Hydrogen for circular industrial high-temperature processes

Opportunities and challenges

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MateQ PROCESS

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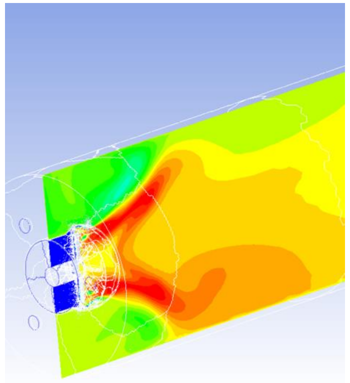
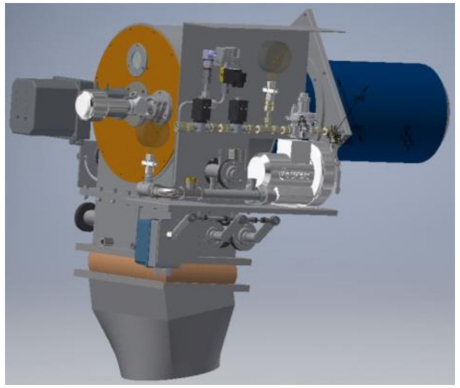
About Mateq Process

Mission: facilitating the energy transfer for industrial high-temperature processes

Focus:

- *Process design of circular heat transfer equipment*
- *Development of tools and models for product and process analysis*
- *(CFD-) analysis of industrial flow and heat transfer*





Overview of activities

Development of ultra-low NOx hybrid hydrogen – natural gas burner

- Joint venture with SUSCOMB (Heteren, GLD): Combustion2 B.V.

Development of circular Iron fuel combustion system

- Technology and Management Consultancy to RIFT | Renewable Iron Fuel Technology B.V.

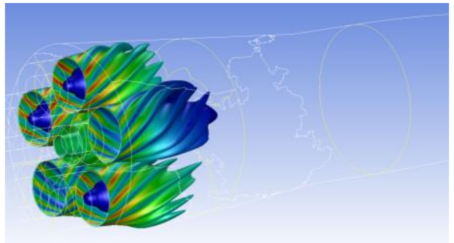
Facilitating transfer to Hydrogen for high-temperature industrial processes

- H2Hub Twente: Program leader of high-temperature working group

2nd year coordinator International Master in Sustainable Energy Technology

- Part-time position at University of Twente

Consultancy on analysis and improvement of complex high-temperature processes



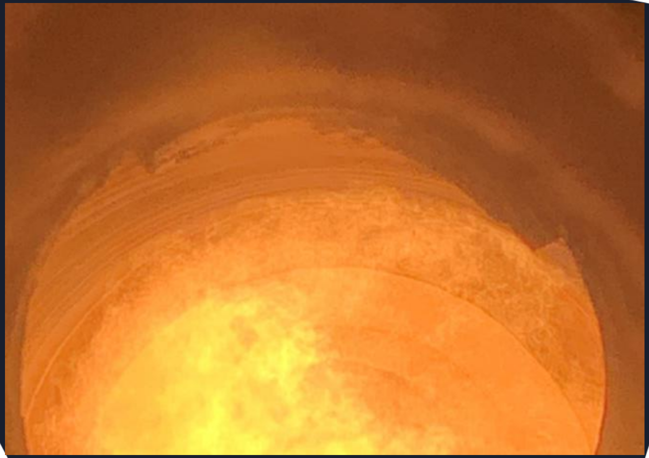
Opportunities for Hydrogen in circular high-temperature industrial processes

For high-temperature (> 650 °C), high-volume industrial thermal processes, combustion is the sole economically feasible means of achieving the required temperatures, at the requested total heat input in MW or gas flow volume

Electrical systems either do not reach the required temperature levels, or cannot handle the desired total heat input, or both

Hydrogen is the logical candidate for a circular fuel for these processes

- Its (future) availability
- Lack of carbon in cycle
- Excellent combustion properties

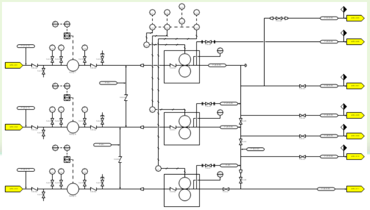


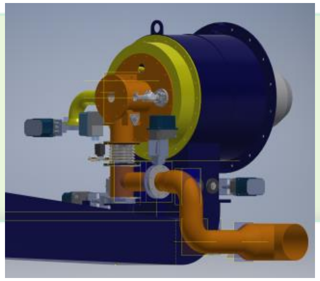
Transition to Hydrogen in practice

In the transition to hydrogen for an industrial process, two main subjects need to be assessed:

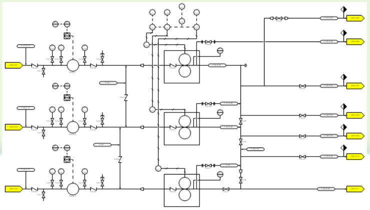
The (continuous) **availability** of green hydrogen

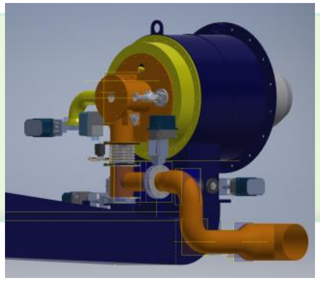
Consequences for the **use** of Hydrogen for the thermal process and its equipment – focused here on firetube water/steam boilers





The availability of green Hydrogen





The availability of green Hydrogen

Hydrogen production via green sources is often dependent on the availability of these sources (mostly sun and wind)

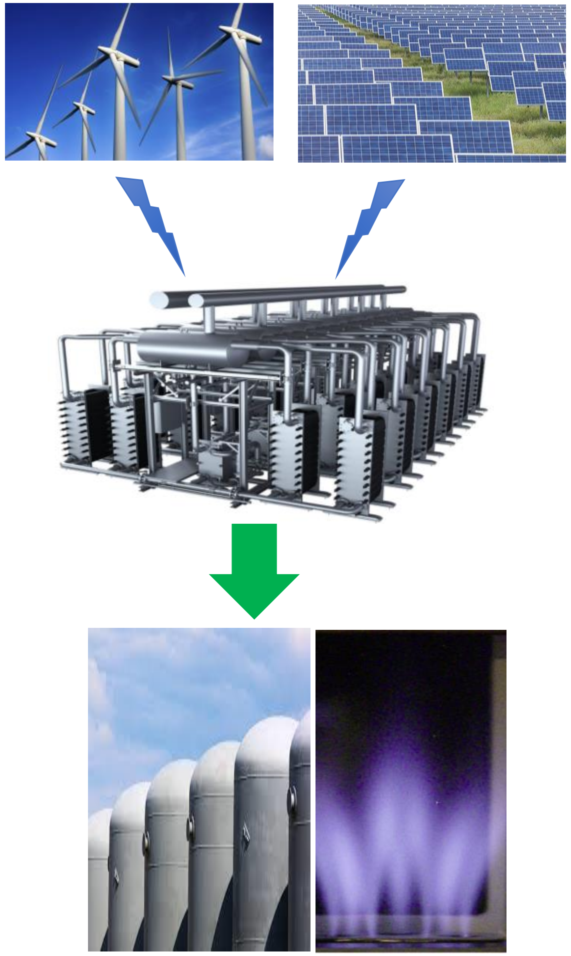
Production processes also typically have a modulating energy demand

Discrepancies between supply and demand of Hydrogen can be resolved with a mix of

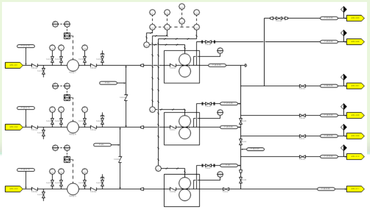
- Optimization of supply and demand by adjusting production process energy cycles
- Hydrogen / energy storage
- Using backup energy sources (usually natural gas is seen as a logical alternative)

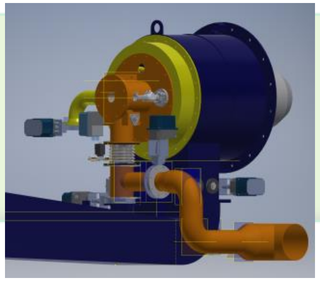
This yields a business case that needs to be assessed and optimized per specific site / process

It is my perception that natural gas will – certainly in the coming years – be viewed as a backup fuel or support fuel and should be considered in the fuel mix



Consequences for boiler combustion equipment





Hydrogen as energy carrier for high-temperature processes

- Hydrogen can very easily be combusted with air in an industrial burner; this technology is decades old

- However, those designs mostly focused on the safe and complete (co-) combustion of residual Hydrogen of industrial processes, and not necessarily on achieving ultra-low emission levels of NOx

- In (Dutch) legislation, Hydrogen is still not considered a reference fuel, and can have less strict emission level requirements for large installations than natural gas

NASA Glenn Hydrogen burner
Source: Comb. Flame 156 (2009) – pp. 1234-1241

Hydrogen as energy carrier for high-temperature processes

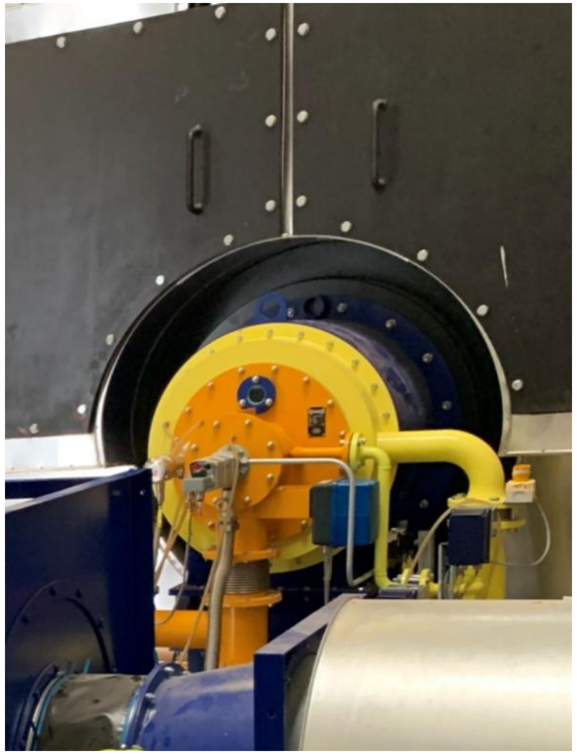
- Achieving ultra-low NOx levels in Hydrogen combustion poses several challenges, due to some specific properties of Hydrogen:
  - High combustion velocities
  - High peak temperatures of Hydrogen – air combustion
  - Wide flammability envelope
  - High diffusivity
  - Low density
  - Influence on materials

- These properties have consequences for both the design and the use of ultra-low NOx Hydrogen combustion equipment

NASA Glenn Hydrogen burner
Source: Comb. Flame 156 (2009) – pp. 1234-1241

Ultra-low NOx design rules for industrial burners

Industrial fuel gas burners usually achieve low NOx emissions by keeping peak flame temperatures low



Peak temperatures are kept low(er) by introducing bulk gases in the combustion zone, that are not participating in the combustion process but do absorb heat

- Excess air
- Flue gases

Methods that are often used are a combination of

- Lean premixing of fuel and air
- Staged combustion of fuel and air
- Use of (external) flue gas recirculation

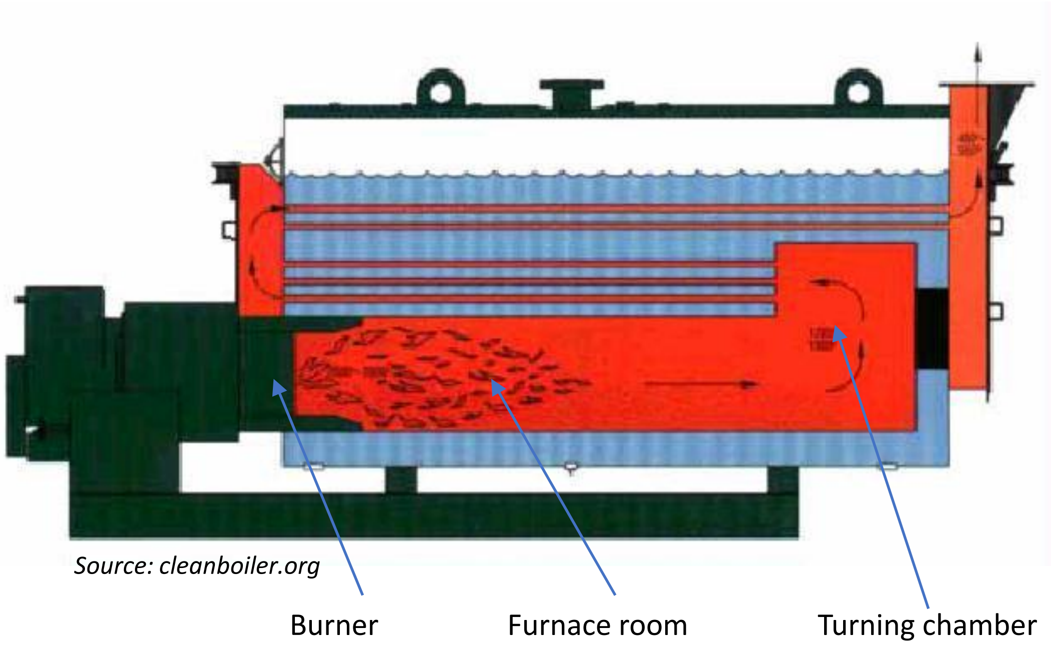
Firetube boiler combustion equipment features

In a firetube boiler, the burner fires into a relatively narrow, long, cylindrical furnace room

The furnace room is surrounded by boiler water, i.e., its walls are very efficiently cooled

At the end of the furnace room, flue gases make a 180 degree turn, into the convection section

Combustion needs to be completed in the furnace room – any reactions are quenched in the convection section



Source: cleanboiler.org

Firetube boiler combustion equipment features

Industrial hot water and steam boilers are operated at an air excess as low as possible – out of efficiency considerations

- Overall air excess typically 5% to 15% for gas-fired boilers

Excess air supply for low NOx must be compensated elsewhere to yield overall near-stoichiometric combustion

- Lean premix needs to be compensated by additional fuel injection elsewhere
- Fuel/air staging must be such that overall ratio is near-stoichiometric

This means that a low-NOx boiler burner inherently has large fuel lean, as well as large fuel-rich zones

SUSCOMB / Mateq Process 30mg SMARTNOX burner in 7.5MW natural gas firetube boiler

Firetube boiler combustion equipment features

Industrial hot water and steam boilers are also designed for maximum possible heat load (in MW per m^3 fire room) – yielding compact flames

Flue gas recirculation (FGR) is an essential part of ultra-low NOx boiler combustion

- External : flue gases are extracted at the stack and mixed with fresh combustion air
- Internal: flue gases flow back into the flame zone inside the furnace room, by clever design of burner and furnace

Flue gas recirculation reduces flame intensity and broadens flame zones – which is conflicting with boiler heat load demands

SUSCOMB / Mateq Process 30mg SMARTNOX burner in 7.5MW natural gas firetube boiler

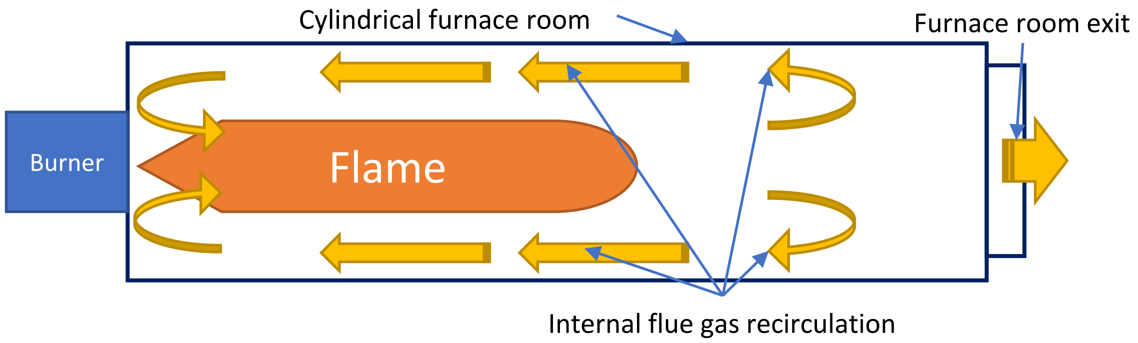
Example – generic low-NOx boiler burner

Firetube boiler burners are 'parallel flow' burners

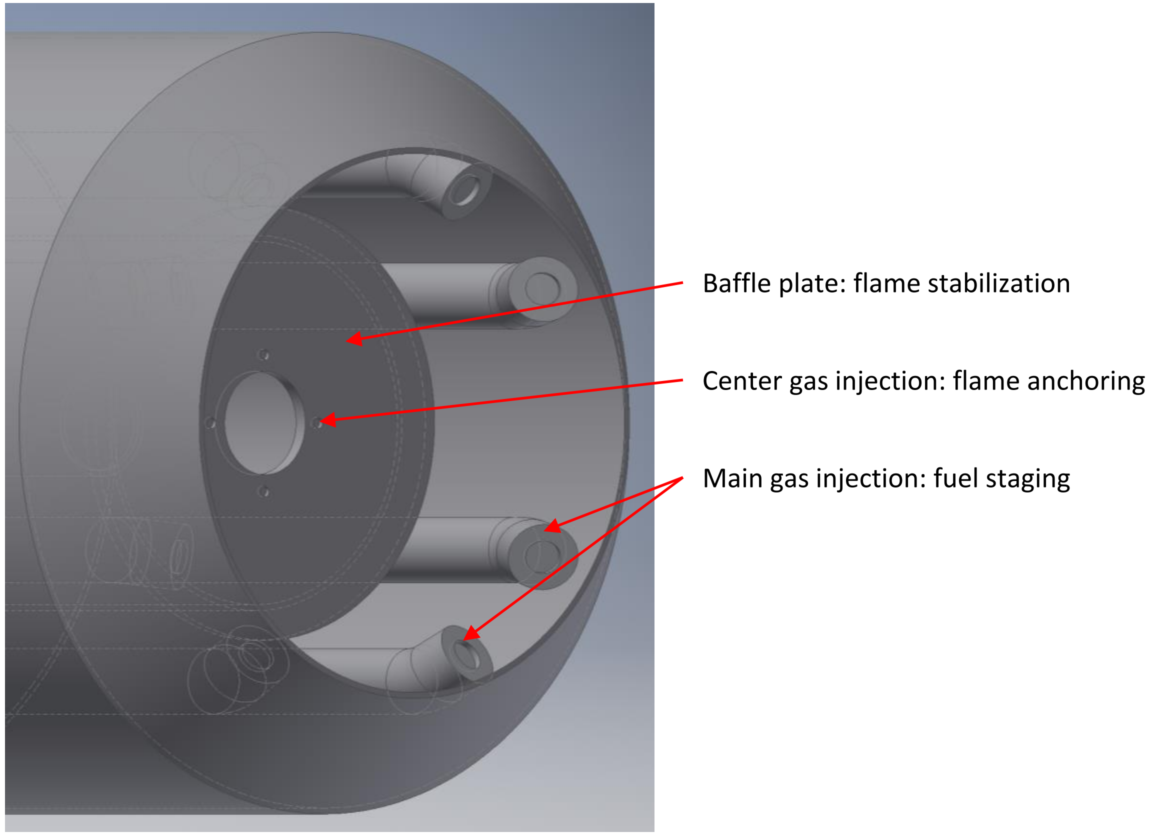
- No swirl in main combustion air
- Optimal internal flue gas recirculation via furnace room side wall

Low-NOx features are

- Fuel lean center flame – sometimes premix or nozzle-mix
- Fuel staging using main fuel
- Flue-gas recirculation



Generic firetube boiler burner head



Design challenges for hydrogen-fueled industrial burners

With premixing, there is a higher risk of flashback

Fuel / air staging is more difficult to achieve

Fuel gas and air volumes are different under Hydrogen than under natural gas combustion

In the material selection / assessment of (existing) equipment, sensitivity to Hydrogen needs to be assessed

- Hydrogen attack / embrittlement
- Hydrogen-tightness

Commissioning SMARTNOX burner by SUSCOMB and Mateq Process

Fuel/air staging: Flammability limits – Cold flow simulation of fuel/air mixing

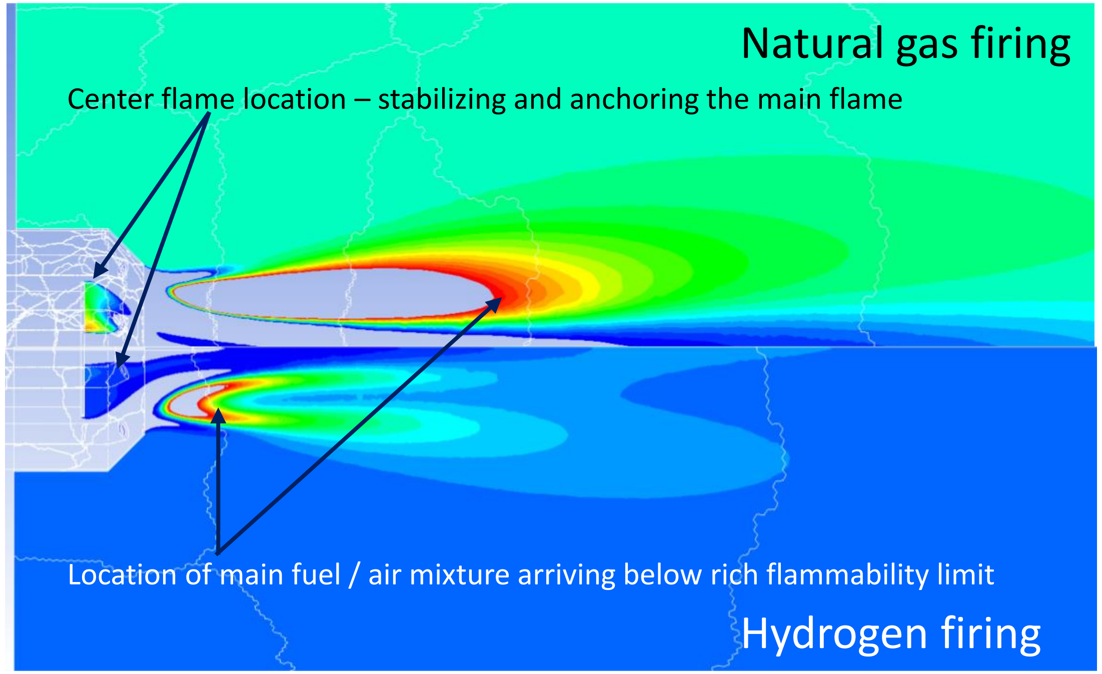
Hydrogen flame staging is less effective than with natural gas

- Less room for mixing with flue gas and center flame combustion products before main gas ignition

Flame will burn more intensely and closer to burner head

- Higher NOx emissions
- Caution for local overheating

Colors indicate degree of mixing within flammability limits – absence of color means not flammable



Comparison of flow volumes – H2 vs CH4 firing 7.5MW burner

Fuel gas flow volume of H2 is significantly higher

- Higher nozzle velocities
- But: due to low density, similar pressure drop

Air requirement is higher for CH4

- Higher throat velocities for CH4 firing than for H2 firing

→ Throat velocity is a design value; compromise or cross section adaption is needed

FGR volume of H2 firing is higher

- Lower FGR velocities in CH4 firing

→ lower FGR velocities may compromise mixing quality

→ Higher FGR volumes may lower flame stability

Feature	CH4 firing	H2 firing
Fuel gas flow	752 m_0^3/h	2.505 m_0^3/h
Air requirement	8.276 m_0^3/h	6.865 m_0^3/h
FRG flow *)	1.350 m_0^3/h	1.850 m_0^3/h

*) FGR flow assessed as flow, needed to reach same overall flame temperature

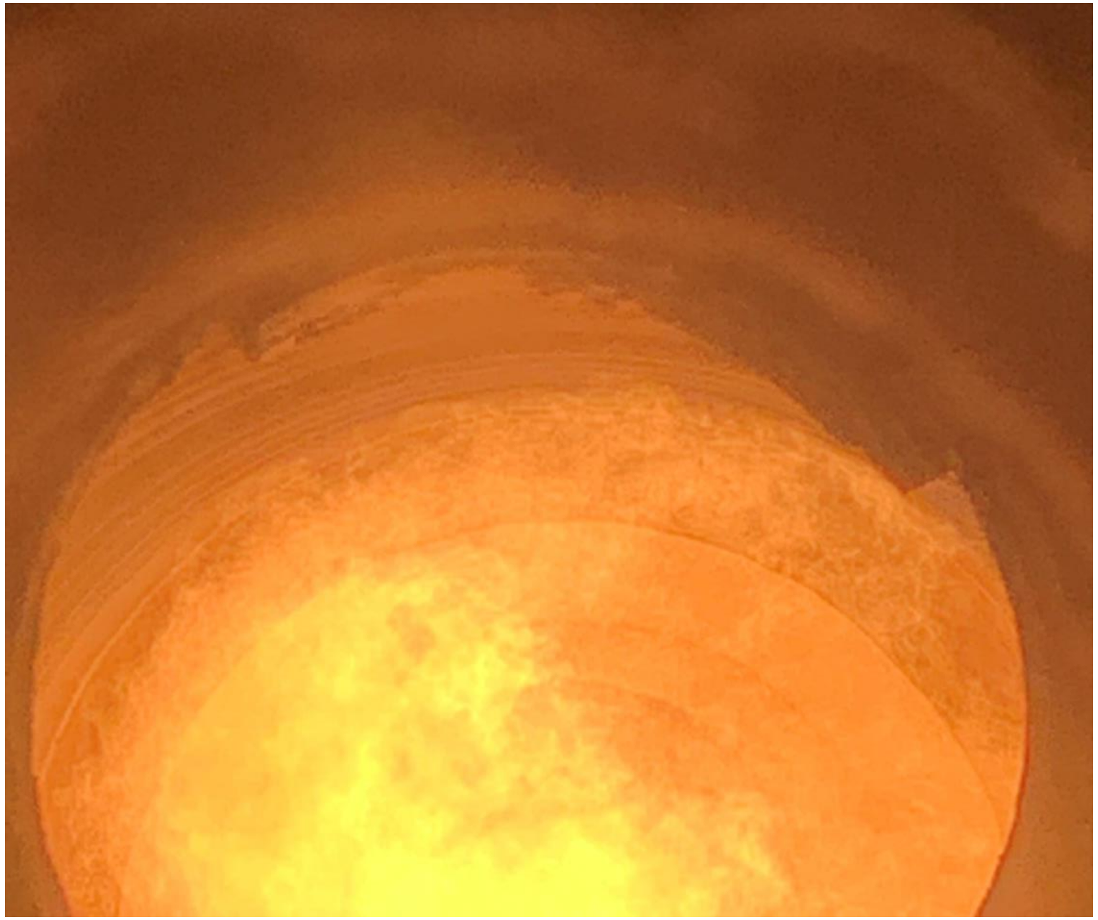
Modeling challenges for low-NOx boiler combustion equipment

Several features yield difficulties for current available combustion models

- Large fuel-rich zones
- Excessive flue gas recirculation
- Large, distributed combustion zones
- H2: high differential diffusion

Most combustion models assume

- Fast combustion
- Well-defined flame fronts
- Equal diffusivity



Modelling challenges for low-NOx boiler combustion equipment

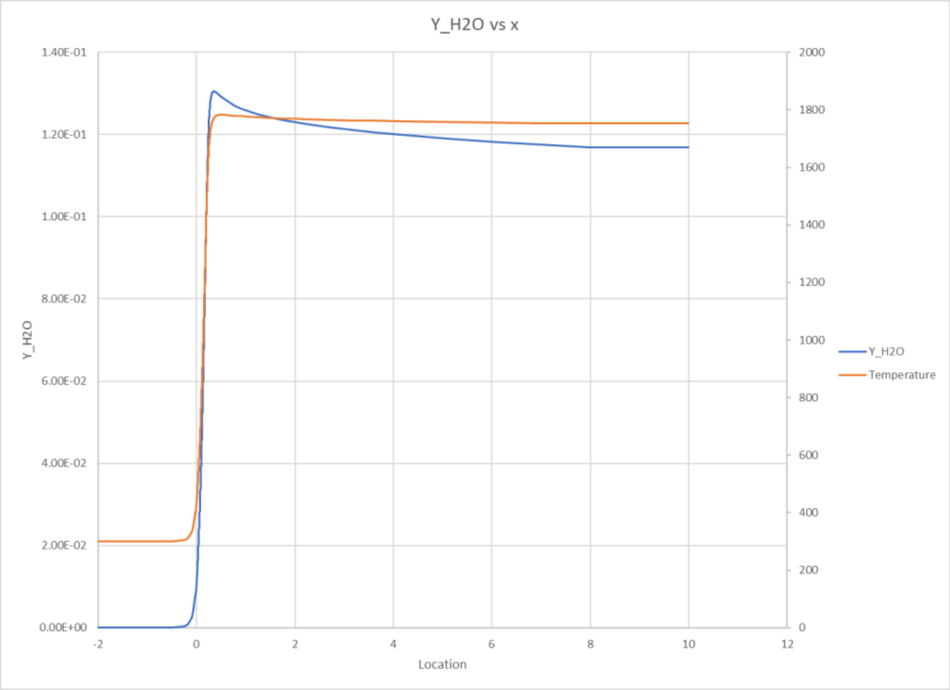
Combustion models incorporating detailed chemistry often use reaction scalars, such as mixture fraction and progress variables (RPV's)

RPV's are usually precalculated using representative laminar flames and stored in a database

- → The mixture fraction approach does not incorporate differential diffusion
- → In fuel-rich flames, profiles sometimes peak in the flame zone; results cannot be easily inverted to setup database
- → This issue is more severe in rich CH4 and CH4/H2 mixed flames than in pure H2 flames

Rich methane-air flame

Temperature and H2O mass fraction profiles



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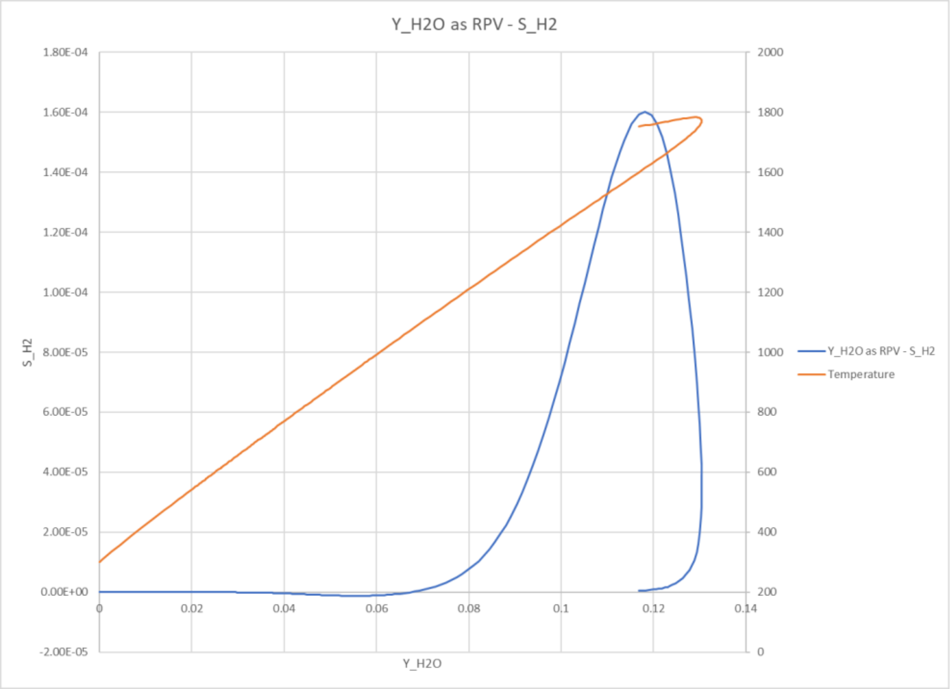
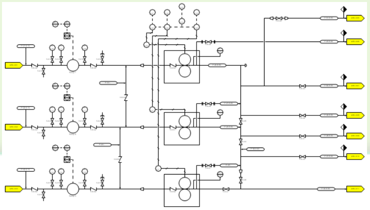
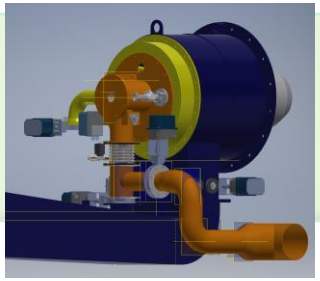
Rich methane-air flame

Temperature and H2 source term fraction mapped onto H2O mass fraction



Conclusion





Conclusion

Hydrogen is one of the main circular energy carriers for high-temperature thermal industrial processes

For a successful transition to Hydrogen, an integral approach needs to be taken, incorporating the complete energy supply chain and being site-specific

For the foreseeable time, backup energy sources such as natural gas should be considered in the energy supply chain

The specific properties of Hydrogen compared to natural gas poses real challenges for developing low-NOx combustion equipment, as well as its CFD combustion modeling

Design rules need to be adapted for low-NOx Hydrogen boiler combustion equipment, as current practice is less effective, poses more inherent risks, and affects boiler design

In modeling of low-NOx industrial boiler combustion processes, accuracy is needed in representing large zones of fuel-rich combustion, distributed combustion, as well as flue-gas recirculation

Thank you for your attention

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Sources

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