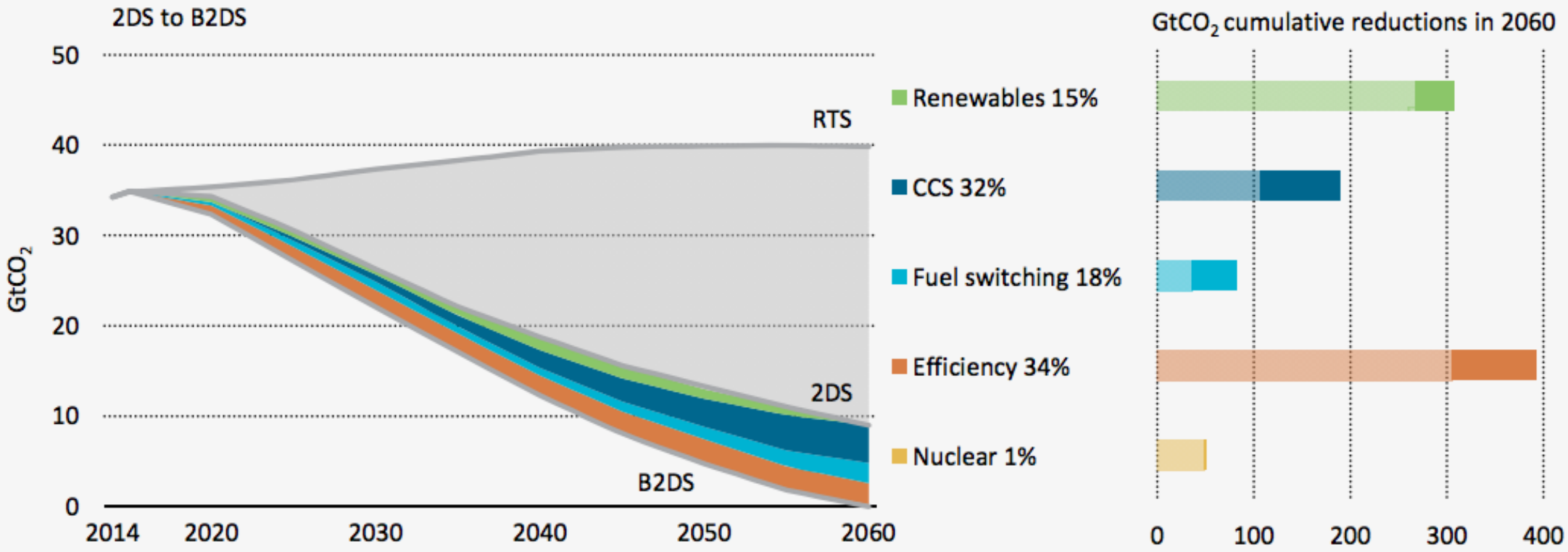
WHEN TRUST MATTERS

Hydrogen as fuel for the glass industry; what are the challenges?

Sander Gersen - DNV, and Oscar Verheijen - Senior consultant, CelSian Glass & Solar

16 June 2021

The need to reduce CO_2 emissions and enhance sustainability of energy supply are major drivers towards the introduction of renewables



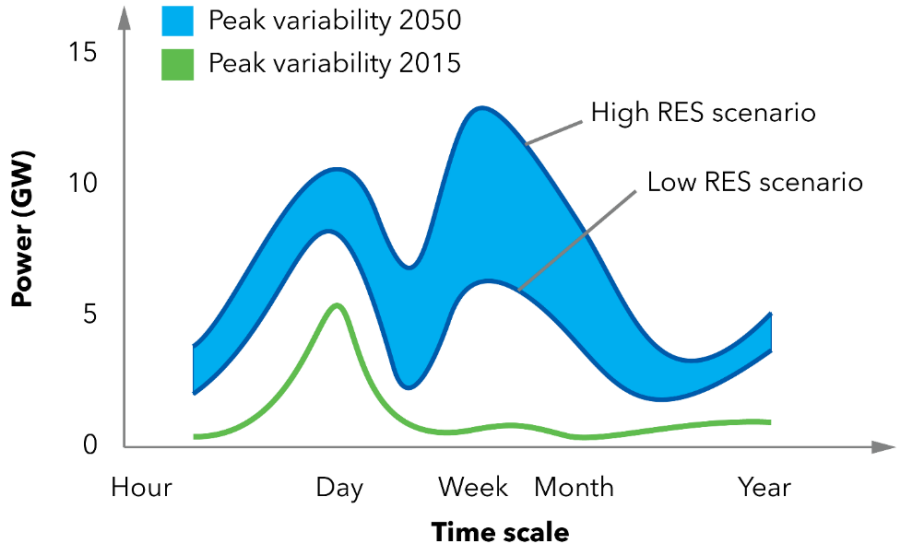
Note: Light areas in the right graph represent cumulative emissions reductions in the 2DS, while dark areas represent additional cumulative emissions reductions needed to achieve the B2DS.

Bron: https://www.carbonbrief.org/iea-world-can-reach-net-zero-emissions-by-2060-meet-paris-climate-goals

source:https://www.iea.org/etp/explore/

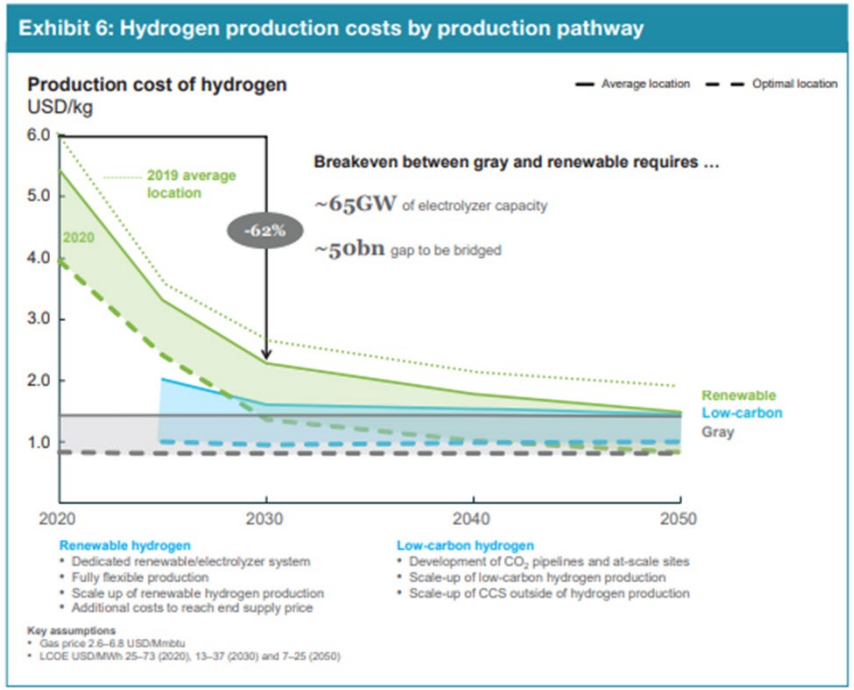
Challenges to accommodate electricity produced from solar PV and wind

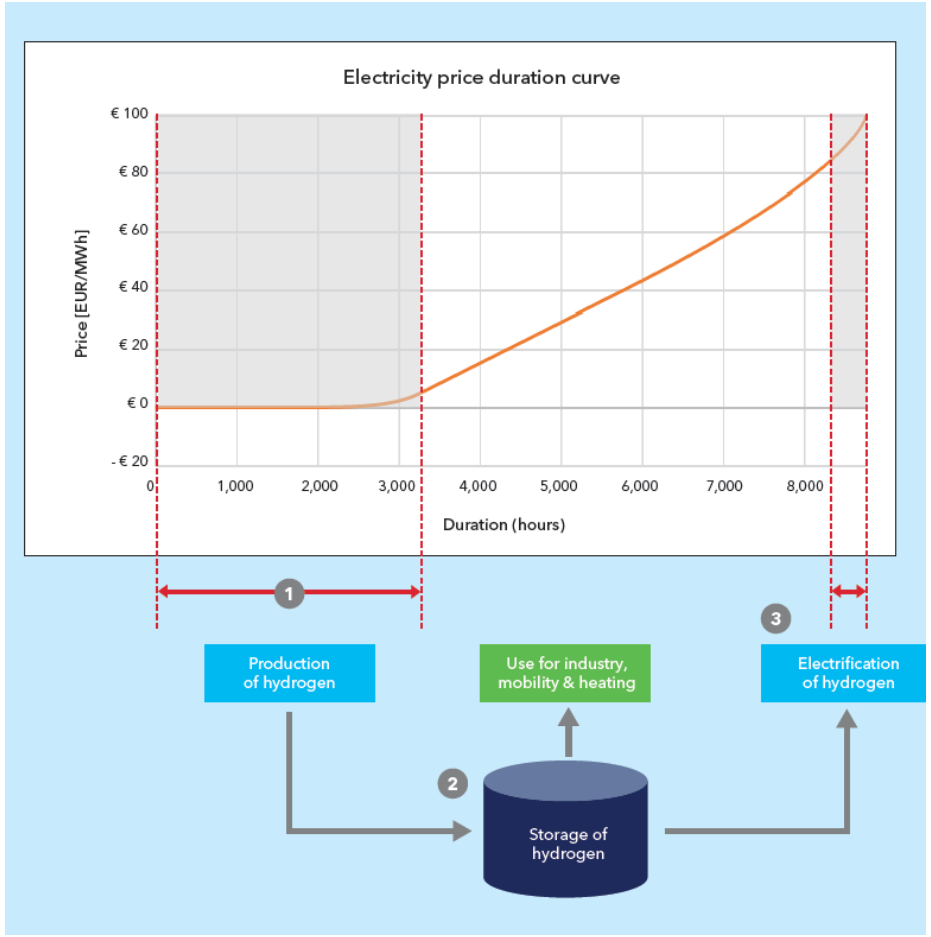
- Electricity produces from solar PV and wind increases substantially
- Intermittent nature of solar and wind energy puts pressure on capacity of power grids
- Excess of renewable electricity can be converted into hydrogen (Power-To-Hydrogen)
- Injecting renewable gas in existing gas grid is an effective means to avoid large investments in new infrastructures



Costs of hydrogen versus natural gas and electricity

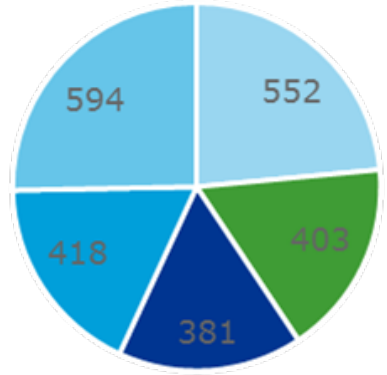
- **Costs 1 MWhr heat:**
  - Natural gas (about 100nm^3) € 20
  - Electricity € 50
  - H_2 from NG (SMR, € 1,65/kg) € 50
  - Green hydrogen € 70
    (elektrolysis, € 2,25/kg)
  - Hydrogen produced from electricity surplus € 35





Renewable gas markets and opportunities

- Hydrogen can be used in the mobility sector, the built environment and the industry
- Natural gas grids are already connected to the built environment and the industry
- Given the large penetration of natural gas in the total global energy mix, the increase of renewable gas in the total gas supply will result in a substantial carbon emission reduction



Netherlands energy consumption in PJ

- Industry
- Transport
- Residential
- Commerce and services
- Non-energy use industry

Industry

Mobility

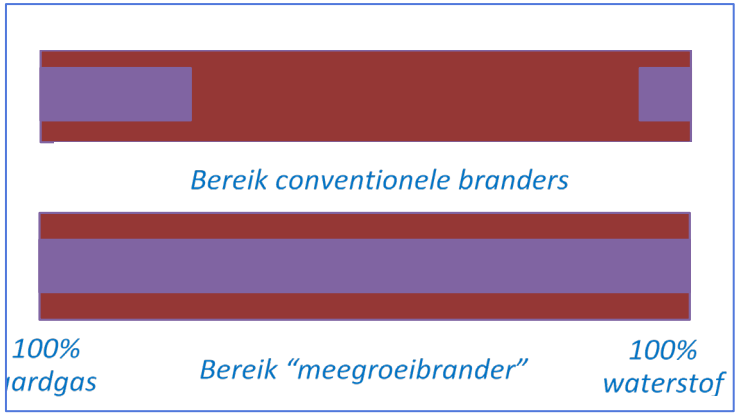
Built Environment

Challenges in the application of hydrogen in the heating industry

1. **Availability of hydrogen**
2. **Unchanged product quality**
   - Combustion properties
   - Changes in temperature, flue gas composition and flame radiation
3. **Simple and cost-efficient implementation**

Challenges when using hydrogen in the industry (1) - Availability

- In the initial phase of the energy transition, it is unlikely that there always will be enough hydrogen available to satisfy the entire industrial energy demand, whose processes usually run continuously (24/7) throughout the year
- Next to 100% hydrogen supply also blending natural gas with hydrogen is consider as an option
- An **attractive solution** is to apply a burner systems that can flexibly utilize the full mix of fuel compositions: 100% hydrogen, 100% natural gas and all mixtures of hydrogen and natural gas in between using a gas adaptive fuel-air ratio control system
- The major economic advantage of such a system is that it offers robust fuel flexibility with only a **limited investment**:
- **The same burner system** can be used throughout the transition, supplied initially with **varying** natural/gas hydrogen mixtures, and in the end with pure hydrogen when the supply has risen to the challenge.



Challenges when using hydrogen in the industry (2) - Combustion properties

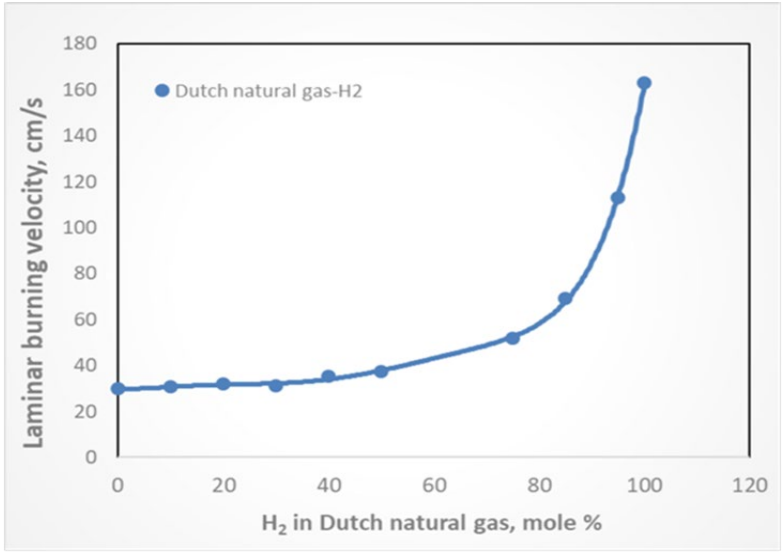
Combustion properties of hydrogen differ substantially from natural gas:

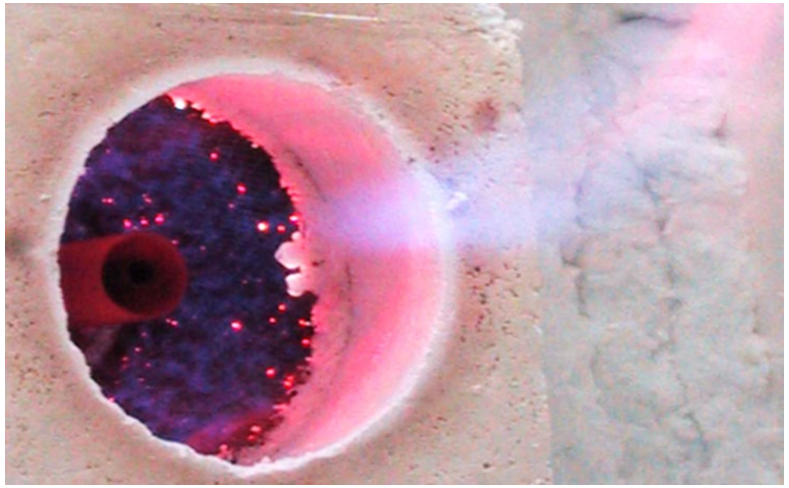
1. Higher flame temperatures
2. Burning velocity of hydrogen is about 6 times higher than natural gas
3. Calorific value of hydrogen is three times lower than natural gas
4. Factor of four difference in the air requirement between hydrogen and natural gas

$H_2 + ½O_2 => H_2O$ 11 MJ/m_n^3

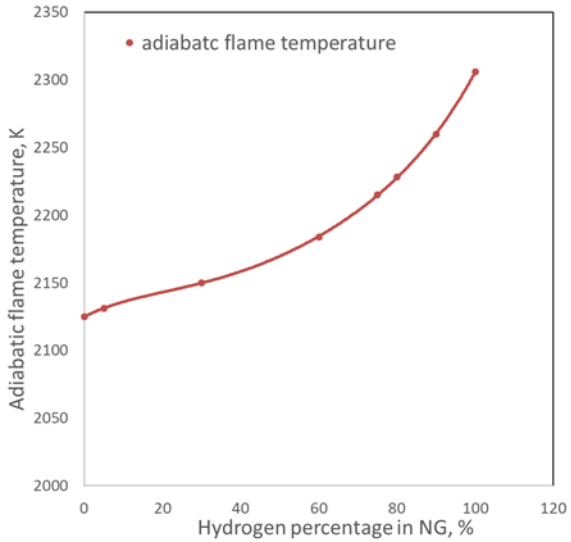
$CH_4 + 2O_2 => CO_2 + 2H_2O$ 36 MJ/m_n^3

5. Potential increasing NO_x with increasing hydrogen fraction in natural gas
6. Changes in the oven atmosphere (flue gas composition)
7. Changes in the heat transfer (radiation/convection)



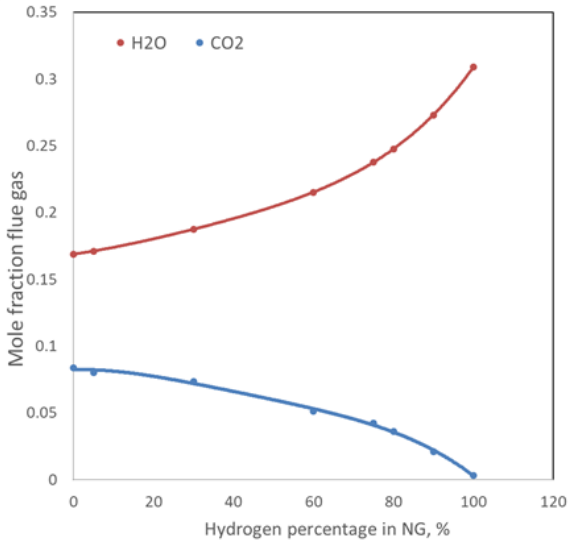


Challenges when using hydrogen in the industry (3)
Changes in temperature, flue gas composition and flame radiation

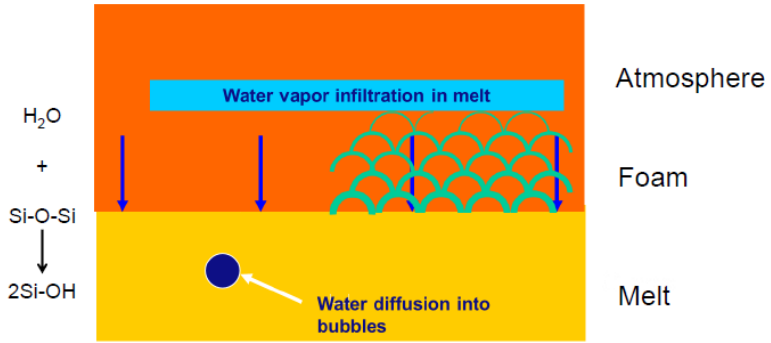


Higher flame temperature increases the 'thermal' NO_x formation via;

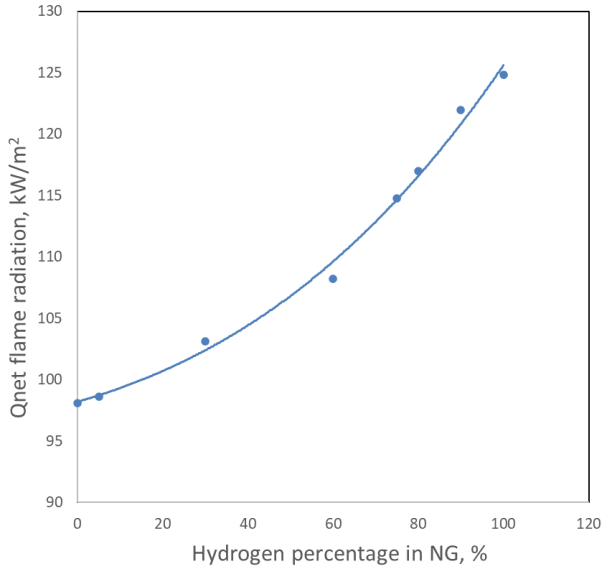
$$N_2 + O \leftrightarrow N + NO$$
$$N + O_2 \leftrightarrow NO + O$$
$$N + OH \leftrightarrow NO + H$$



Change in combustion atmosphere can affect production processes and product quality. For example for melting glass;



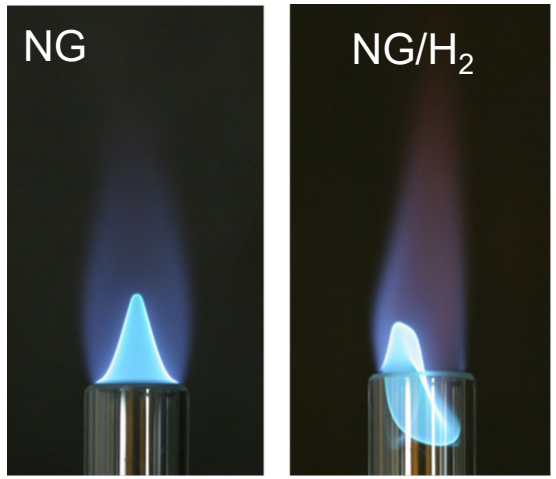
Source: Celsian



Increase in flame radiation as result of increasing temperature and change in composition impacts heat transfer and product quality

Example: changes in burner performance when adding hydrogen to natural gas

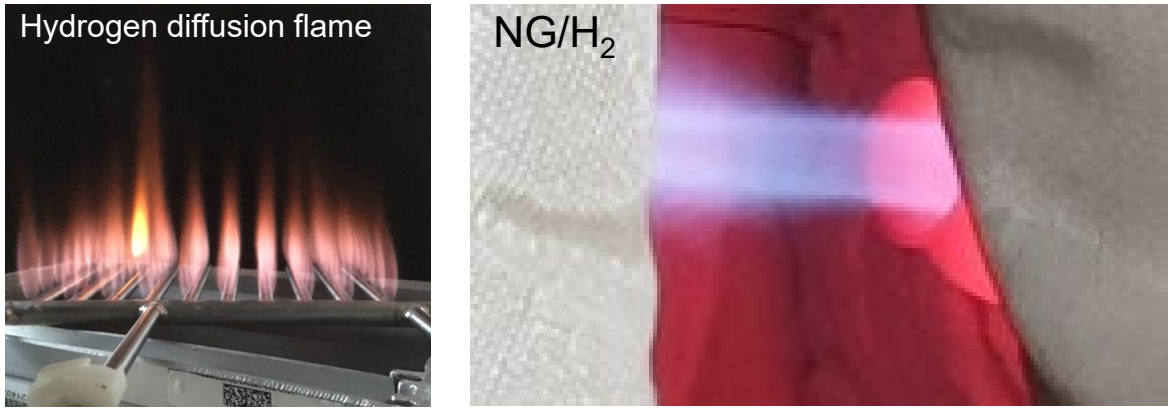
Premix burners (fuel and air premixed)



Some potential issues premixed burners such as domestic boiler and industrial pencil burners (glass industry):

- increase in burning velocity results in flash back
- About 70% hydrogen in NG in premixed appliances results in flash-back
- Increase NO_x and over heating burner deck
- Mitigating measure increasing air factor (excess air)

Diffusion burners (fuel and air not premixed)



Potential issues diffusion burners

- Change in flame stability
- Increase NO_x and over heating burner deck
- Change in air factor and burner power
- Mitigating measures: applying gas adaptive control and flue gas recirculation

Example combustion behaviour when adding hydrogen to swirl burners

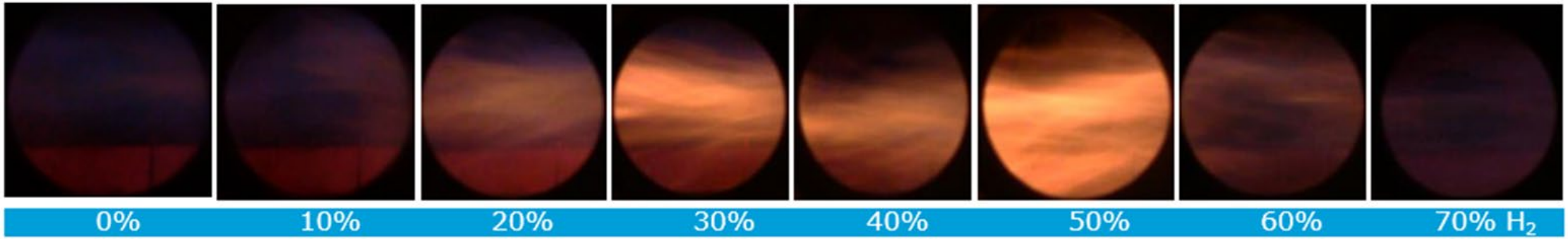
Natural gas combustion

(F. Cozzi et al)

Natural gas combustion + 50% H2

(F. Cozzi et al)

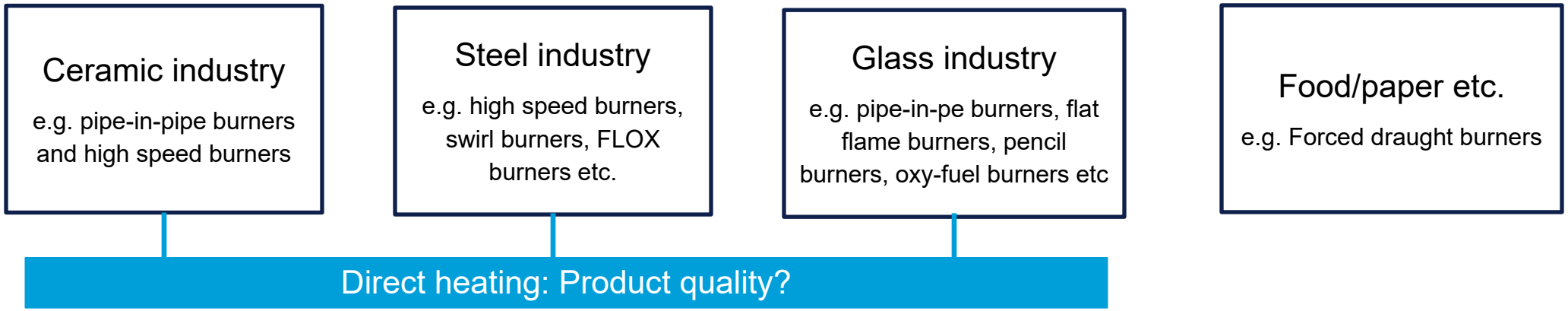
- Top: Increased soot (and radiation heat flux) formation is measured in diffusive swirl stabilized burners when 50% hydrogen is addend to natural gas
- Bottom: Increased soot (and radiation heat flux) in industrial swirl burners when between 20-50% hydrogen is present in natural gas



Measurements performed at DNV in a 500 kW furnace using an industrial swirl burner

Challenges when applying hydrogen

- Addition of hydrogen affects burner performance e.g.;
  - NO_x emission increases
  - Soot formation can occur
  - Changes in heat transfer (convection/radiation)
  - Can result in overheating & Flame flash-back (premix burners)
- Important: burner performance changes upon hydrogen addition strongly depends upon the type of burner installed.
  - Many burner types are used in the different industrial sectors:



To address the challenges when using hydrogen in industrial heating processes CelSian and DNV started an industry Joint Industry Project:

‘Hydrogen as a fuel for heating processes’

Currently more than 35 partners involved in the project

Goal of project: Remove the perceived barriers and show the industry how hydrogen can deliver a sustainable solution

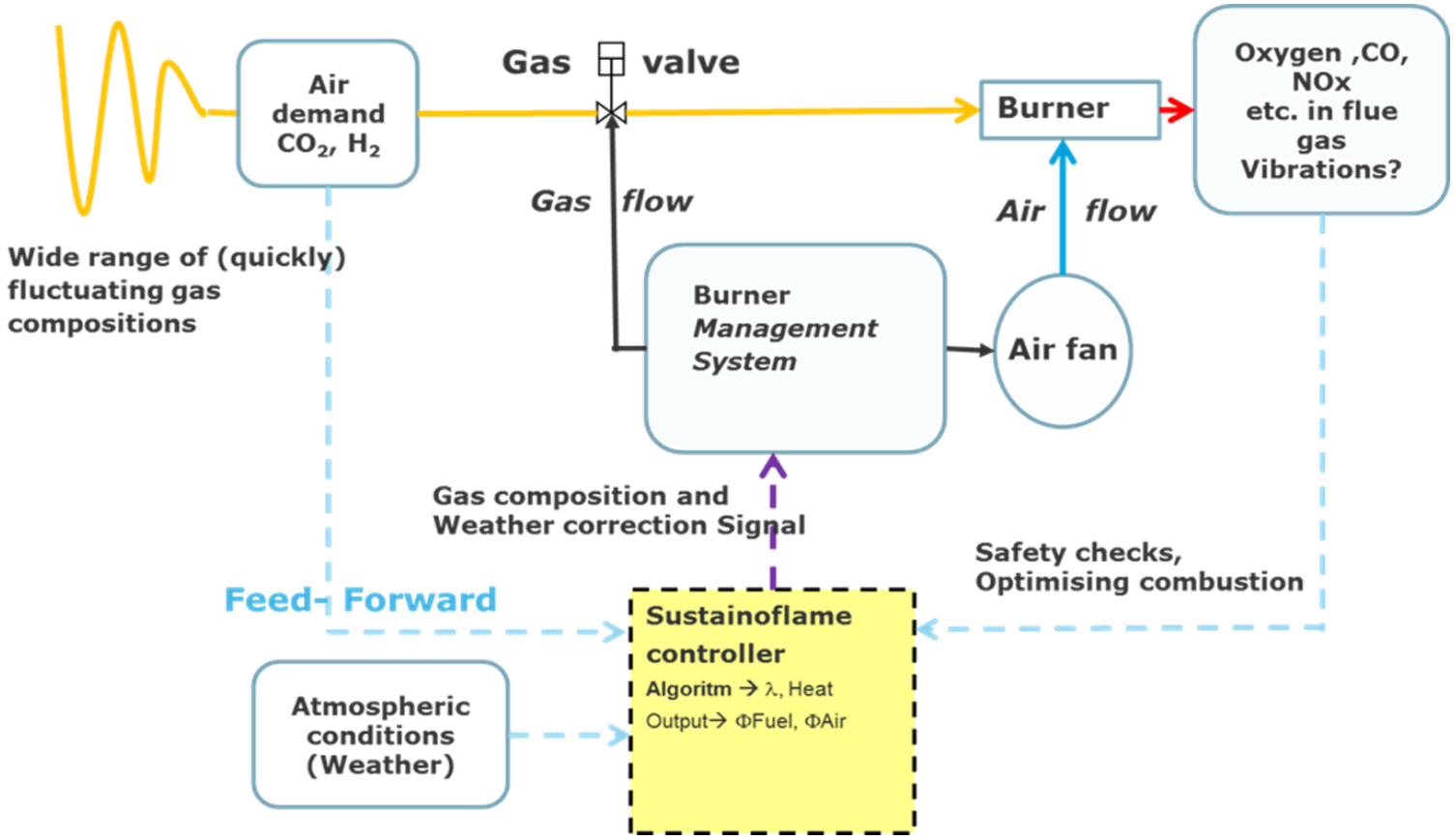
- Our JIP program aims for: understanding basis principles, development of proofs-of-concept, demonstration projects at the industry and ultimately introduction of hydrogen

  - Developing gas adaptive burner control systems and combustion algorithms
  - Determine the changes in combustion behaviour (flame length, emissions etc.)
  - Determine the changes in heat transfer when adding hydrogen to natural gas (0-100%) hydrogen
  - Develop and test NO_x mitigating measures
  - Demonstrate oxyfuel combustion (H_2/O_2)
  - Performing 3-D CFD modelling of the kiln for both air and oxy-firing
  - Validated CFD model will provide new design rules for oven designers for next generation high temperature kilns and to optimize current heating processes when using hydrogen as a fuel

Fuel adaptive burner control system: sustainable gases and high efficiency

- **Novel Algorithms and gas analysers**
  - Combustion control algorithms based on fuel gas composition and operational conditions of installation
  - Taken into account external factors (e.g. humidity, temperature, etc)

- **Optimal equipment performance:**
  - Fuel adaptive control for a wide range of fuel compositions
  - Safe and reliable operation within a wide range of gas compositions
  - Fuel savings
  - Acceptable emission levels

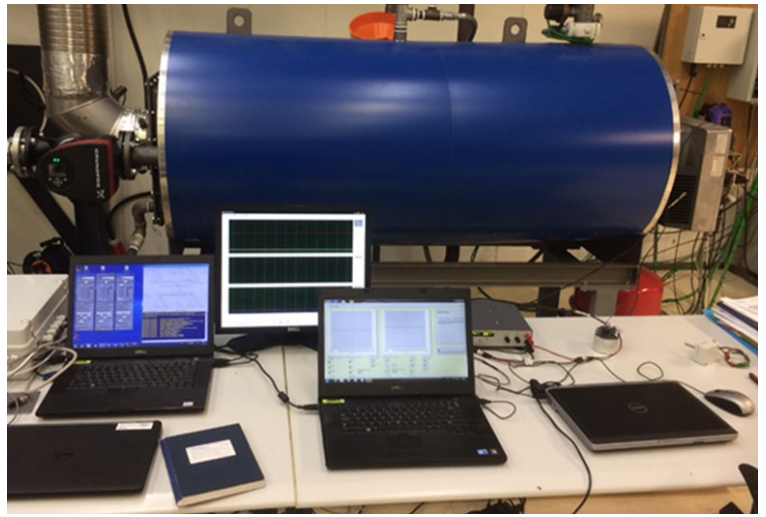


Example: Development of a Natural Gas/Hydrogen Boiler System for low temperature processes

Goal: Development of a fuel flexible burner system for hydrogen/natural gas mixtures (0-100% H_2)

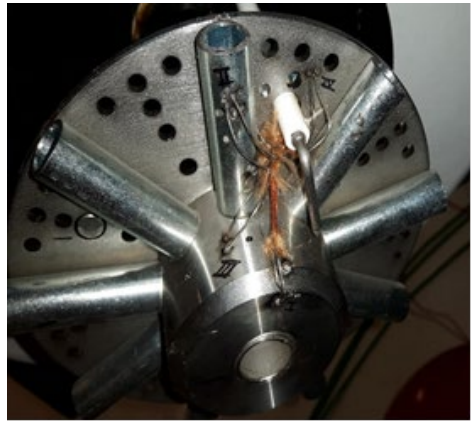
Experimental set-up contains:

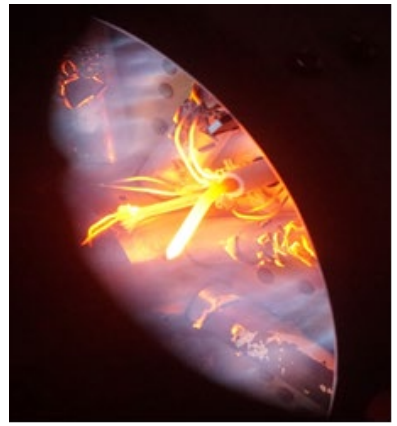
- 475 kW Novum boiler system
- Zantingh/Unigas LowNOx-forced draft burner
- Lamtec Etamatic burner management system
- UV sensor as flame guarding system
- Real time hydrogen sensor
- Natural gas sensor
- Fuel adaptive control system



475 kW boiler system

Forced draft burner

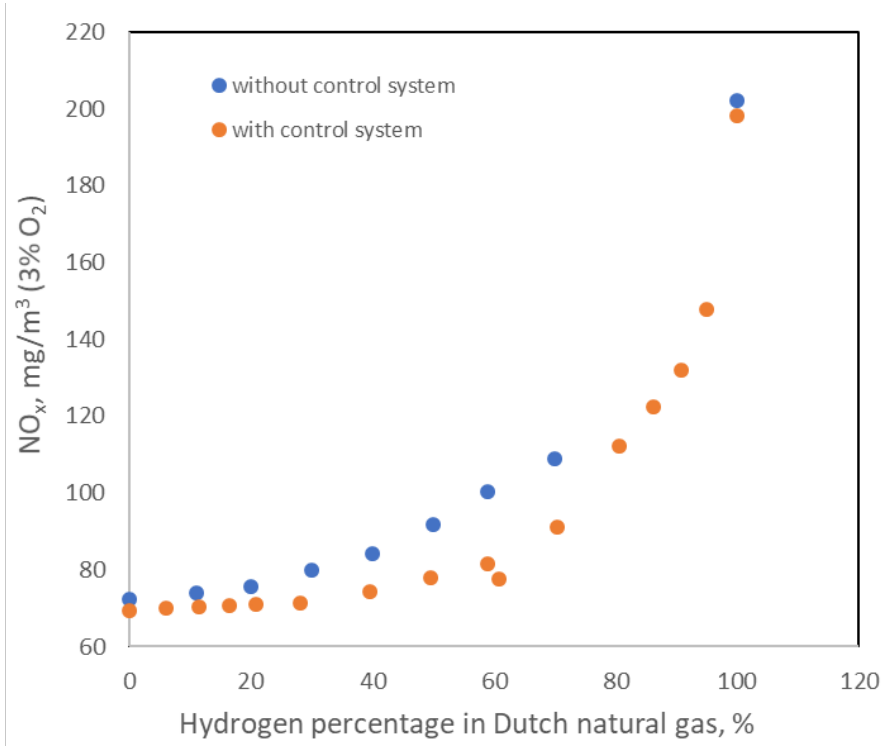




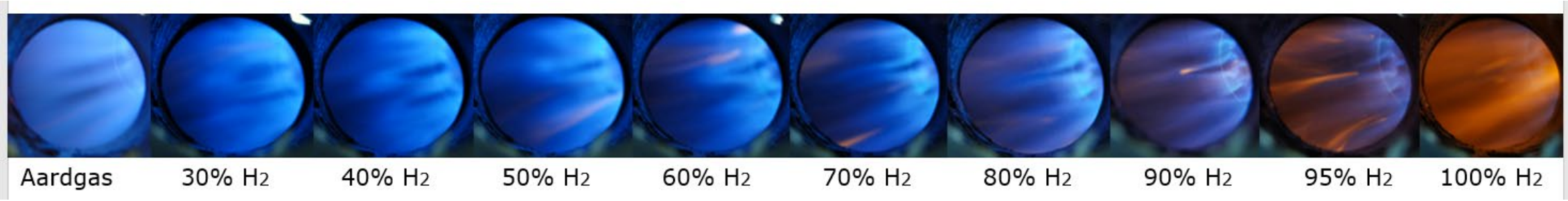
Left: 475 kW burner deck with thermocouples to monitor the temperature. Right: flame image burner

General results of hydrogen fuelled industrial forced draft burner

- When adding hydrogen to natural gas the fuel adaptive control system keeps:
  - Fuel-to-air ratio constant
  - Thermal input (load) is constant
- Flame colour changes from the typical blue colour of natural gas flames to orange (hydrogen)
- No over-heating of the burner is observed
- Hydrogen addition to NG results in an increase in the NO_x emission

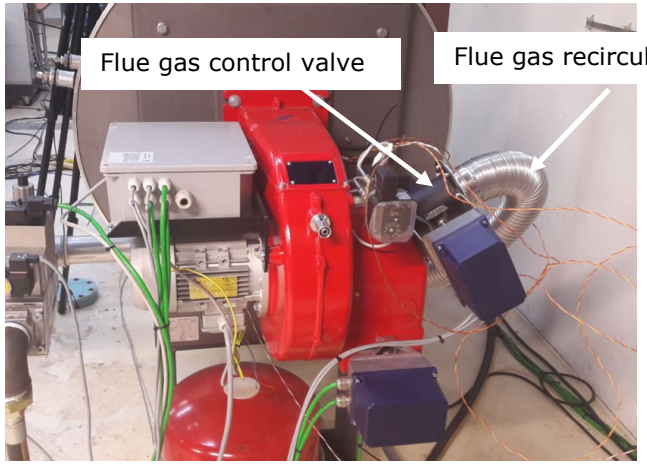


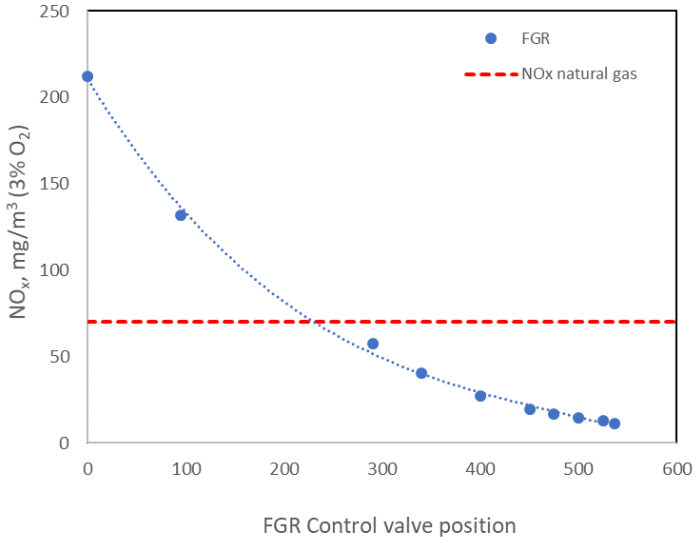
NO_x emission should be decreased by applying NO_x mitigating strategies



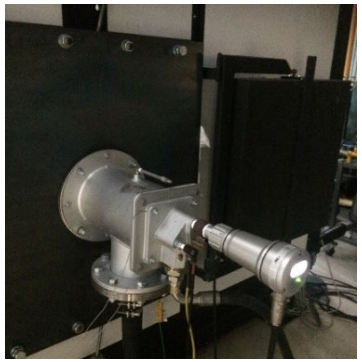
Applying Flue Gas Recirculation (FGR) as NO_X mitigating strategy Preliminary results FGR SBIR project

- A part of the flue gases is returned to the combustion air inlet.
- The dilution of combustion air with (inert) flue gases reduces the adiabatic flame temperature and consequently reduces the (thermal) NO_x formation.
- The preliminary results show that applying flue gas recirculation results in a reduction of the NO_x emission with more than a factor of 10.
- From this we conclude that flue gas recirculation is a very effective strategy to reduce the NO_x emission for hydrogen flames.
- **Conclusion:** The burner system developed enables the flexible introduction of hydrogen as a fuel in the natural gas grid in the energy transition period and afterwards, when natural gas is fully replaced by hydrogen





Experimental set-up for studying high temperature processes
DNV Groningen (NL)



BIC burner & Flame scanner

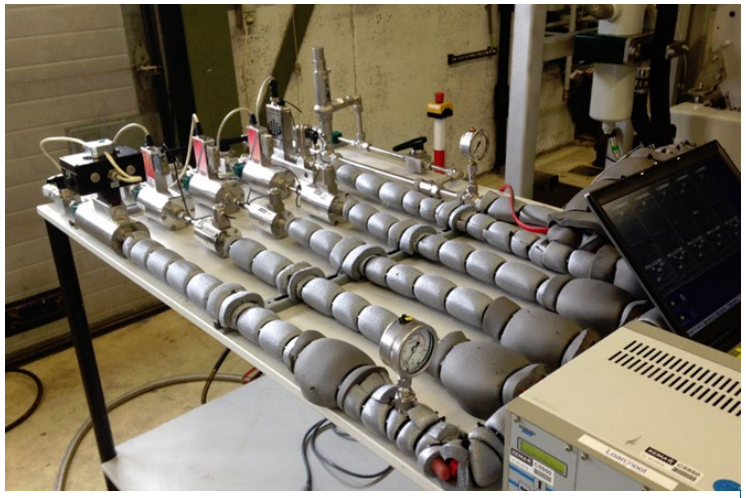
Celsian sensor (O_2, CO H_2O & T)

Flue gas analysers

500 kW air heater (up to 600 °C)

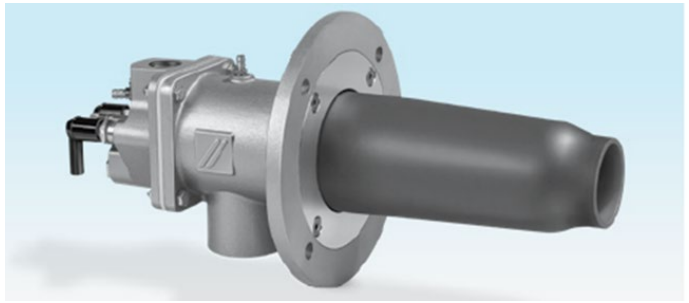
500 kw Furnace + cooling floor

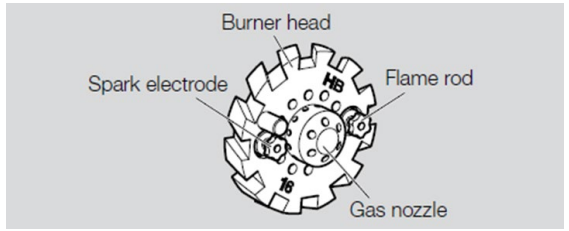
Cooling infrastructure

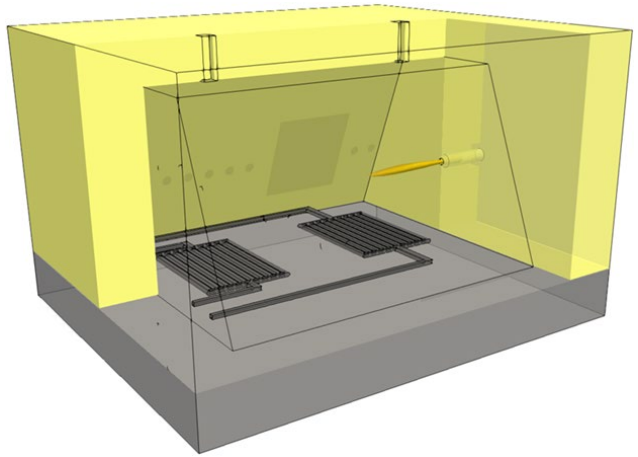


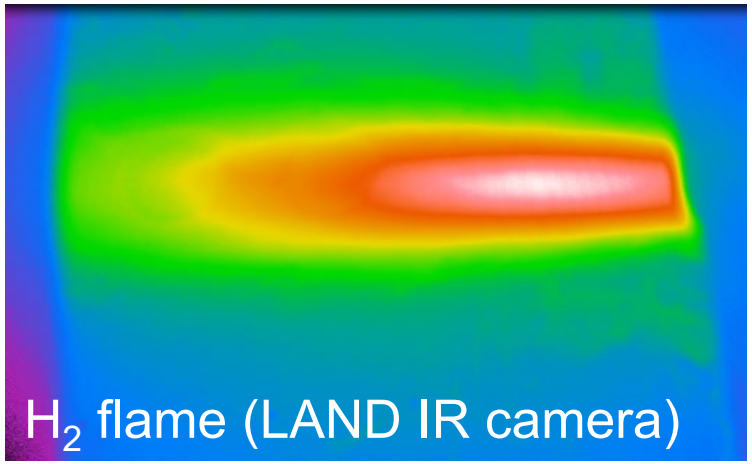
Gas blending unit

Preliminary results first burner tested: *Swirl burner*
High temperature processes:





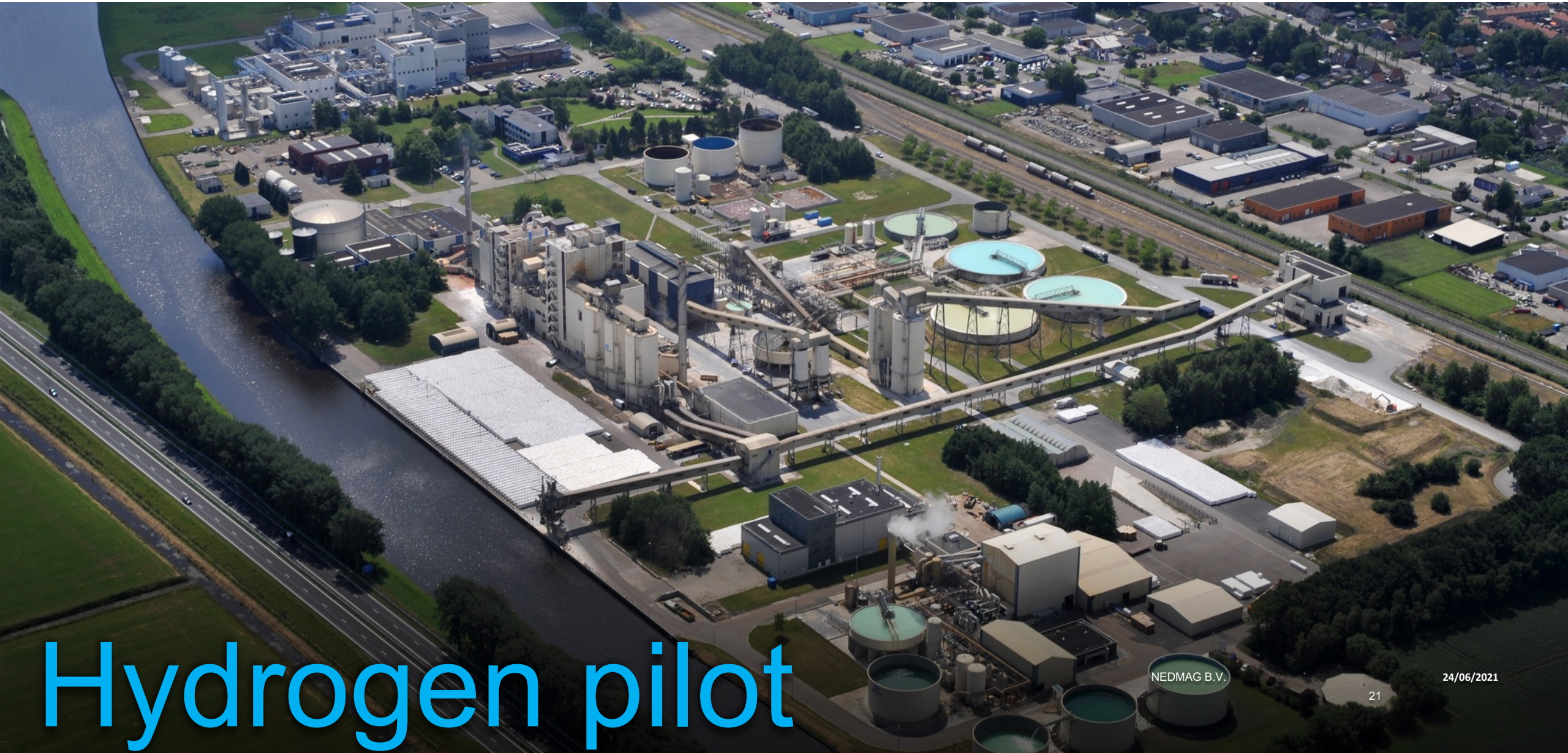




- Good performance of the burner (0-100% H_2 in NG):
- The increase in NO_x emission with increasing hydrogen content was successfully mitigated by applying external ‘flue gas recirculation’
- When using the fuel adaptive control system the air ratio and the thermal input was kept successfully constant for all H_2/NG blends
- The furnace and burner behaviour have been successfully simulated using the CFD package developed by CelSian providing insights in the combustion behaviour and heat transfer of H_2/NG blends
- Changes in flame length observed with varying preheat temperatures and hydrogen fraction in natural gas

Burner control strategy developed within the project is in large scale demo project

2 MW furnace to heat oil will be fuelled using NG/H_2 (0-100% H_2): planning mid-2021



Hydrogen pilot

Next Phase - to be started in cooperation with the industry

“Preparing for future use of hydrogen in the industry”

1. Further optimizing and development of high performance hydrogen burners for the industry
   - Optimization heat transfer
   - Reducing NO_x emission
   - Development of safety protocols for the industry

2. Studying impact switching from natural gas to hydrogen combustion on product quality for specific industries:
   - Ceramic
   - Glass
   - Steel industry
   - …

WHEN TRUST MATTERS

Thanks you for your attention

Questions?

Sander.Gersen@dnv.com
+31615012156

www.dnv.com

DNV