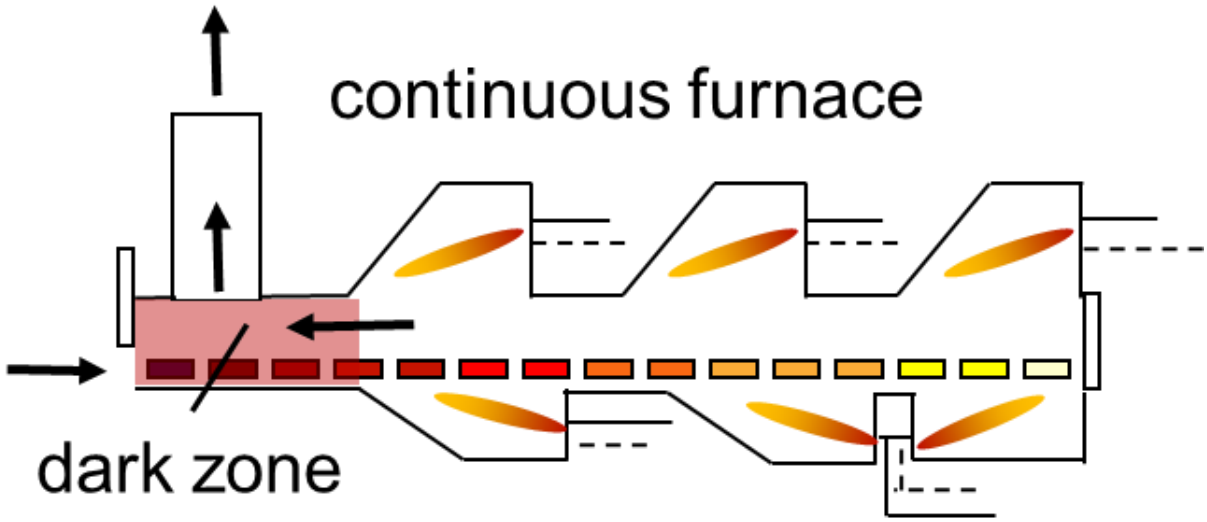

Figure 3 : Heating of products in the dark zone

c. The impact of measures on efficiency in specific plants and use cases.

d. The impact of heating technology, hydrogen combustion, electrical heating and combinations, on product and plant:
   - Influence on product-material, temperature uniformity, scaling, …
   - Influence on the furnace and the heating equipment when technologies are combined: i.e. the impact of high H2O content in exhaust gas on resistance heaters and refractory and insulation.
   - Security when handling H2 and/or O2

e. Specific combinations of combustion and electric heating driven by:
   - Availability of future fuels and renewable energy:
     - Impact on use of H2 produced by electricity or direct use of electricity for heating
     - Local availability of biofuels
   - Product geometry and material:
     - Efficient induction heating not possible for all formats of casted steel by current induction heating technology
     - Impact of heating method on materials / product
   - Hydrogen combustion (Figure 4) will be the most simple retro-fitting option, as the current infrastructure can be preserved to a large degree. Investments will however be needed regarding the supply of H_2 by an electrolyzer or bought from the market, preferable through a gas grid with possible H_2 storage. Electrolyzers are currently undergoing upscaling to levels that match reheating furnaces.
   - From industrial point of view electrical heating will require:
     - Greenfield installations: new electrical furnace, induction furnace pre-heating for productivity, resistive for soaking and the possibility to use protective atmospheres
     - The retro-fitting of existing furnaces: induction heating but with relatively large losses, resistive heating but due to power density only partial replacement of fuel possible, or RDH (RotoDynamic Heater) with higher power density in the future (Figure 5).

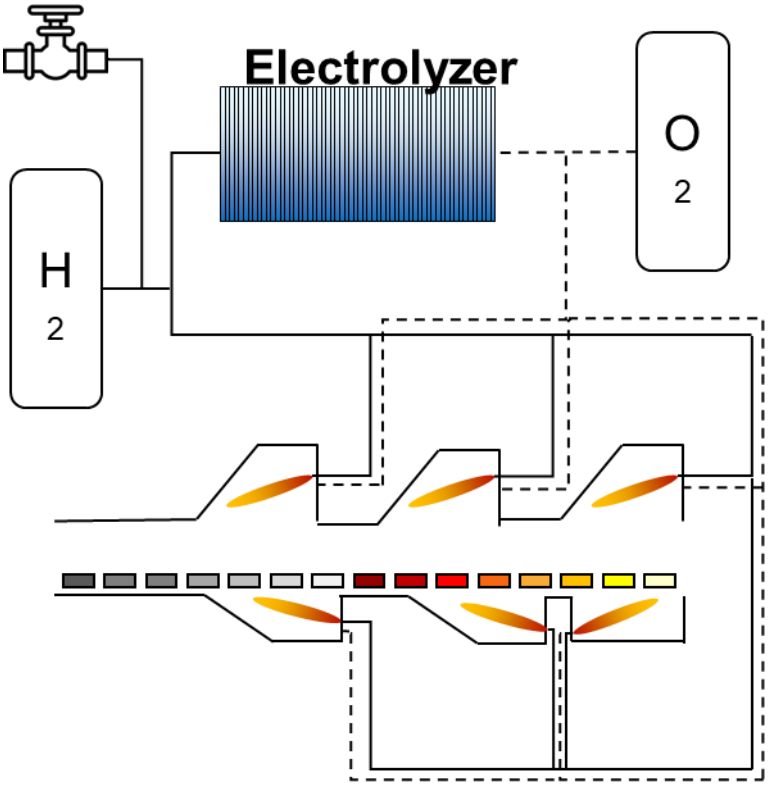

Figure 4 : Hydrogen combustion

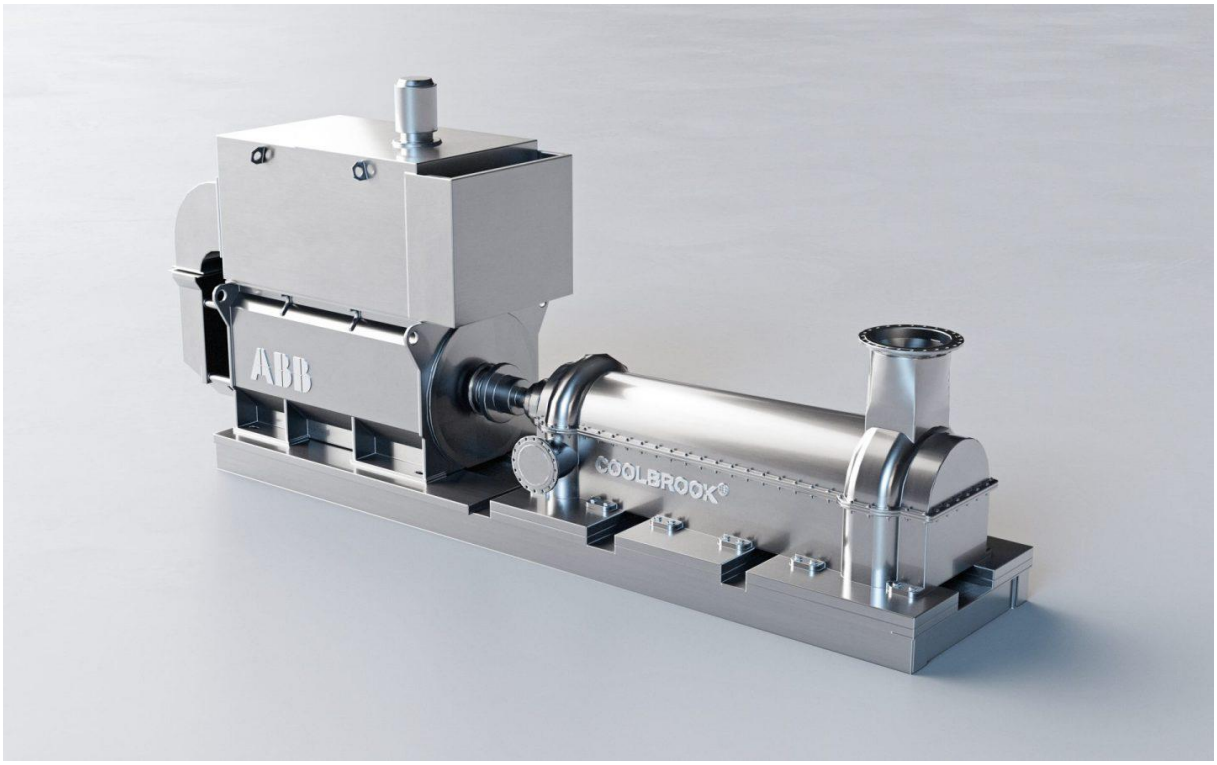

Figure 5 : Coolbrook RDH (RotoDynamic Heater)

4 Modelling and control (level 2) of entire furnaces

Technology impact and integration research will focus on:

a. To have an improved determination of the kinetic scheme, pollutant prediction (including the formation of NOx and particulate emissions) and flame shape. Different tools will be applied such as Kinetic scheme interpreters (CHEMKIN, Cantera), CFD software (Fluent, OpenFOAM, …) and increased CPU calculation power (clusters, servers)
b. To have an extended statistical approach based on observation, formulating a hypothesis to explain observations, hypothesis testing, data analysis and conclusions (Figure 6).

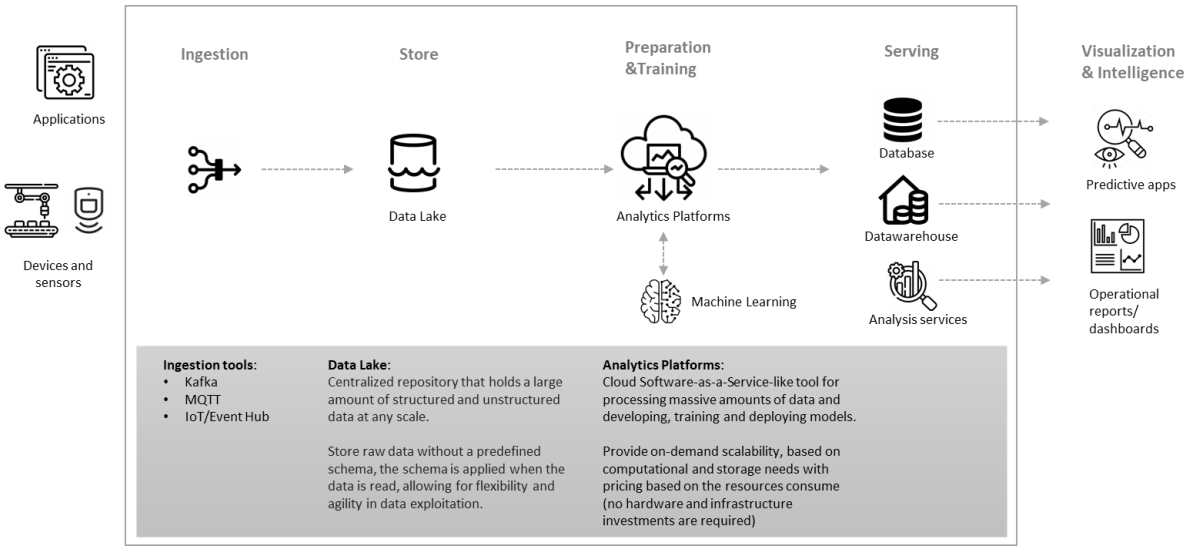

Figure 6 : Big Data and Advanced Analytics overview

c. To apply Artificial Intelligence and Machine Learning approaches (Figure 7).

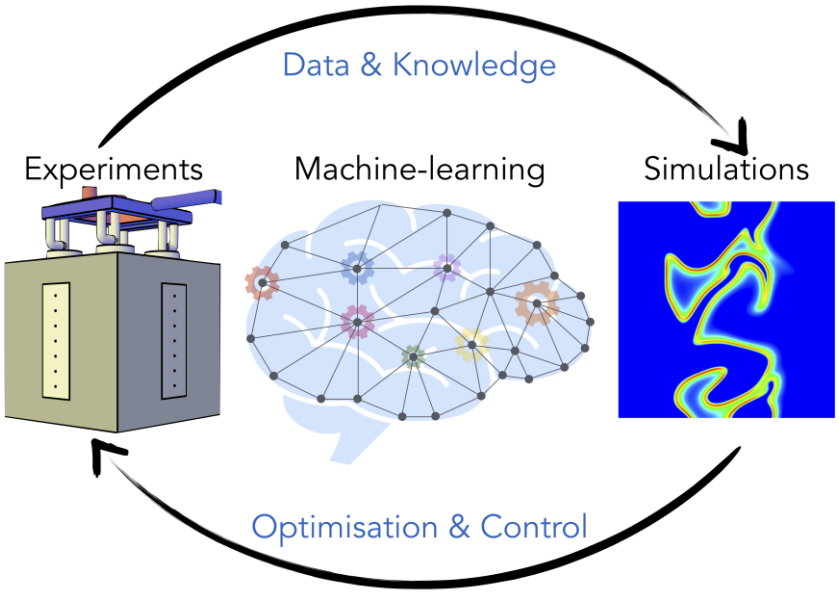

Figure 7 : AI and Machine Learning

d. The application of physical-injected neural network strategies
e. Dynamic and/or auto-adaptive modeling for process control

5 Sensors and control (level 1), standards, regulations

Technology impact and integration research will focus on:

a. Adapted burner control systems and furnace operation related to multi-fuel burners (Figure 8).

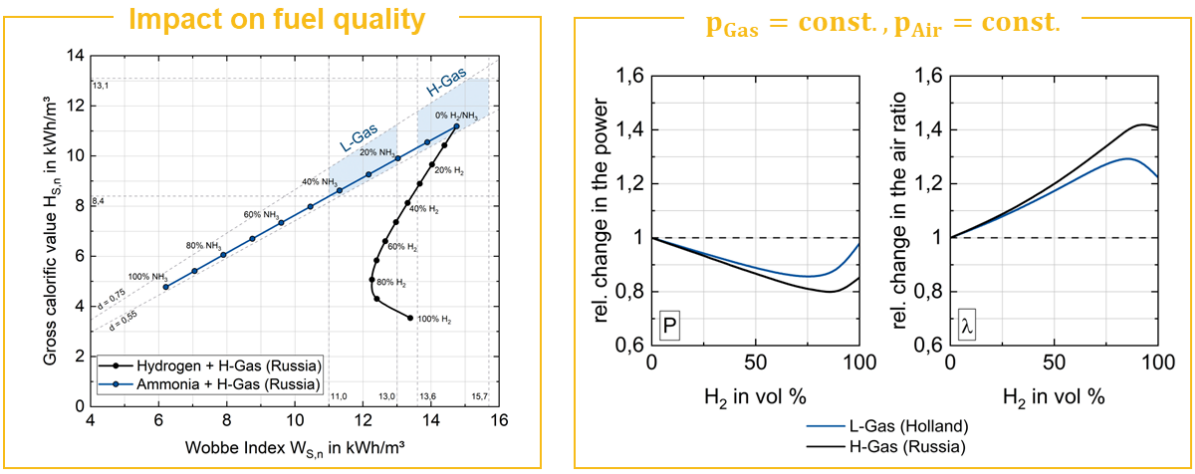

Figure 8 : Impact of alternative heating systems on furnace control

b. Impact of alternative heating systems on off-gas measurement: water content in off-gas using alternative fuels and oxyfuel can have an impact (Figure 9). For instance for a fair comparison of NOx emission, measurement on moist basis is recommended.

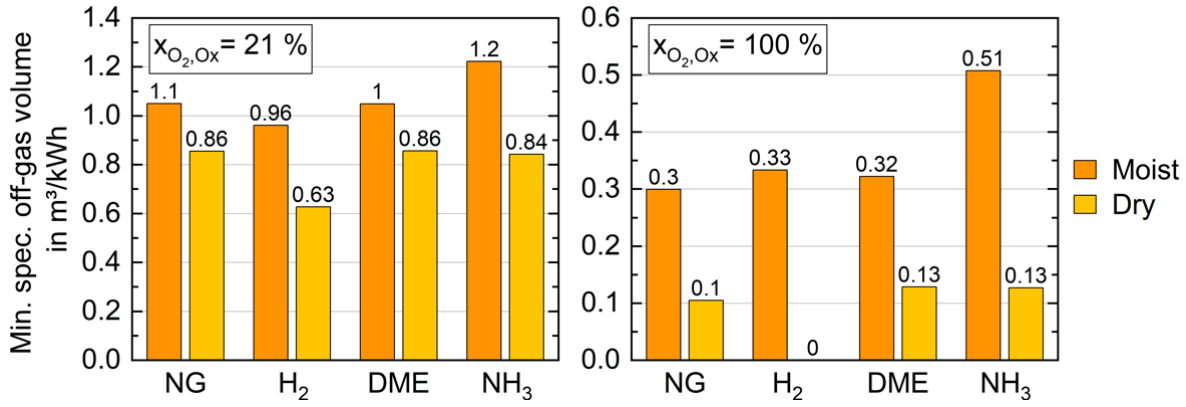

Figure 9 : Impact of alternative heating systems on off-gas measurements

c. Impact of alternative heating systems on standards and regulations :
   - A revision will be required of emission measurement standards for measurement on moist basis (Figure 10).
   - Revision of NOx limit definitions for flexible operation for flexible fuel operation and for hybrid heating operation (electric & gas).
   - Revision of BREF Ferrous Metals Processing to include new BAT-AELs definitions. To date BAT-AELs for the heating of feedstock in hot rolling are only defined for two fuel categories: “100% natural gas” and “other fuels”.

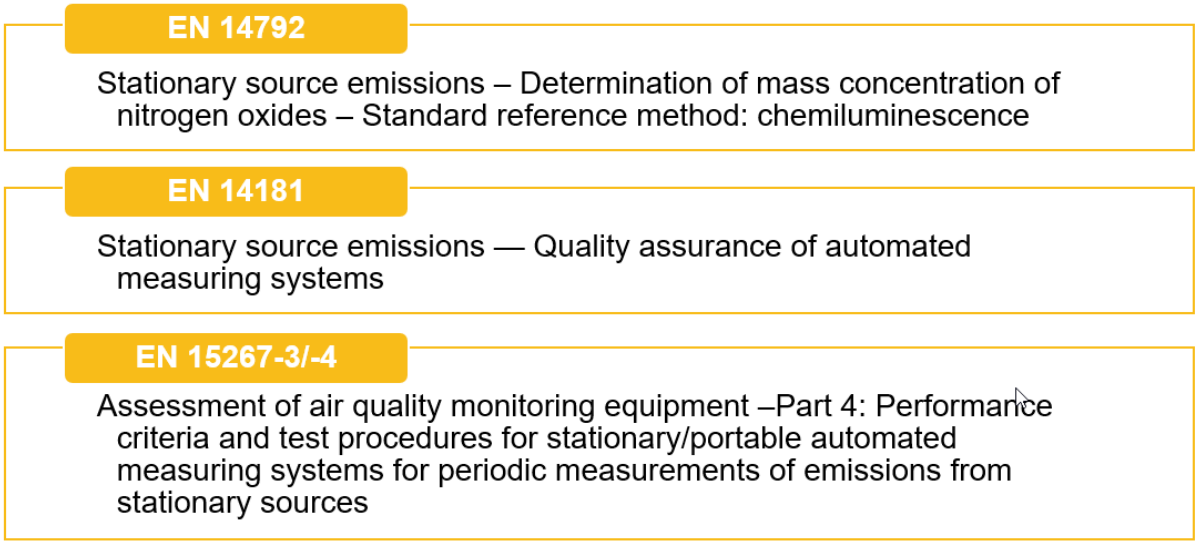

Figure 10 : Revision of emission measurement standards

- Use of alternative fuels according to ISO 13577-2 "Industrial furnaces and associated processing equipment - Safety - Part 2: Combustion and fuel handling systems":
  - *"When other fuels like e.g. hydrogen are used additional risk assessment is conducted to prove suitability of components"*
  - *"Where fuel gas with a volume fraction of more than 80 % hydrogen (H_2) is used additional risk assessment shall prove suitability of components etc. and procedures"*
  - *"In case of hydrogen and fuel gases with a volume fraction of more than 80 % hydrogen the safety time for ignition shall be limited to 3 s"*
  - *"In case of gaseous fuels with a volume fraction of more than 80 % hydrogen or acetylene (C_2H_2) residual fuel from the automatic shut-off valves to the burners shall be safely discharged or burned"*

6 Materials in the furnace and product quality

Technology impact and integration research will focus on:

a. New insulation materials for reheating furnaces to limit heat loss
b. Application of reflective coatings on the furnace walls
c. New ceramic materials with improved resistance for humidity and different scale layers.
d. Study of the impact of residuals on product quality and reheating strategy. By moving from the blast furnace route to the DRI-EAF more residual elements are expected with could have an impact on the product quality during reheating. For instance:
   - Cu will diffuse quickly leading to segregation, roughening of the interface and intergranular oxidation
   - Mo above 0.25% will increase scale adhesion

e. A full screening of all grades, with all different hybrid reheating configuration related to scale growth, scale composition, descaling, decarbonization and hydrogen embrittlement. For instance with 100% hydrogen firing scale growth is increased by 20 to 35% but also a different scale layer can be observed on a dual phase steel (Figure 11). Scale spalling took place in a different location for NG and H2 firing. A separate phase is observed containing Si and Al.

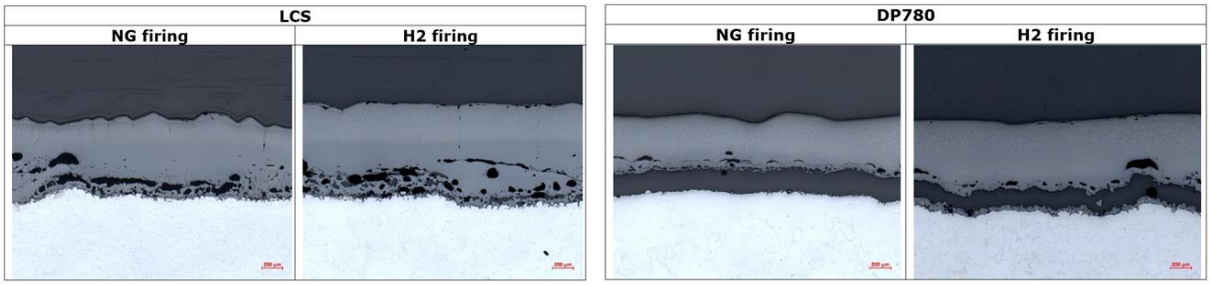

Figure 11 : Impact of 100% hydrogen firing on scale growth and composition

f. Application of protective coatings (Figure 12)

Figure 12 : Application of protective coatings

g. Alternative metallurgical compositions to improve product quality
h. Wear of new hybrid reheating components:
    - Burner nozzle wear by hydrogen flame
    - Wear of electrical resistances

7 Heat transfer, heat recovery, productivity, economy

Technology impact and integration research will focus on:

a. Flexible strategies: optimization of hybrid fuel usage (H2, NG, O2, electricity)
b. Technology integration research: hybrid furnace operation (induction, combustion, resistive), retrofit or greenfield (Figure 13).

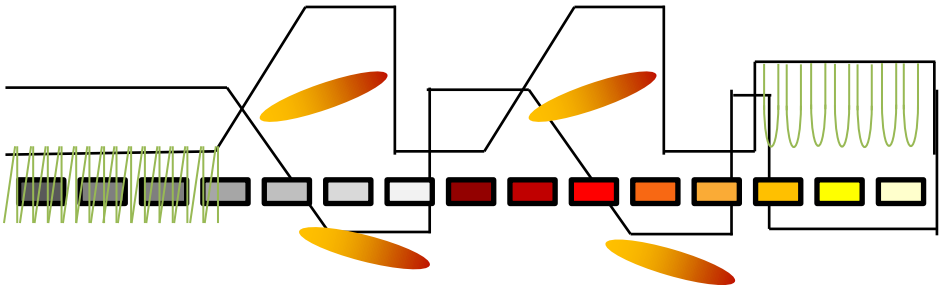

Figure 13 : Hybrid furnace operation

c. System integration research (Figure 14)
   - Internal integration within steel mill
   - Options for CCS/CCU
   - Flexible interaction with gas and power grids
   - Oxygen use
   - Integration with chemical industry for synthetic fuel production
   - Heat integration with steam production or hot water production
   - Steel flow logistics for optimal hot charging

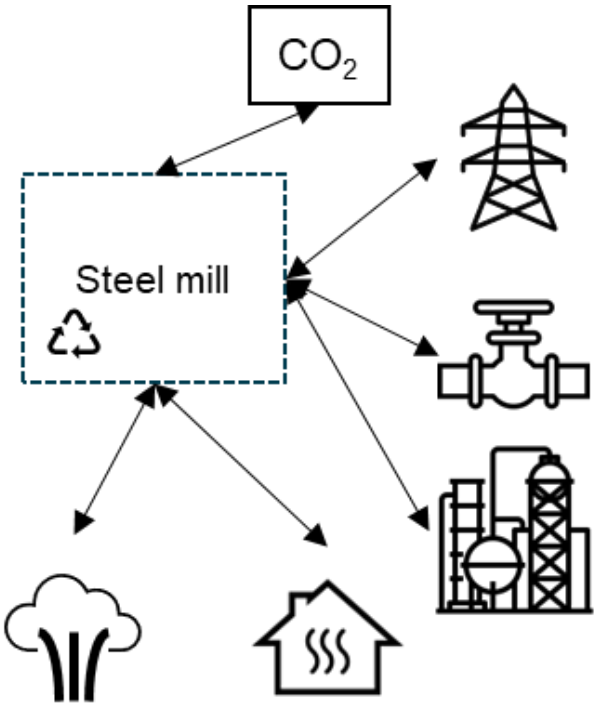

Figure 14 : Integration of heating

9 Final conclusions

The project has been completed at the end of 2023. On the homepage “www.dissheat.eu” all the following material is available:

- Reports
- Abstracts
- Recorded webinars with one webinar per main topic incl guest speakers
  - Heating and burner technology
  - Modeling of the entire furnace
  - Measurement technology and standards, regulations
  - Materials in the furnace and product quality
  - Heat transfer, heat recovery, productivity and CAPEX, OPEX
- Recorded webinar of this event- Roadmap
- Presentation material from Workshop at ESTAD 2023

10 ANNEX 1 : ROADMAP presentation during the ESTAD conf.

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Figure 1: presentation title.

Figure 2: Impact on heating.

Figure 3: Heating of products in the dark zone of the reheating furnace. Efficiency.

Figure 4: Impact the product and the plant by H2 combustion, electrical heating and hybrid.

Figure 5: Driving forces on hybrid heating combinations.

Figure 6: Solution with an electrolyser.

Figure 7: Driving forces for greenfield or brownfield installations.

Figure 8: Future demands on traditional modelling solutions

Figure 9: Statistical and AI approaches

Figure 10: AI and ML modeling loops and process control

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Figure 12: Impact of fuel quality.

Figure 13: Water content in off-gases under air and pure O2 combustion of various fuels.

Figure 14: Standards subject to suggested revisions.

Figure 15: Impact of new heating systems on standards and regulations

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Figure 17: Technology impact and integration research related to materials in the furnace.

Figure 18: Impact of 100% hydrogen firing on scale growth and composition

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Figure 20: One hybrid furnace solution.

Figure 21: Future system integrations research

Figure 22: Final comments on project during ESTAD roadmap workshop

Figure 23: Presenters during the ESTAD workshop, biography

Figure 24: Closing page


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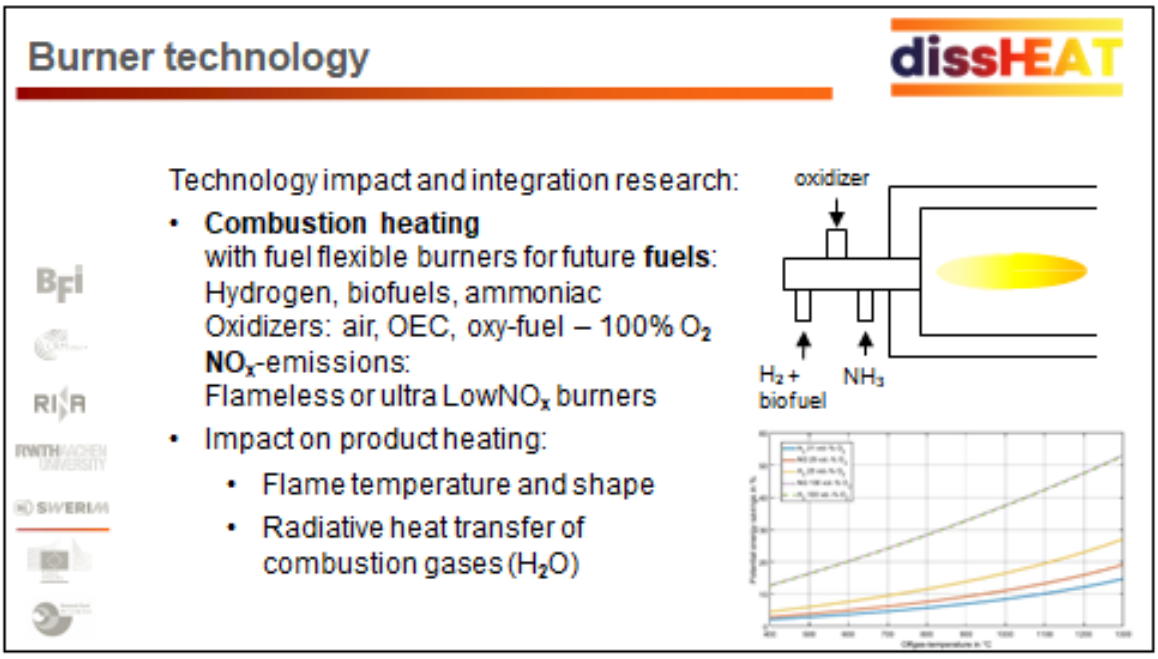
ROADMAP presentation for low carbon future for steel reheating furnaces

1


Burner technology
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Technology impact and integration research:
• Combustion heating
with fuel flexible burners for future fuels:
Hydrogen, biofuels, ammoniac
Oxidizers: air, OEC, oxy-fuel – 100% O2
NOx-emissions:
Flameless or ultra LowNOx burners
• Impact on product heating:
• Flame temperature and shape
• Radiative heat transfer of combustion gases (H2O)
oxidizer
H2 + biofuel
NH3

2

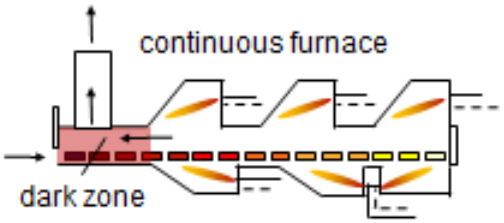
Heating technology - efficiency

Technology impact and integration research:

- **Efficient** heating with new technologies by heatrecovery from exhaust to preheat:
  - Oxidizer, future fuels or mixtures with exhaust
  - Product in dark zone / heating with off gas from new fuels, hybrid and combinations
- Impact of measures on efficieny in specific plants / use cases

Oxidizer	Preheating oxidizer	Dark zone
Air		
OEC*		
100 % O_2		

* OEC: oxygen enhanced combustion



3

Heating – product and plant

Technology impact and integration research:

Impact on **product and plant**

- Hydrogen combustion, electrical heating and combinations:
  - Influence on product-material, temperature uniformity, scaling
  - Influence on furnace and heating equipment when technolgies are combined: i.e. high H_2O content in exhaust gas
    => influence on resistance heaters
    => influence on refractory and insulation
  - Security when handling H_2 and/or O_2

4

Combustion and electric heating

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Technology impact and integration research:

Specific combinations of combustion and electric heating driven by

- Availability of future fuels and renewable energy:
  - Impact on use of H_2 produced by electricity or direct use of electricitiy for heating
  - Local availability of biofuels
- Product geometry and material:
  - Efficient induction heating not possibel for all formats of casted steel by current induction heating technology
  - Impact of heating method on materials / product

5

Hydrogen combustion

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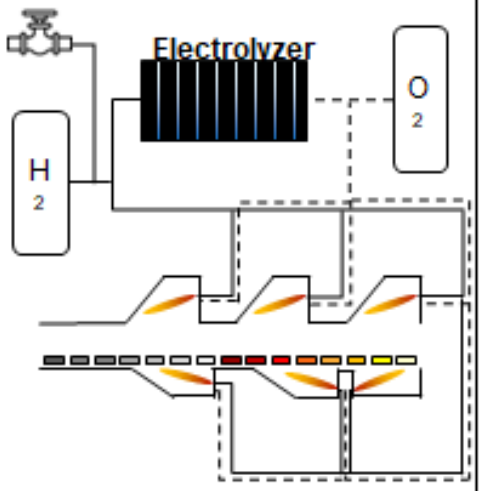
- Most simple retrofitting option, can preserve current infrastructure to a large degree
- Needs investment in electrolyzer or bought from market, preferably through gas grid
  - Electrolyzers currently undergoing upscaling to levels matching reheating furnaces
  - Gas grid a possible H_2 storage



6

Electrical heating from industrial PoV

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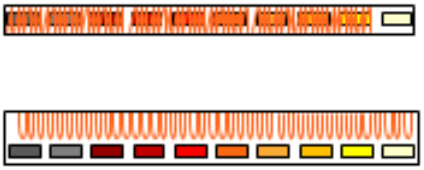
Greenfield installations

- New electrical furnace
- Induction furnace pre-heating for productivity
- Resistive for soaking
- Possible to use protective atmosphere



Retrofitting of existing furnaces

- Induction heating, but with relatively large losses
- Due to power density of resistive heating, only partial replacement of fuel possible
- RDH possible future market competitor with higher power density

Coalbrook RDH

7

Future research need
Relevant new technologies

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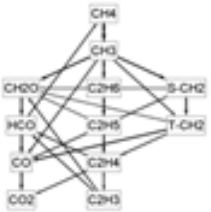
- Improved Kinetic Scheme
- pollutant prediction (including the formation of NOx and particulate emissions)
- Flame monitoring



Cantera

Tools:

- Kinetic scheme interpreter (CHEMKIN, Cantera)
- CFD software (Fluent, OpenFOAM…)
- CPU (Cluster, Servers)

ANSYS FLUENT

8

Future research need
Relevant new technologies

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- Extended statistical approach

- Artificial Intelligence and Machine Learning approach

9

Future research need
Technology impact and integration research

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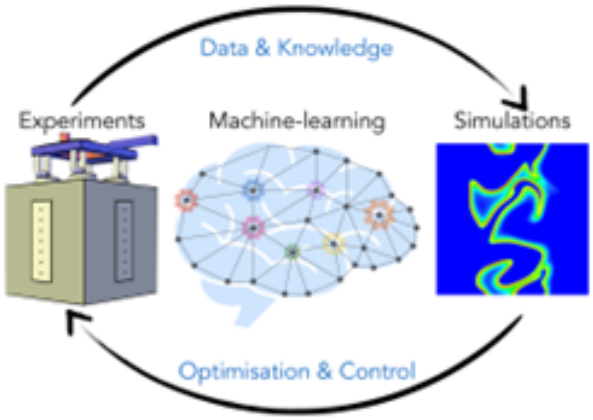
- Artificial Intelligence and Machine Learning approach
- Physical-injected neural network
- Dynamic and/or auto-adaptive modeling for process control



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Future research need
Big Data and Advanced Analytics overview
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Ingestion
Store
Preparation &Training
Serving
Visualization & Intelligence
Applications
Devices and sensors
Data Lake
Analytics Platforms
Machine Learning
Database
Datawarehouse
Analysis services
Predictive apps
Operational reports/ dashboards
Ingestion tools:
Kafka
MQTT
IoT/Event Hub
Data Lake:
Centralized repository that holds a large amount of structured and unstructured data at any scale.
Store raw data without a predefined schema, the schema is applied when the data is read, allowing for flexibility and agility in data exploitation.
Analytics Platforms:
Cloud Software-as-a-Service-like tool for processing massive amounts of data and developing, training and deploying models.
Provide on-demand scalability, based on computational and storage needs with pricing based on the resources consume (no hardware and infrastructure investments are required)

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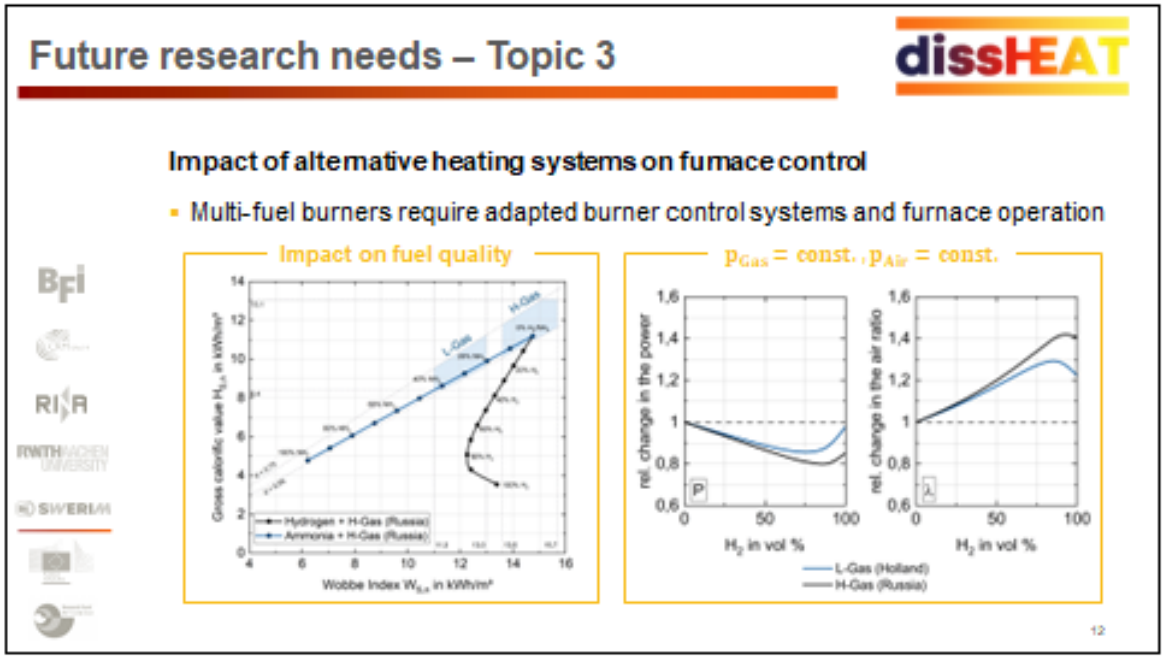

Future research needs – Topic 3
dissHEAT
Impact of alternative heating systems on furnace control
Multi-fuel burners require adapted burner control systems and furnace operation
Impact on fuel quality
Gross calorific value $H_{s,n}$ in kWh/m³
Wobbe Index $W_{s,n}$ in kWh/m³
L-Gas
H-Gas
Hydrogen + H-Gas (Russia)
Ammonia + H-Gas (Russia)
p_{Gas} = const., p_{Air} = const.
rel. change in the power
rel. change in the air ratio
H_2 in vol %
L-Gas (Holland)
H-Gas (Russia)
12

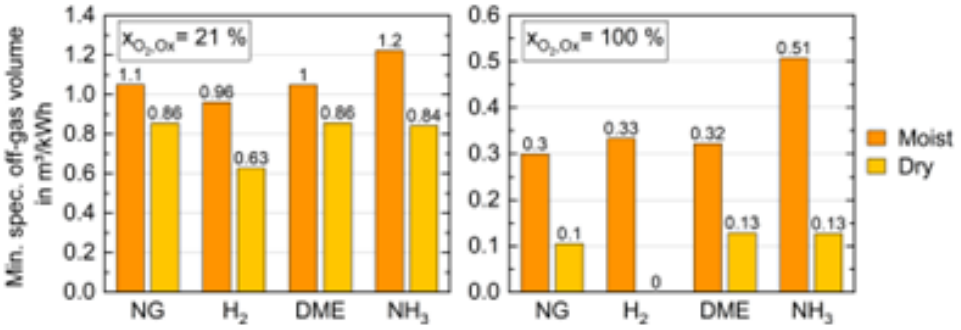
12

Future research needs – Topic 3

dissHEAT

Impact of alternative heating systems on off-gas measurements

- Water content in off-gas using alternative fuels and oxyfuel



For a fair comparison of NO_x emission, measurement on moist basis is recommended

13

13

Future research needs – Topic 3

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Impact of alternative heating systems on standards and regulations

- Revision of emission measurement standards for measurement on moist basis

EN 14792

Stationary source emissions – Determination of mass concentration of nitrogen oxides – Standard reference method: chemiluminescence

EN 14181

Stationary source emissions — Quality assurance of automated measuring systems

EN 15267-3/-4

Assessment of air quality monitoring equipment –Part 4: Performance criteria and test procedures for stationary/portable automated measuring systems for periodic measurements of emissions from stationary sources

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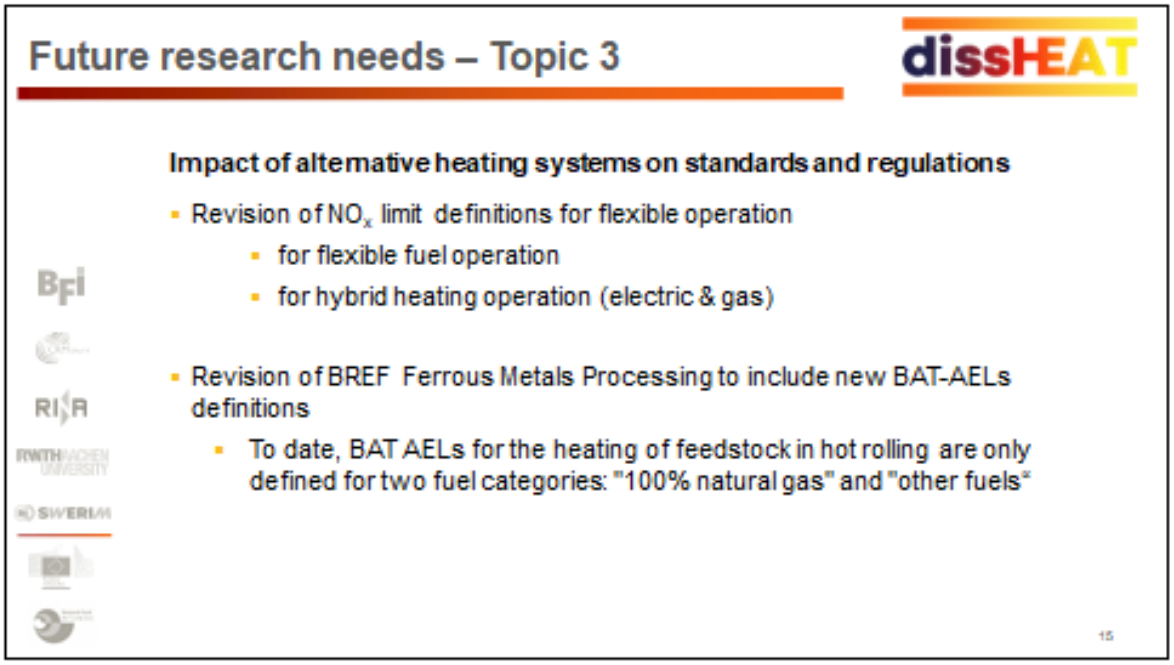
14


Future research needs – Topic 3
dissHEAT
Impact of alternative heating systems on standards and regulations
Revision of NO_x limit definitions for flexible operation
for flexible fuel operation
for hybrid heating operation (electric & gas)
Revision of BREF Ferrous Metals Processing to include new BAT-AELs definitions
To date, BAT AELs for the heating of feedstock in hot rolling are only defined for two fuel categories: "100% natural gas" and "other fuels"
15

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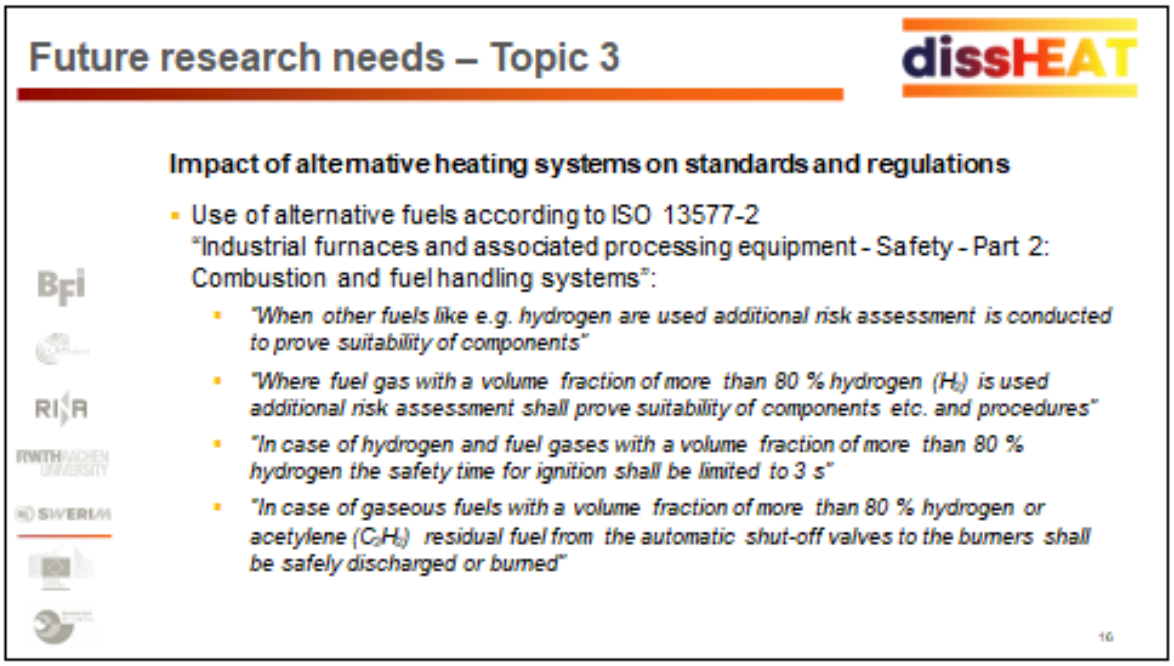
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Use of alternative fuels according to ISO 13577-2 "Industrial furnaces and associated processing equipment - Safety - Part 2: Combustion and fuel handling systems":
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"Where fuel gas with a volume fraction of more than 80 % hydrogen (H_2) is used additional risk assessment shall prove suitability of components etc. and procedures"
"In case of hydrogen and fuel gases with a volume fraction of more than 80 % hydrogen the safety time for ignition shall be limited to 3 s"
"In case of gaseous fuels with a volume fraction of more than 80 % hydrogen or acetylene (C_2H_2) residual fuel from the automatic shut-off valves to the burners shall be safely discharged or burned"
16

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Materials and product quality

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1. New insulation materials for reheating furnaces to limit heat loss
2. Application of reflective coatings on the furnace walls
3. New ceramic materials with improved resistance for humidity and different scale layers.
4. Study the impact of residuals on product quality and reheating strategy
   - Cu: diffuses quickly leading to segregation, roughening and intergranular oxidation
   - Mo: above 0,25% will increase scale adhesion

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Materials and product quality

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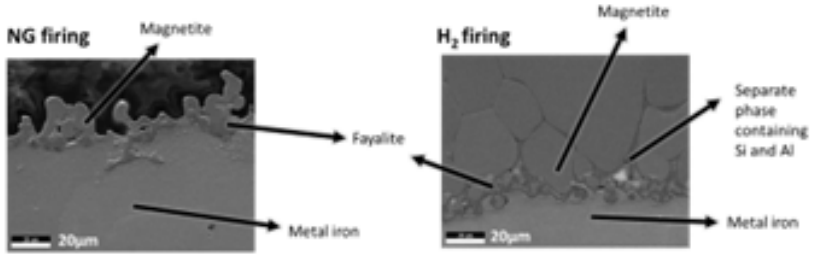
1. Perform a full screening of all grades related to the different reheating alternatives (e.g. 100% Hydrogen combustion)



DP780: Scale spalling took place in a different location for NG and H_2 firing.
A separate phase (Si & Al content) is observed for H_2 firing.

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Materials and product quality

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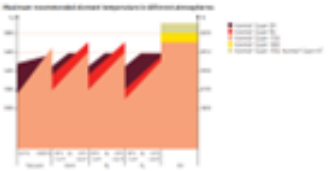
3. Adaptations :
   - Gas flow and composition (e.g. Nitrogen injection at exit)
   - Coatings
   - Alternative metallugical composition

4. Wear of components :
   - Burner nozzle wear by hydrogen flame
   - Wear of electrical resistances



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Heat recovery, heat transfer, productivity

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Flexifuel strategies

- Optimization of hybrid fuel usage (H_2, NG, O_2, electricity)

Technology integration research

- Hybrid furnace operation (induction, combustion, resistive)
  - Retrofit
  - Greenfield

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Heat recovery, heat transfer, productivity

System integration research

- Internal integration within steel mill
- Options for CCS/CCU
- Flexible interaction with gas and power grids
- Oxygen use
- Integration with chemical industry for synthetic fuel production
- Heat integration with steam production or hot water production
- Steel flow logistics for optimal hot charging

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Final comments

- The project runs until end of 2023 and all following material is available on the homepage www.dissheat.eu
  - Reports
  - Abstracts
  - Recorded webinars with one webinar per main topic incl guest speakers
    - Heating and burner technology
    - Modeling of the entire furnace
    - Measurement technology and standards, regulations
    - Materials in the furnace and product quality
    - Heat transfer, heat recovery, productivity and CAPEX, OPEX
  - Recorded webinar of this event- Roadmap
  - Presentation material from Workshop at ESTAD 2023

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Acknowledgement

This project has received funding from the Research Fund for Coal and Steel under grant agreement No 101057930.

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