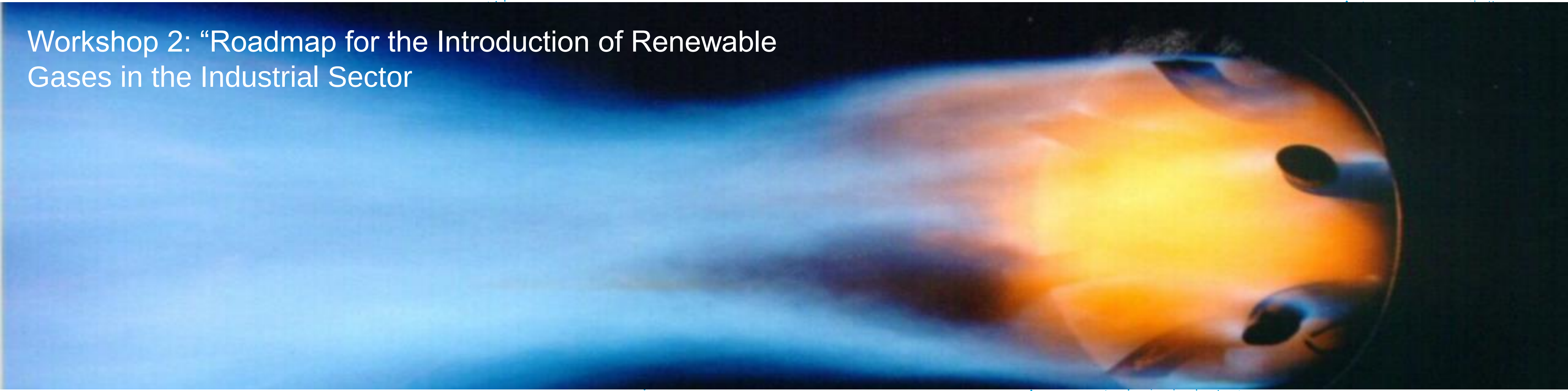
WHEN TRUST MATTERS

What are the challenges when switching to hydrogen as a fuel for heating processes?



Workshop 2: "Roadmap for the Introduction of Renewable Gases in the Industrial Sector

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29 March 2023

Workshop program

1. Challenges and questions from industry when switching to hydrogen as a fuel
2. Differences between hydrogen and methane combustion
3. Impact hydrogen blending to natural gas for non- premix burners
4. Presentation on burner and control system adaptation
5. Examples hydrogen pilot projects Netherlands
6. Case study: Nedmag Industries Veendam
7. Q&A and discussion

Part 1: hydrogen blending and switching to hydrogen combustion

Challenges when using hydrogen in the ceramic industry (1)

Questions industry:

- How do existing burner systems perform when blending hydrogen to natural gas?
- Can existing burning systems be **flexibly utilized** for the full mix of fuel compositions: 100% **hydroge**n, 100% natural gas and all mixtures of hydrogen and natural gas in between?
- How can we perform **measurements** (emission flame visualization, flame detection etc.) on pure hydrogen flames?
- What are the expected changes in the **oven atmosphere** and **emissions**?
- Do the changes in the oven atmosphere impact the **refractory lifetime** and **product quality**?

Calculated Physical parameters of natural gas/hydrogen

Table 1. Physical parameters methane and hydrogen (combustion and safety related)

	CH_4	H_2
LEL, %	5.3	4.0
UEL, %	15	75.3
Minimum ignition energy (stoichiometric mixture)	0.274	0.017
AIT, °C	630	520
Wobbe index, MJ/m³ (25, 0)	53.47	48.35
Net calorific value, MJ/m³n	35.89	10.79
Gross calorific value , MJ/m³n	39.89	12.75
Density, kg/m³n	0.72	0.09
Burning velocity, m/s	0.4	3.2

Table 2. Changes in main components in the combustion gases at λ=1

	CH_4	H_2
H_2O, mole%	18.3	32.4
N_2, mole%	70.1	63.8
CO_2, mole	8.5	0
Ar, mole%	0.8	0.8
Other components, %	0.8	1.1
$T_{adiabatic\ flame\ temperature}$ °C	1953	2108
Water dewpoint (at 3% O_2 in flue gas)	**59.2**	**72.6**

Differences in physical and chemical properties affects:

- Safety
- Gas transport/distribution
- **Combustion behaviour (end-use)**
- **Product quality (direct heating)**

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Natural gas versus hydrogen – selected features

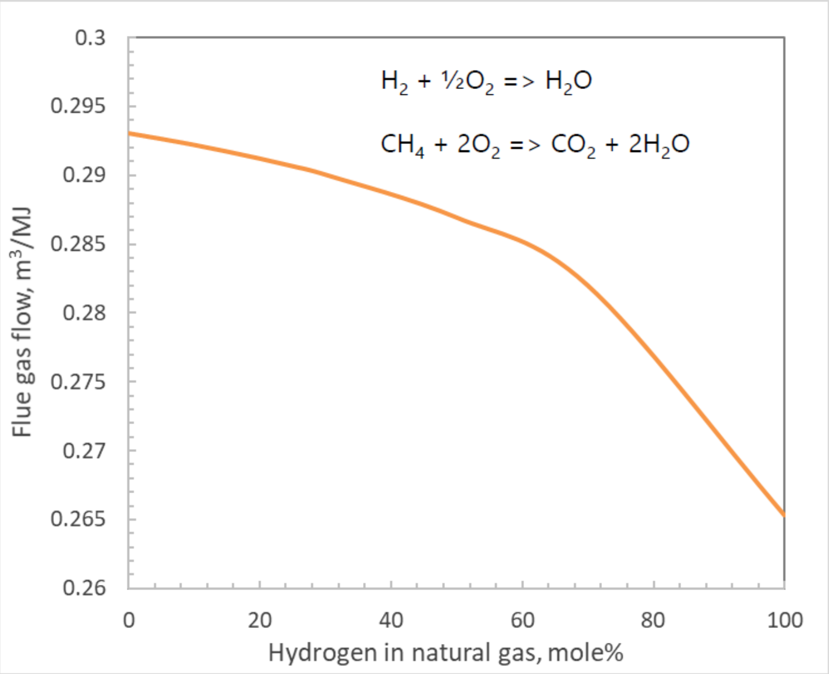
	Hydrogen	Natural gas
Flammable range	Ignites in a much wider mix range (4% to 75% of volume)	Narrow flammability mix range (5.3% to 15% of volume)
Ignition energy	Ignitable by low energy sources - phones, and human static electricity (0.020mJ)	10 times higher than hydrogen (0.29mJ)
Flame velocity	3.2 m/s 8 times faster flame velocity than NG - much higher explosion pressure potential	0.4 m/s
Dispersion	Disperses much faster than NG. Limited potential for ground accumulation	Large gas cloud may form. In some conditions as heavy gas on the ground (LNG)

Flue gas composition and adiabatic flame temperature for a stoichiometric fuel/air mixture

H_2, [vol%]	H_2O, [vol%]	CO_2, [vol%]	Temperature [K]
0	18.3	8.5	2226
0.05	18.5	8.4	2228
0.1	18.7	8.3	2230
0.2	19.2	8.0	2235
0.3	19.8	7.6	2242
0.5	21.4	6.6	2258
0.75	24.8	4.4	2295
0.8	25.8	3.9	2306
1	32.3	0	2381

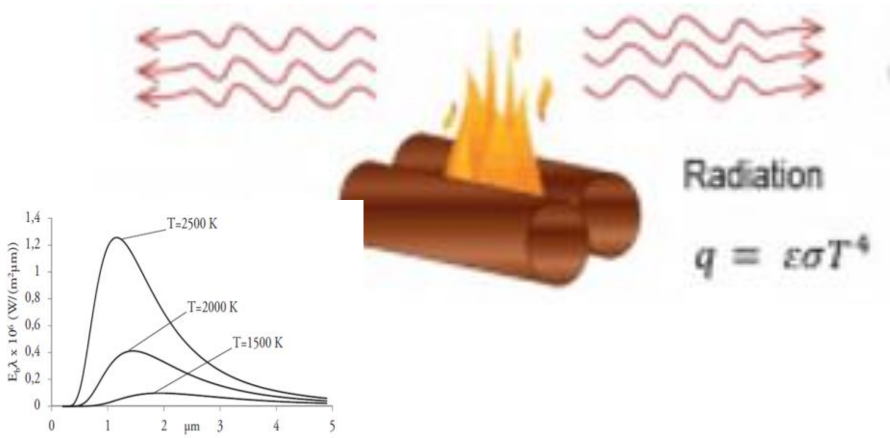
- Hydrogen blending results in **higher flame temperature** which increases the 'thermal' NO_x formation via;

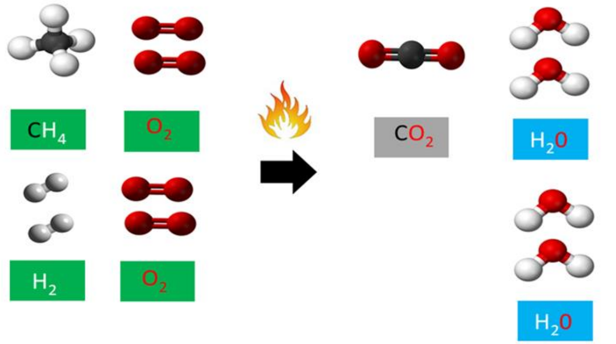
$$N_2 + O \leftrightarrow N + NO$$
$$N + O_2 \leftrightarrow NO + O$$
$$N + OH \leftrightarrow NO + H$$

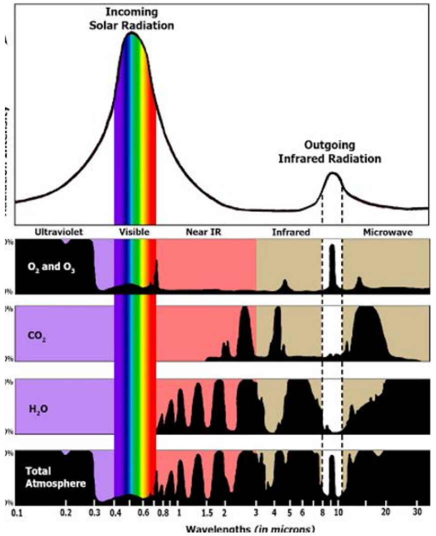


- Hydrogen blending results in changes in flue gas composition and a reduction in the flue gas flow:
  - **11% decrease** in flue gas flow when switching from natural gas to hydrogen
- The change in flue **gas composition** and **flame temperature** can affect the **radiation flux**

Which changes in flame radiation can we expect when adding H_2
Changes in flame radiation assume same flame geometry ?







- When adding hydrogen to natural gas the flame temperature and the combustion products will change
- As a result, the **heat radiation flux** will change accordingly;

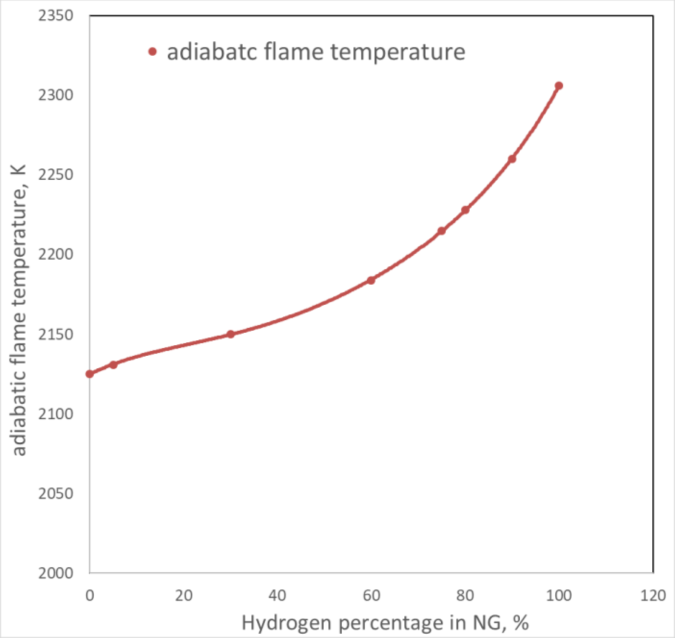
$$q_{flame\ radiation} = \varepsilon_{flame}\sigma T_{flame}^4$$

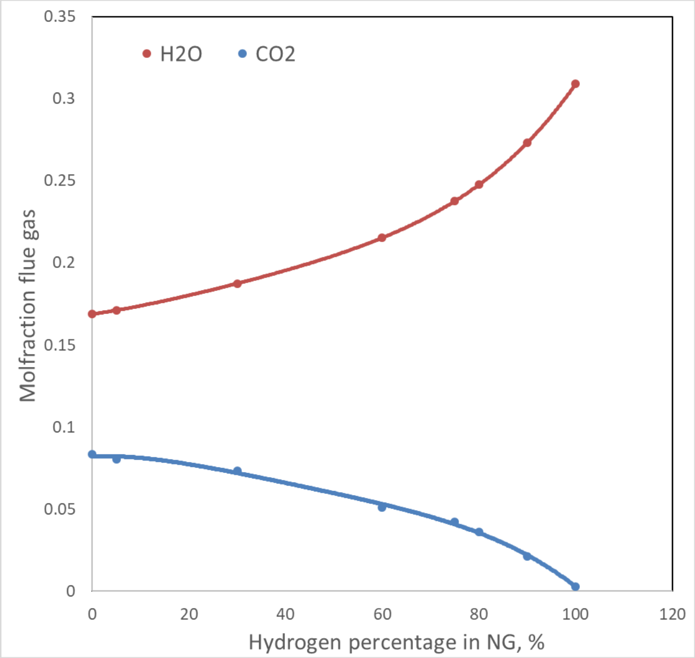
- The emission coefficient (ε) of the flame gases depends upon the partial pressures of the **gas composition**, the absorption path length, and the **temperature**.
- The gas composition and temperature is calculated via an equilibrium model and is used as input in the Leckner model that calculates the emissivity ε of the flame according to;

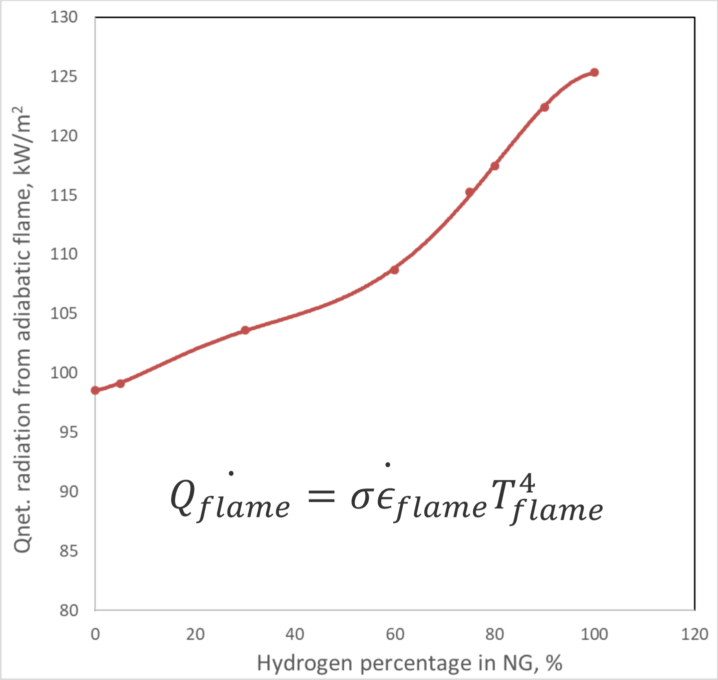
$$\varepsilon_{flame} = \varepsilon_{CO2} + \varepsilon_{H2O} - \Delta\varepsilon_{overlap}$$

- The (total) emissivity calculations, including pressure and overlap functions are derived from empirical relations derived from spectral data

Which changes in flame radiation can we expect when adding H_2
Changes in flame radiation assume same flame geometry (Leckner approach)







<u>Calculations show that:</u>

- The flame temperature increases with increasing hydrogen content
- The water fraction increases and CO_2 fraction in flue gas decreases with increasing hydrogen content
- As a result the estimated net radiation flux from the flame increases with increasing hydrogen content with about 25%

Calculated thermal efficiency Based on higher heating value

- To get insights in the efficiency changes we calculated the thermal efficiency

$$thermal\ efficiency, \% = 100 * \frac{H_{fuel} - H_{flue\ gas}(T_{flue\ gas})}{H_{fuel} - H_{flue\ gas}(298K)}$$

- Up to about a flue gas **of 56°C no large differences** are expected between methane and hydrogen; the thermal efficiency of hydrogen is slightly better (up to ~1.5%)
- For flue gas temperatures above **73 °C (dew point hydrogen)** the efficiency of hydrogen is lower than methane; **up to about 6%** as a result of the higher water content (condensation enthalpy) in the flue gases of a hydrogen flame
- Advice: for boiler systems condensation of the flue gases is recommended to maintain efficiency (e.g. installation condenser)
- Note: these calculations are thermodynamic calculations and heat transfer from H_2 might be different from NG and, in consequence impact in a different way the thermal efficiency

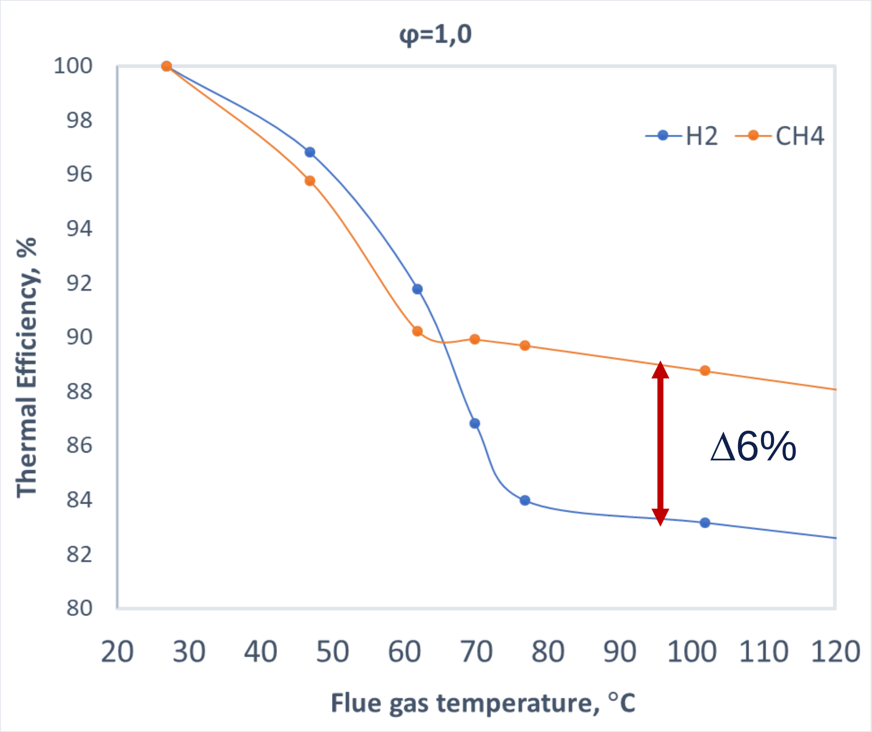
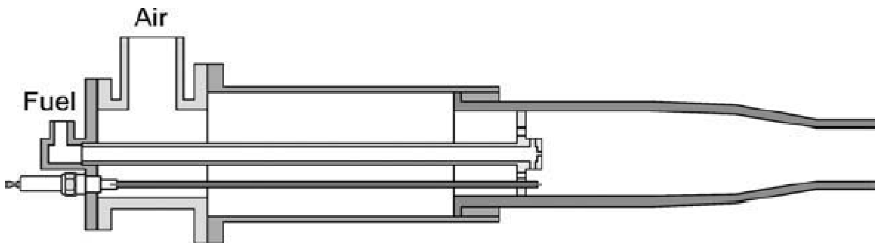


Figure: Calculated thermal efficiencies for methane and hydrogen using a thermodynamic equilibrium model

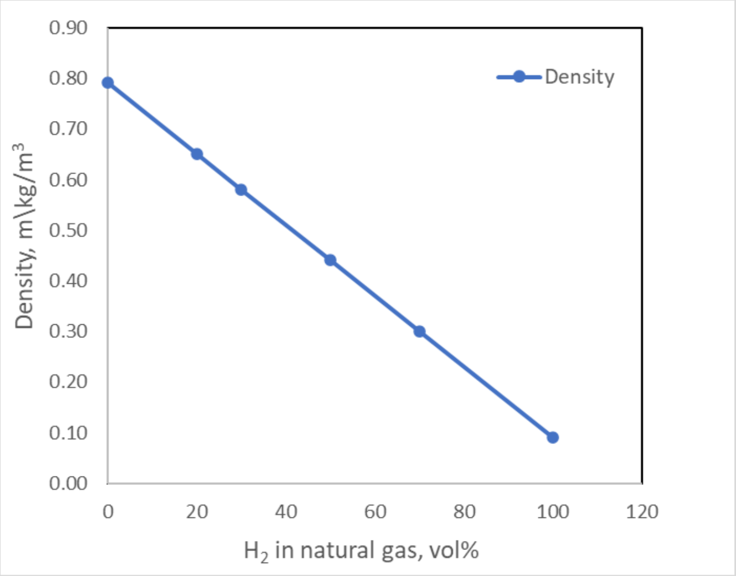
Effects hydrogen addition to methane on the thermal heat input of burners that do not use a fuel adaptive control system

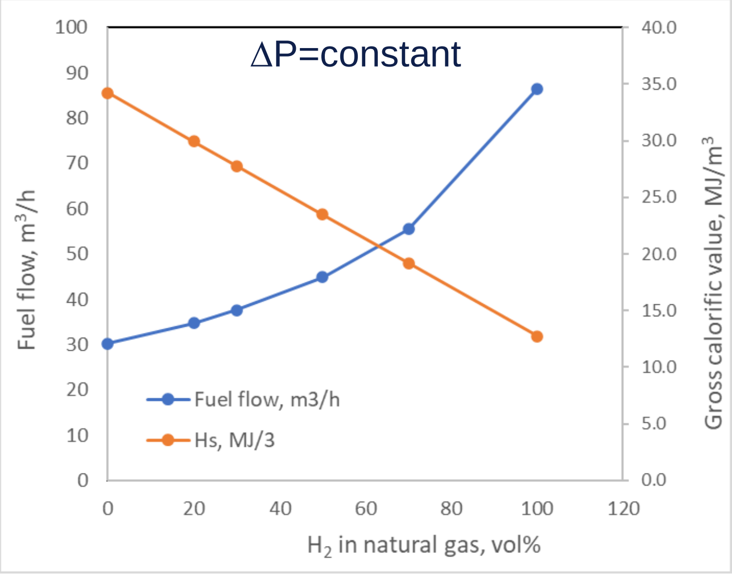


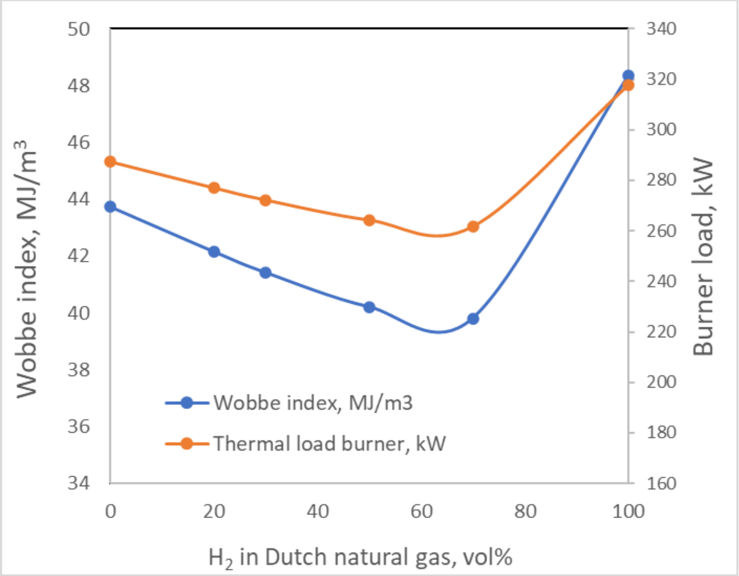
$$Q_v \approx \sqrt{\frac{2\Delta P}{\rho_{fuel}}}$$

$$Thermal\,burner\,load \approx Q_v H_s$$

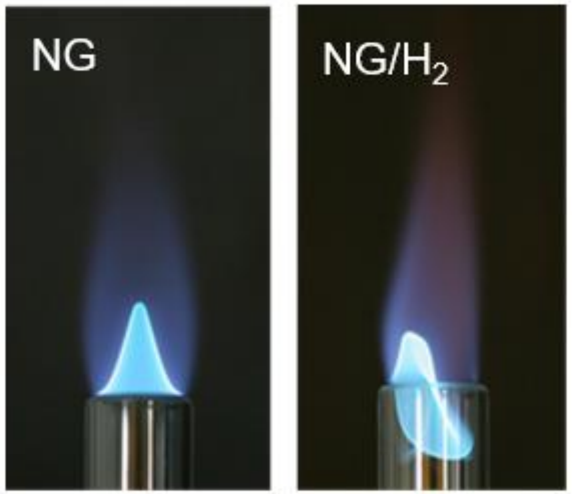
Addition of H_2 to DNG results in a variation in the thermal load







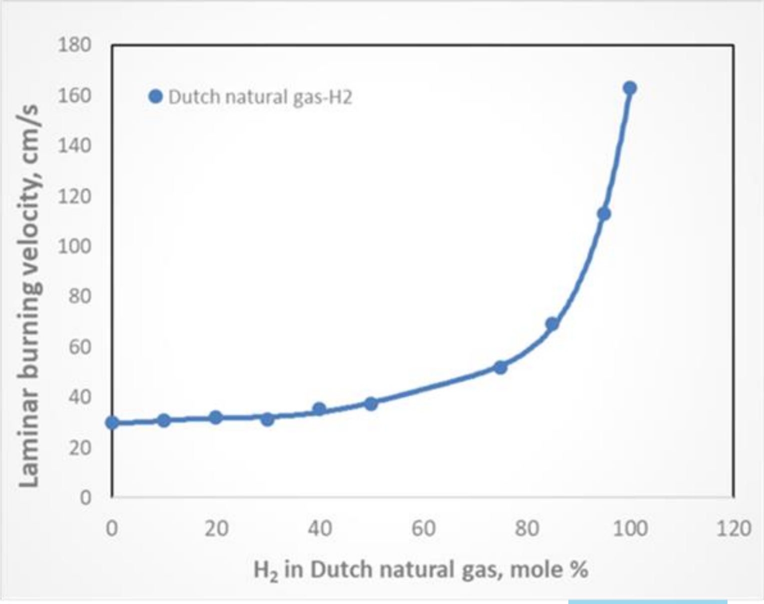
Effects hydrogen addition to methane on the burning velocity



- Hydrogen addition results in an increase in the burning velocity

- Increase in burning velocity can result in:
  - Overheating burner surface
  - Result in flame flash-back

- Important for partially and premix burner systems (domestic and industrial burners)



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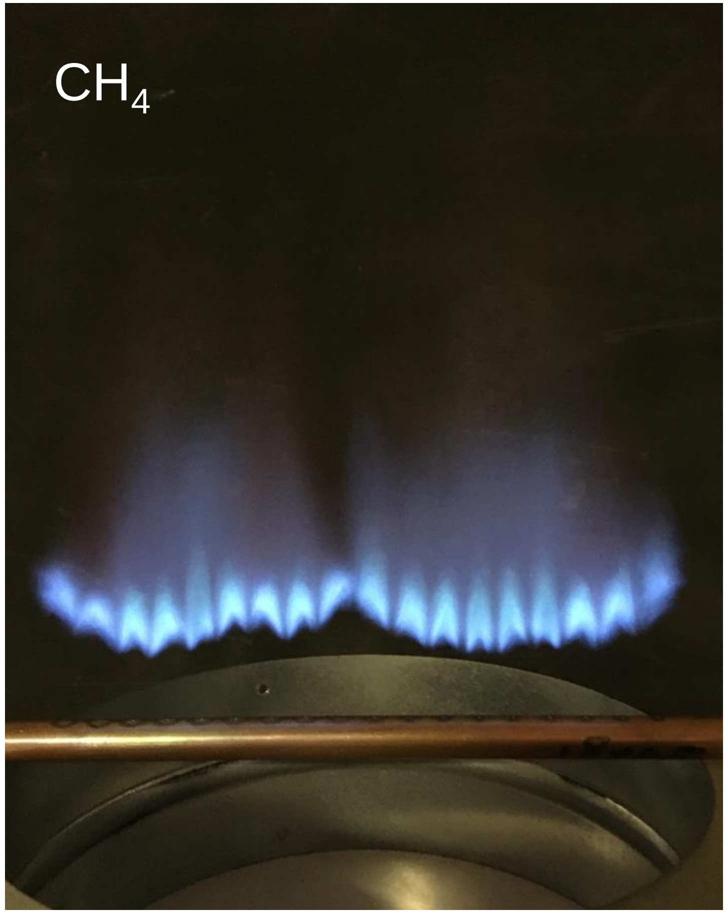
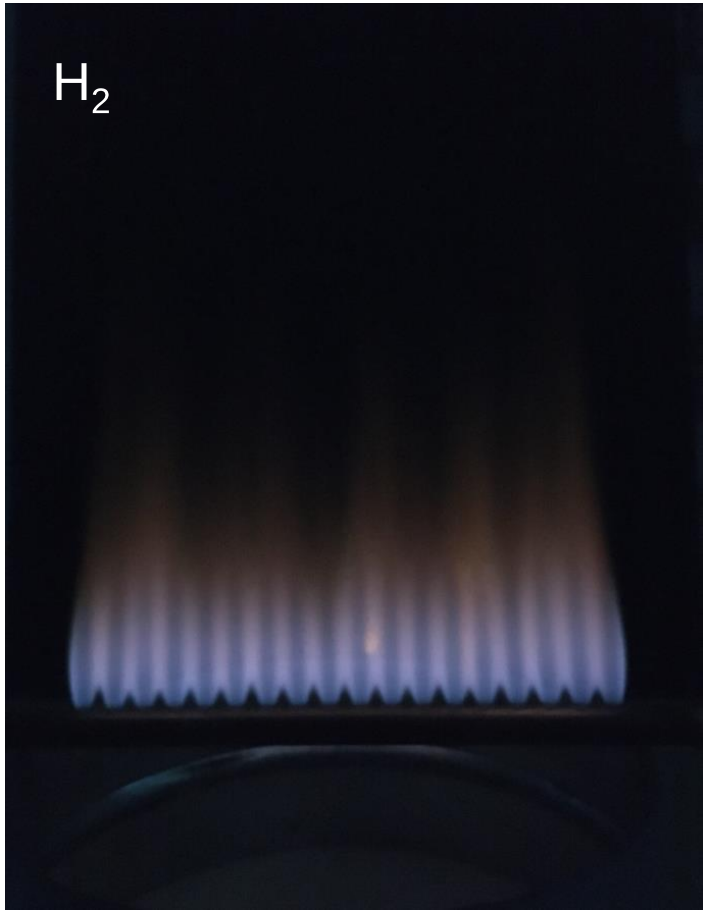
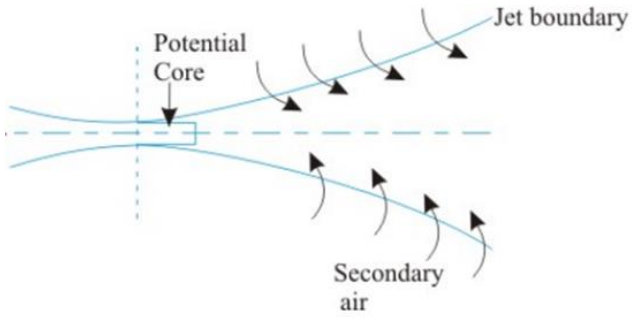
Flame zone shift closer to burner surface when switching from NG to H_2







Challenges when applying hydrogen for (industrial) burners

- Addition of hydrogen may affects burner performance for example;
  - NO_x emission
  - Changes in heat transfer (convection/radiation)
  - Can result in overheating & flash-back (premix burners)

- **Important:** burner performance changes upon hydrogen addition strongly depends upon the type of burner installed.

Ceramic industry
e.g. pipe-in-pipe burners and high speed burners

Steel industry
e.g. high speed burners, swirl burners, FLOX burners etc.

Glass industry
e.g. pipe-in-pe burners, flat flame burners, pencil burners, oxy-fuel burners etc

Food/paper etc.
e.g. Forced draught burners

Direct heating: Product quality?

Practical examples:

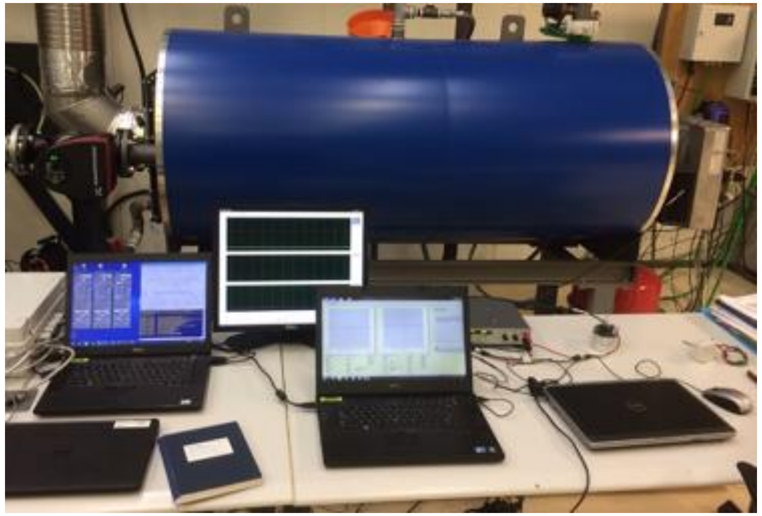
Impact hydrogen blending to natural gas for non- premix burners

Example: Development of a Natural Gas/Hydrogen Boiler System for low temperature processes (SBIR project)

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

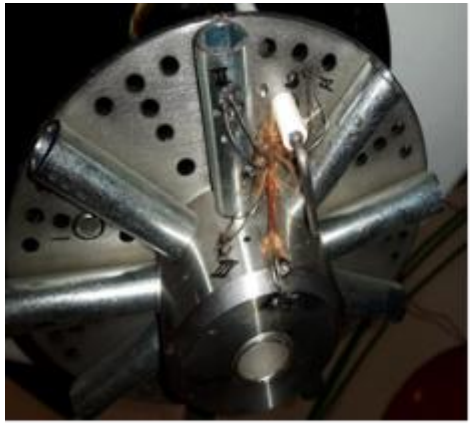
Experimental set-up contains:

- 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



ZANTINGH

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

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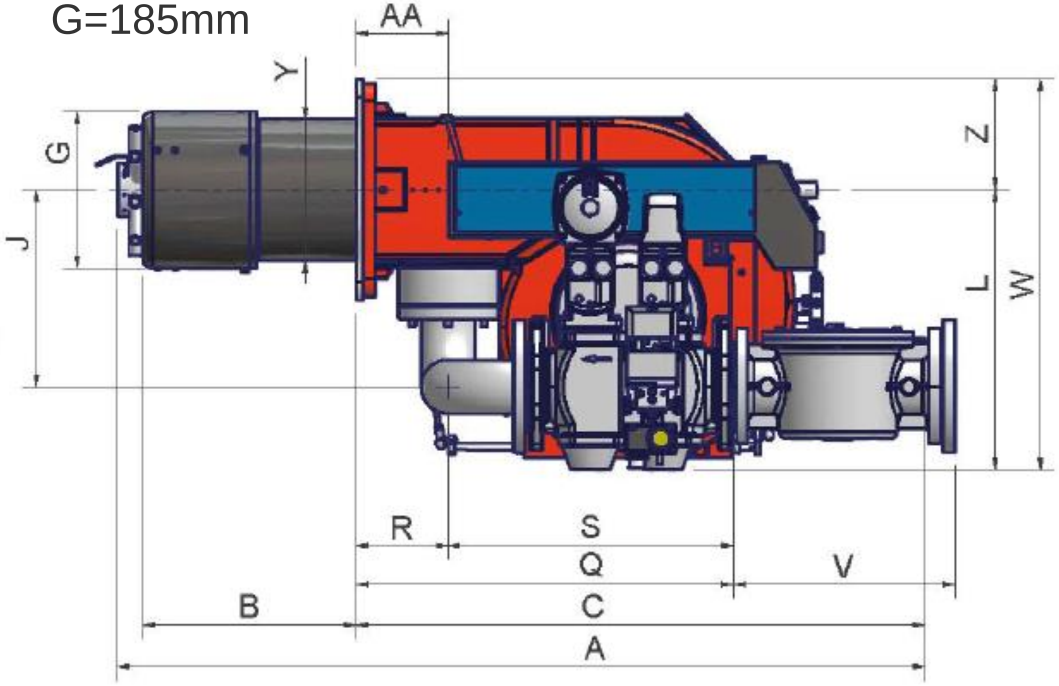
Burner details

- Burner type: Unigas LX 60 M PR S NL A 1.DN50.EA

G=185mm



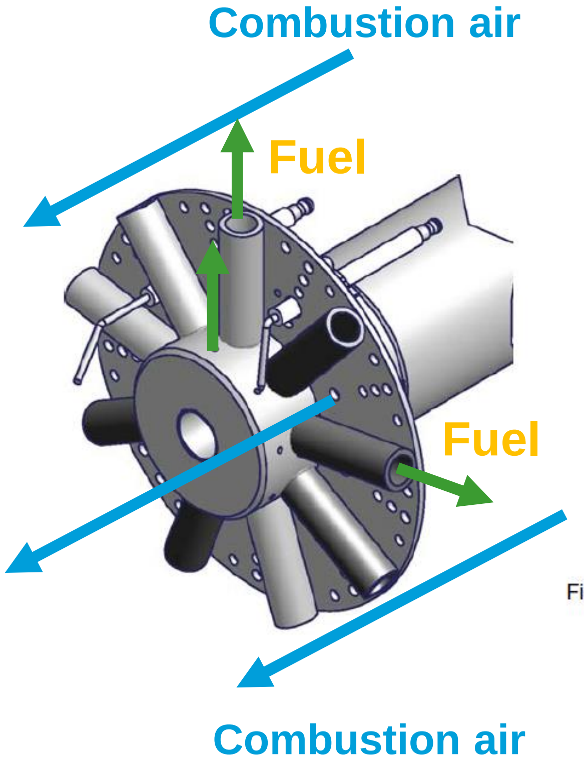
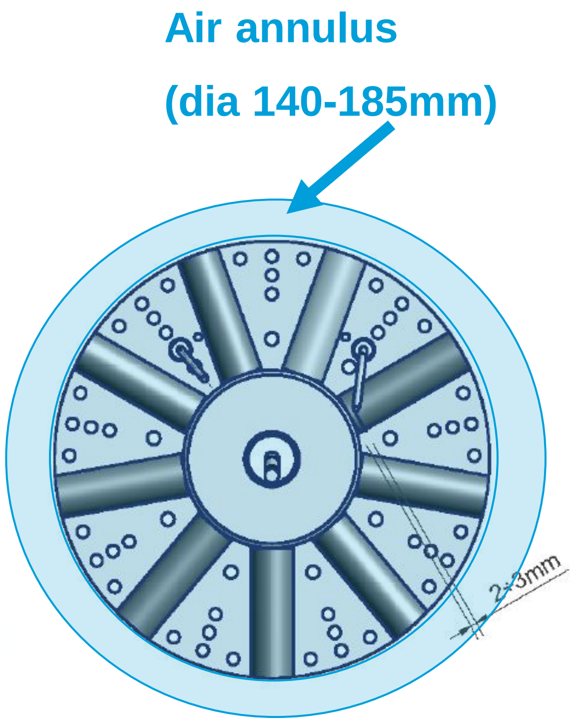
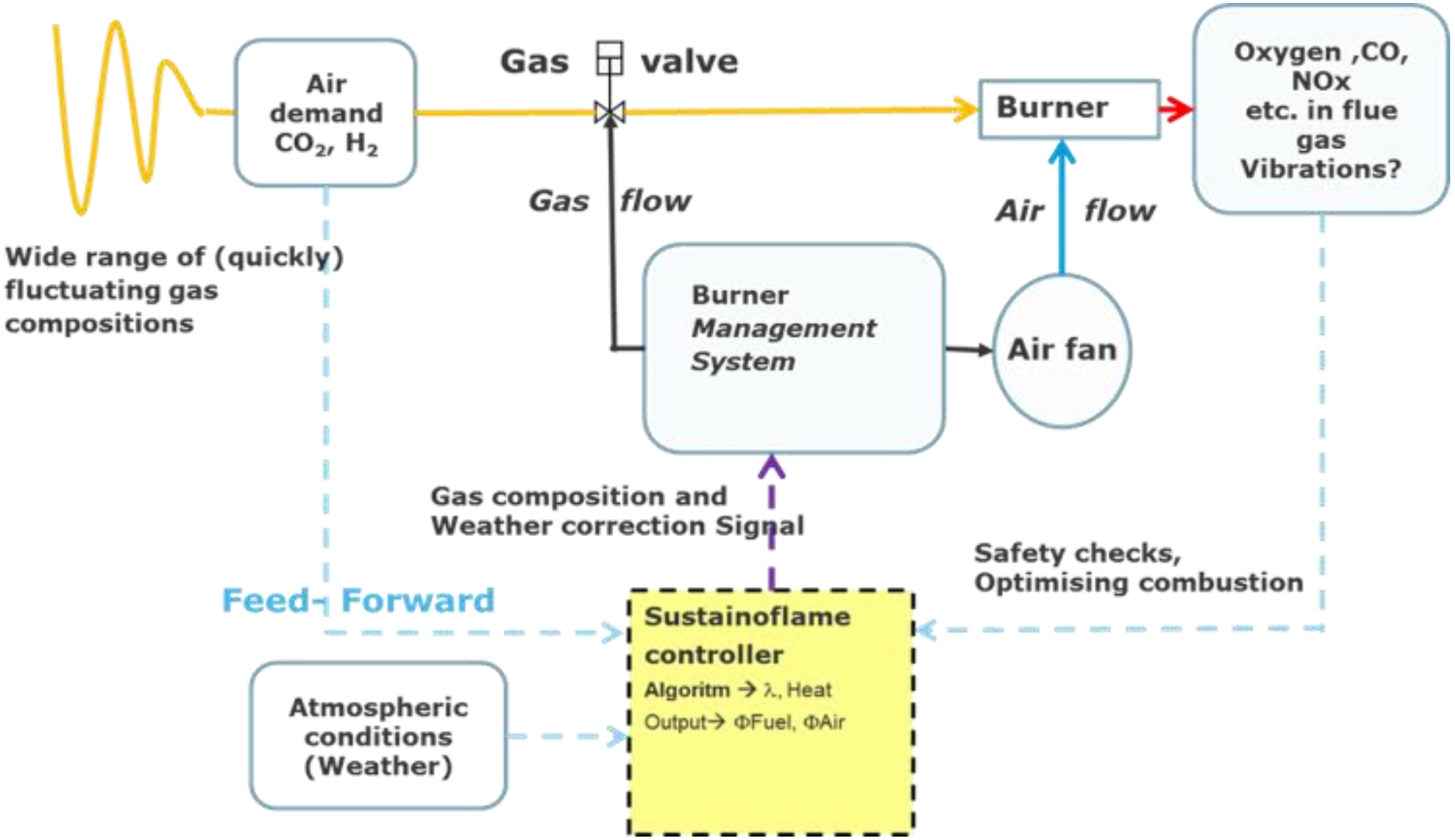


Fig. 33

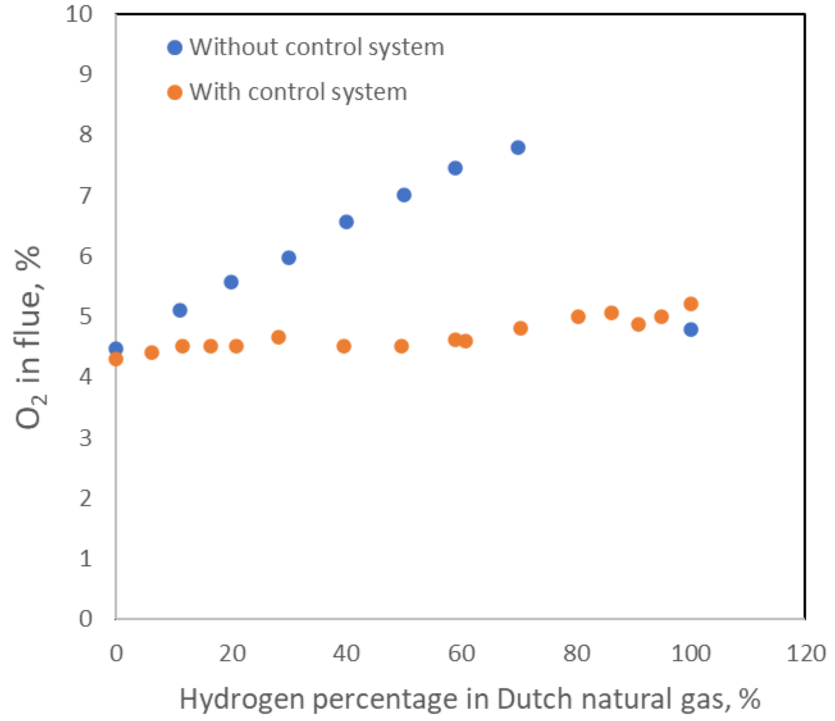


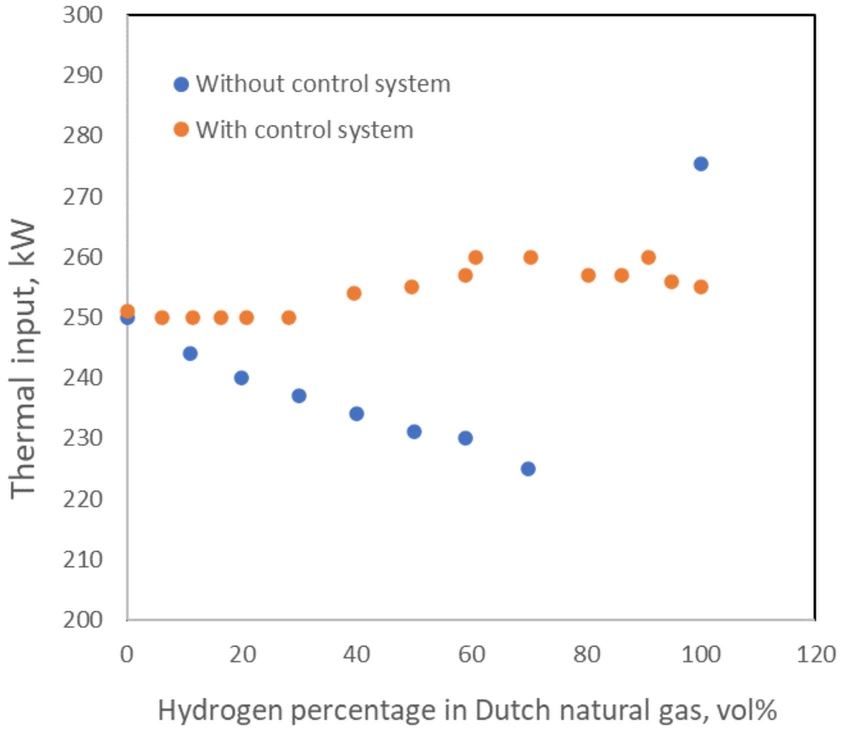
Fuel adaptive burner control system: sustainable gases and high efficiency



- **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

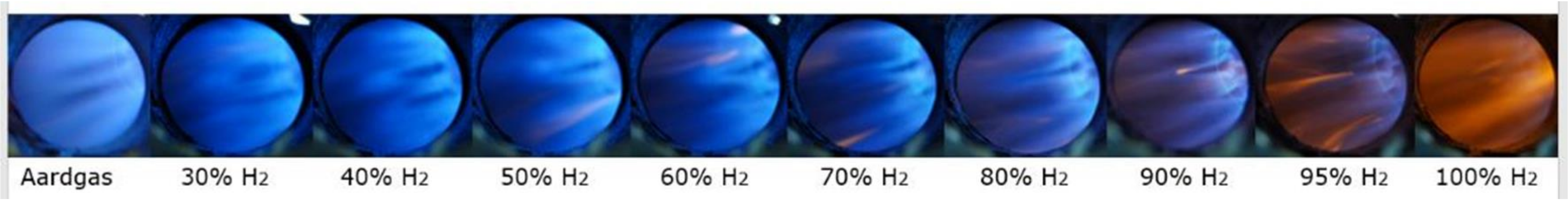
General results of industrial forced draft burner (1)



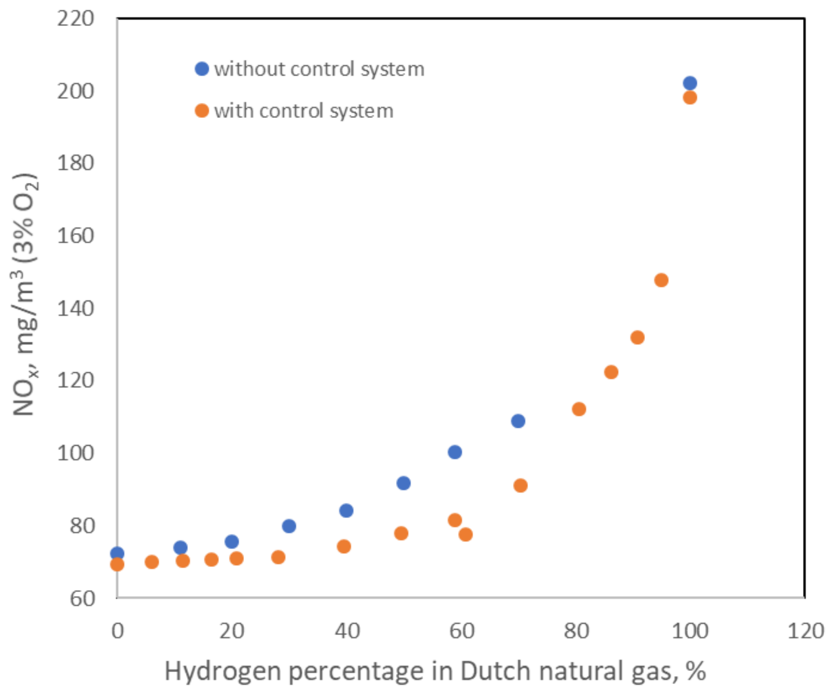


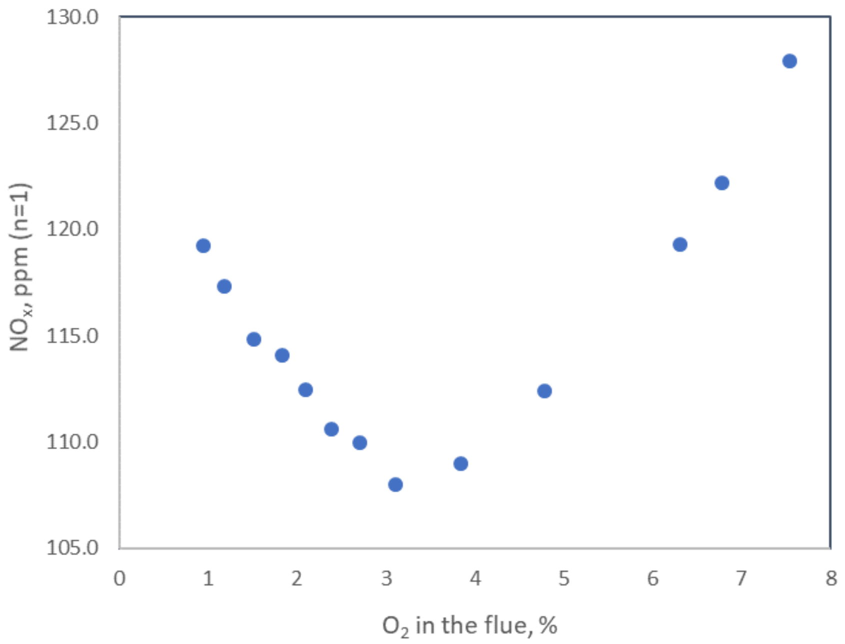
Effects H_2 addition 0-100%

- Stable combustion over the entire range observed
- **No large changes** in flame length and width
- No overheating burner observed
- Fuel adaptive control needed to keep air factor and burner power constant



General results of industrial forced draft burner (2)



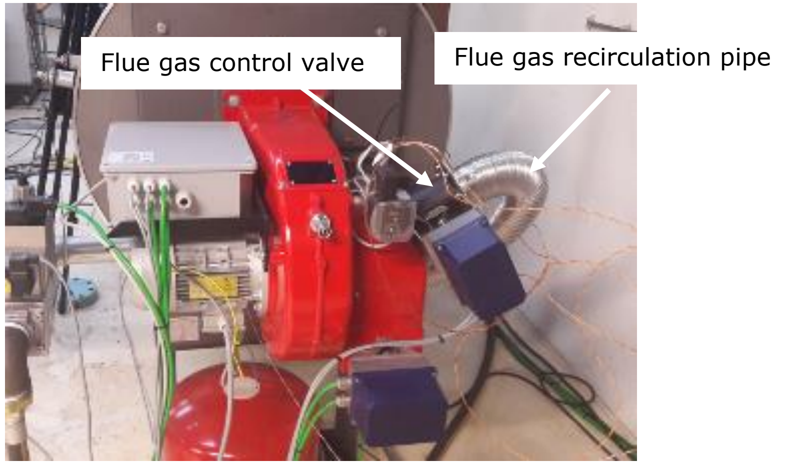


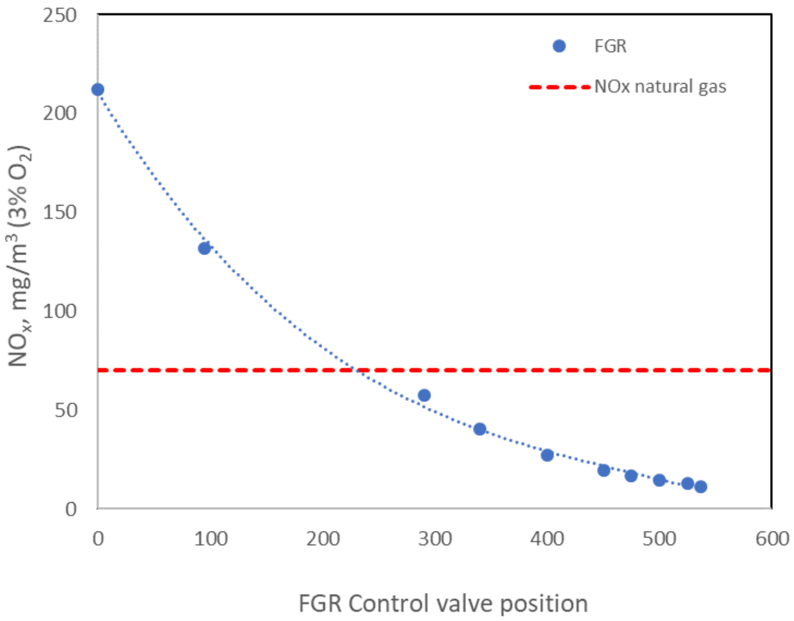
- Hydrogen addition to NG results in an increase in the NO_x emission
- Changing air factor **is not** an effective NO_x mitigating strategy

NO_x emission should be decreased by applying NO_x other mitigating strategies

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

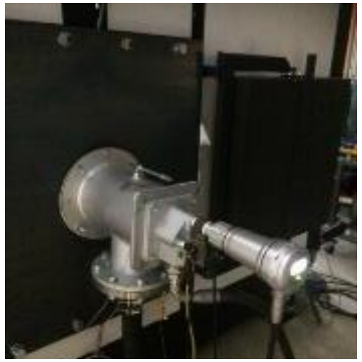
- A part of the flue gases is returned to the combustion air inlet.
- The dilution of combustion air with (inert) flue gases reduces the adiabatic flame temperature and consequently reduces the (thermal) NO_x formation.
- The preliminary results show that applying flue gas recirculation results in a 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)



Burner & Flame scanner

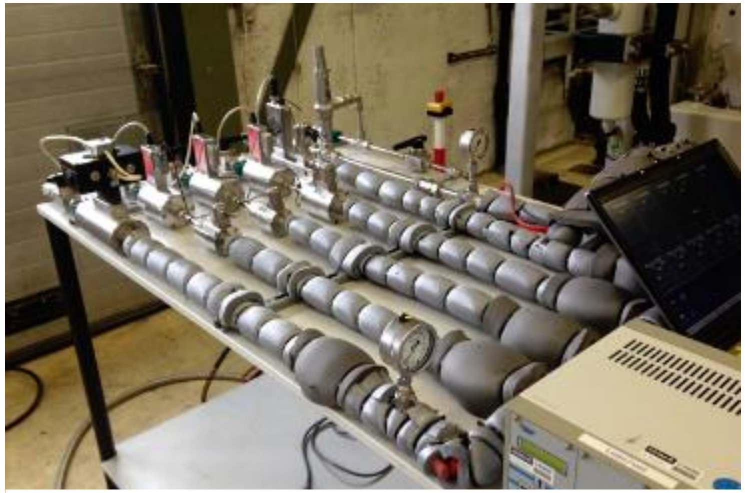
Celsian sensor (O_2, CO H_2O & T)

Flue gas analysers

500 kW air heater (up to 600 °C)

500 kw Furnace + cooling floor

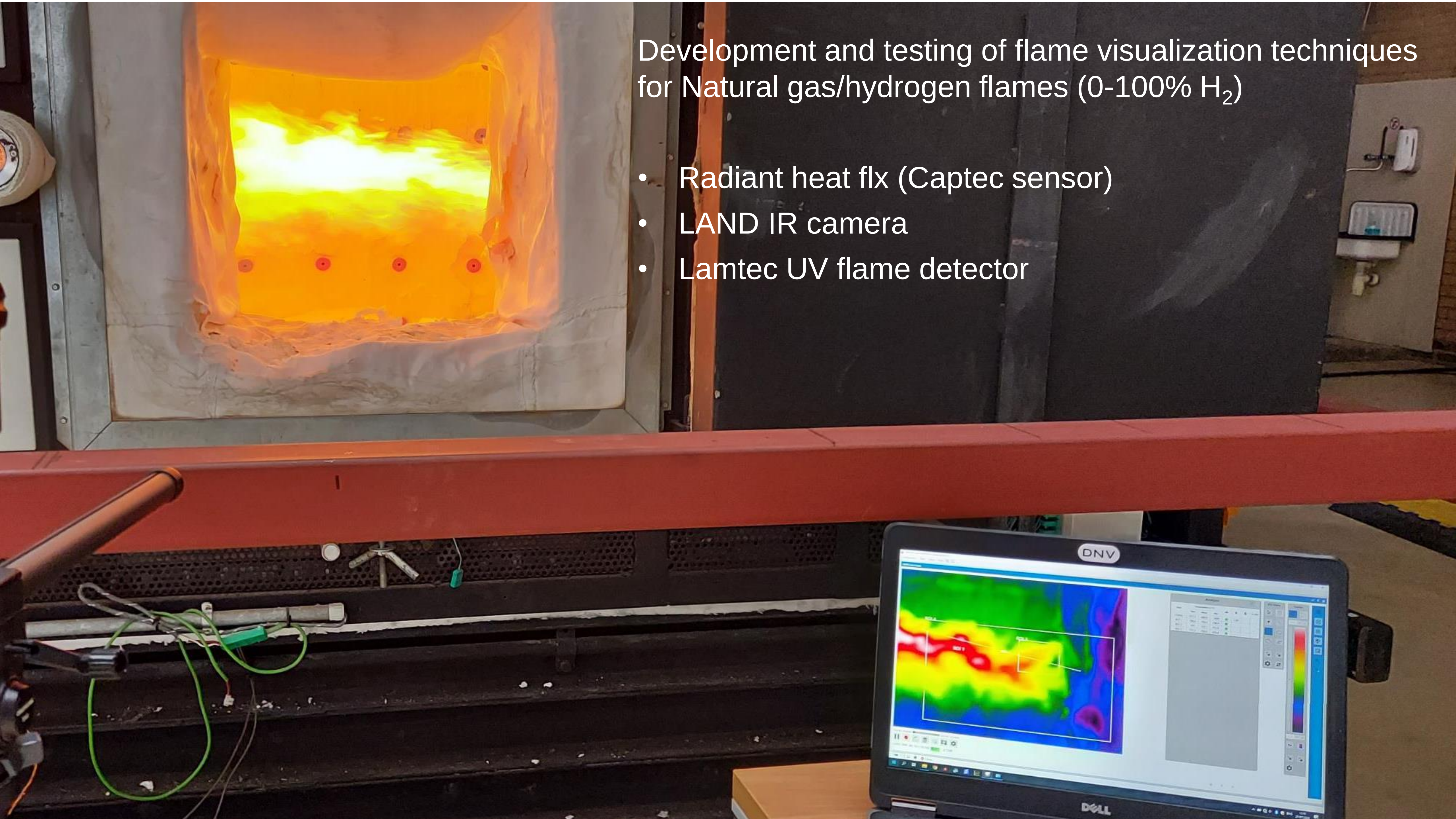
Cooling infrastructure

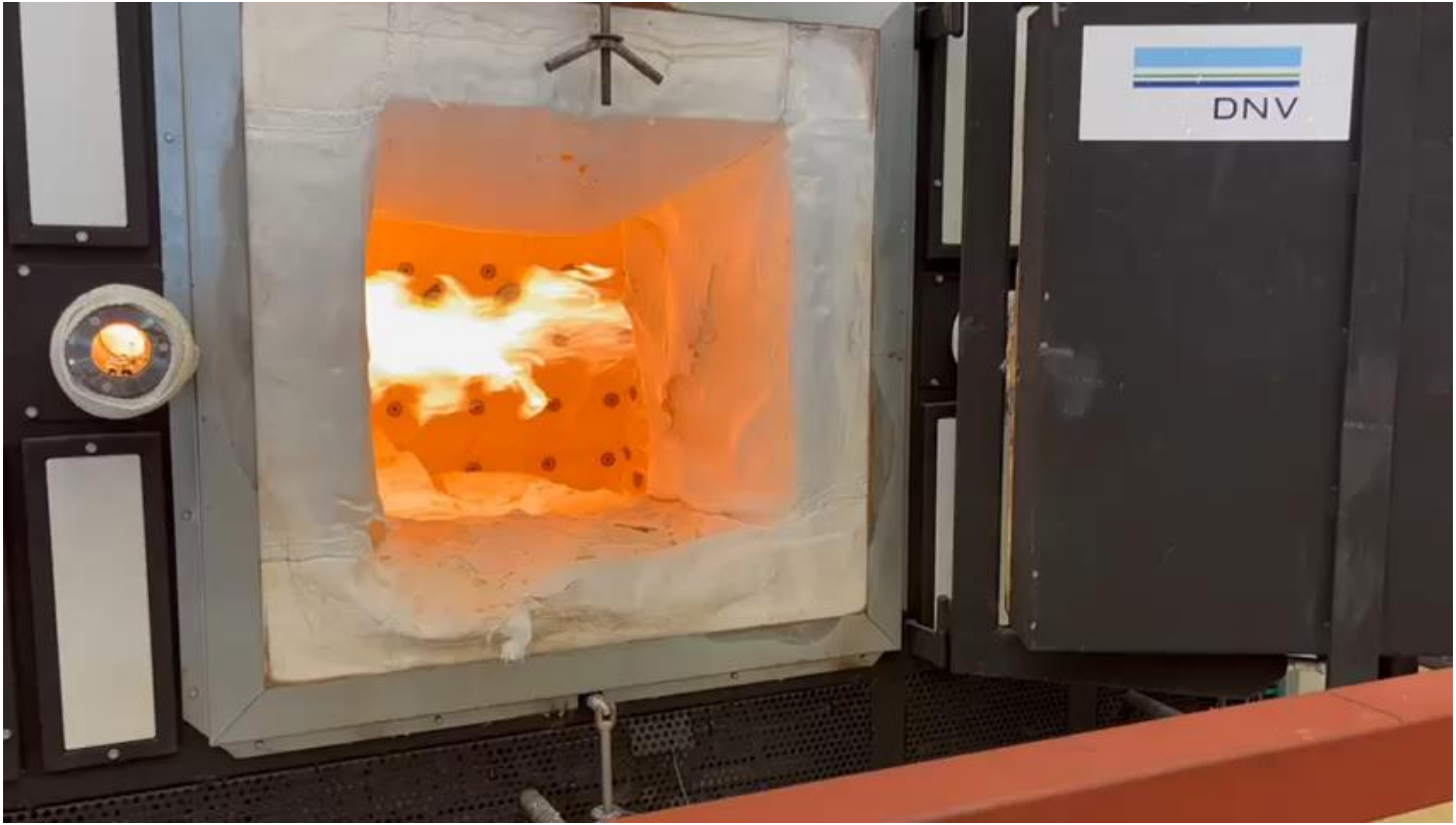


Gas blending unit

Development and testing of flame visualization techniques for Natural gas/hydrogen flames (0-100% H_2)

- Radiant heat flx (Captec sensor)
- LAND IR camera
- Lamtec UV flame detector

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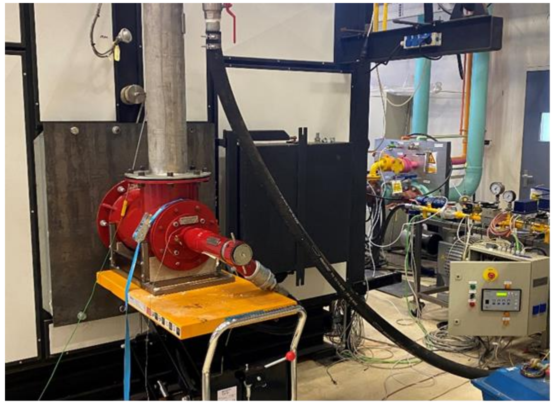
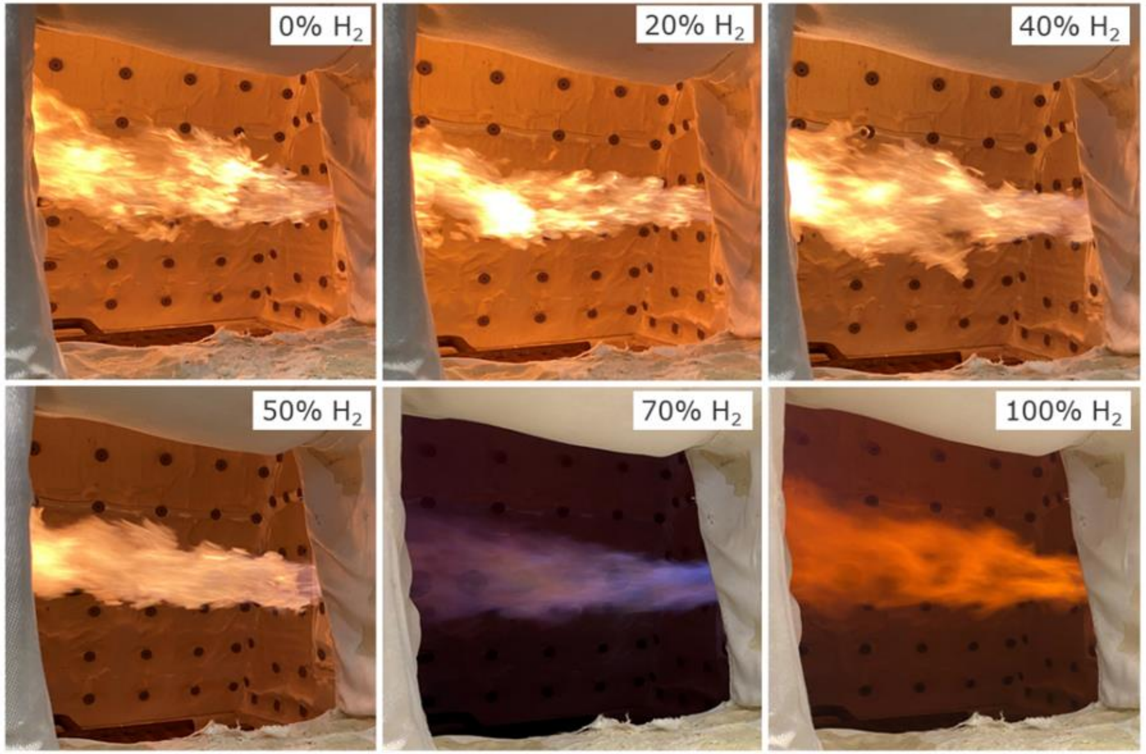
Hydrogen blending tests on a hot air burner used in the metal and glass industry

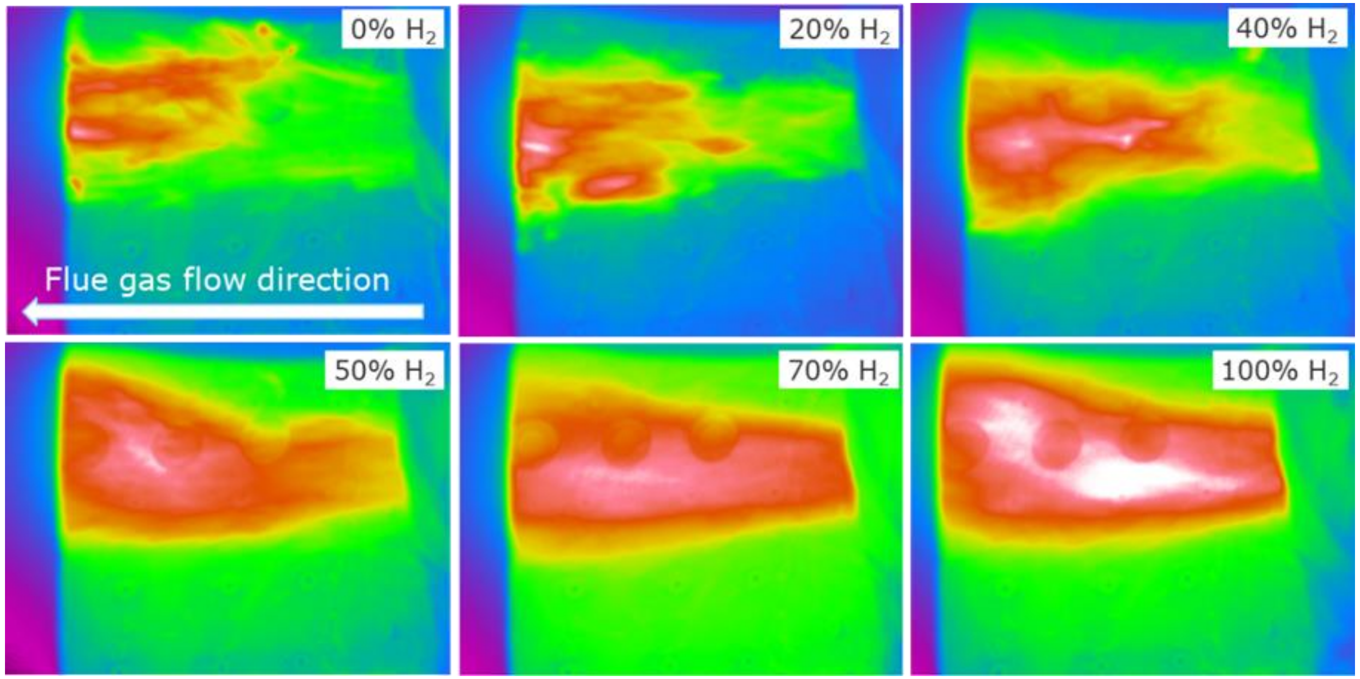


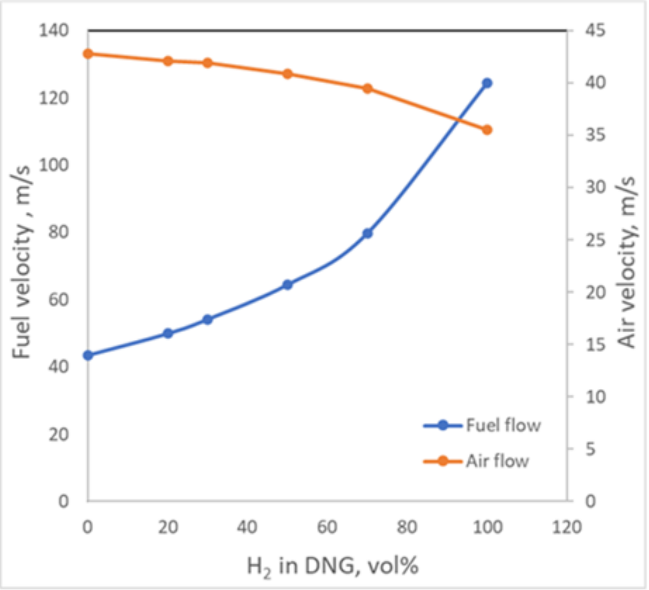


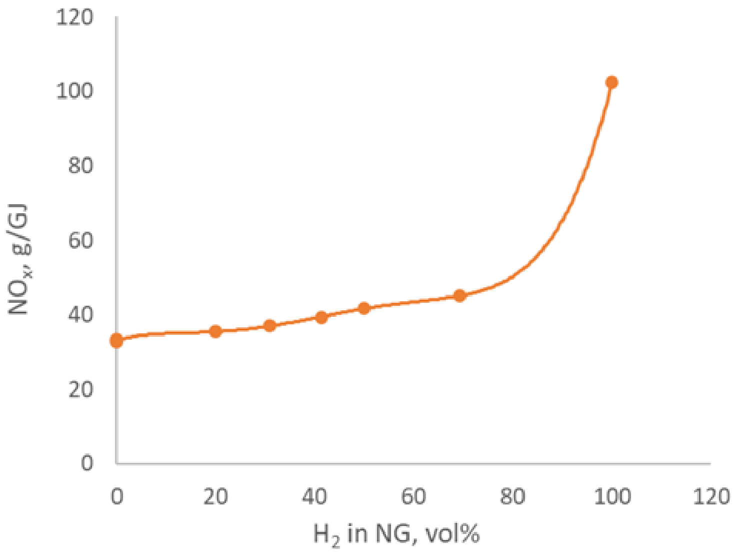
- Thermal input (power) and the air factor was kept constant upon hydrogen addition
- The images show a change in color from a yellow (sooting) flame up to 50 vol% hydrogen.
- At 70 vol% hydrogen the color becomes blue because of the emission from the carbon containing molecules
- At 100% hydrogen the color of the flame becomes orange.
- No large changes in the visible flame length were observed upon hydrogen addition.

Results hot air burner

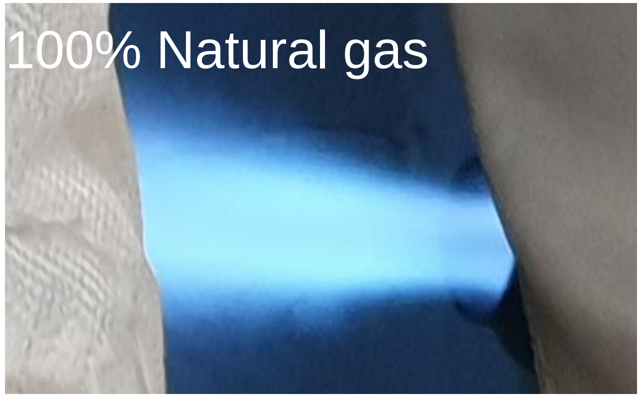
- Switching from natural gas to hydrogen combustion:
  - Increases fuel velocity with a factor of three
  - Combustion closer to the burner head (broader flammability limits, faster diffusion and higher flame speed)
  - Higher (local) flame temperature resulting in higher NO_x emission for most of the burner types

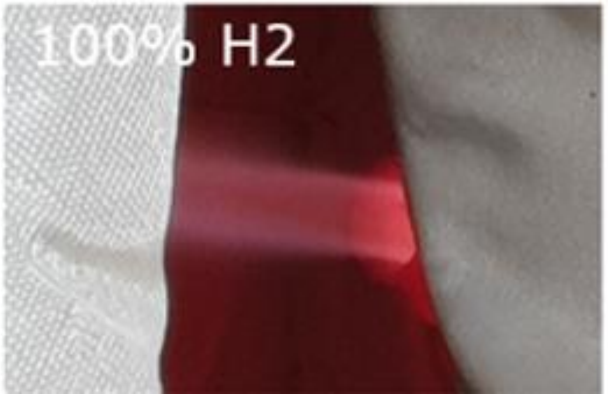


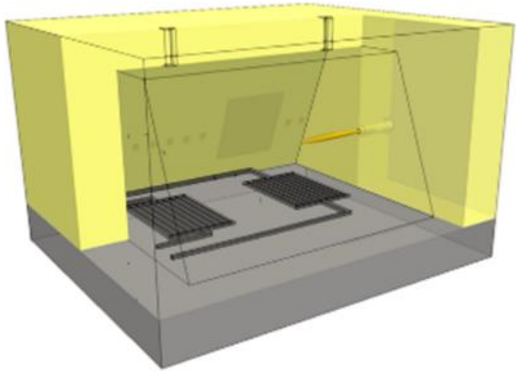




Hydrogen blending tests **medium speed swirl burner** with ceramic tube



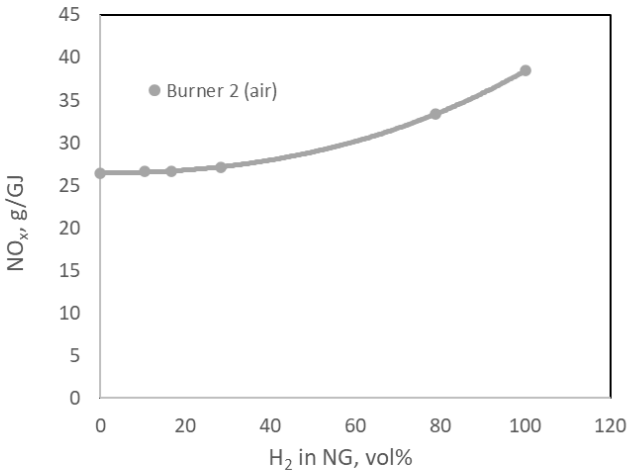




CFD modelling by CelSian

Measurements and CFD modelling show the following upon hydrogen blending

- Change (increase) visible **flame length** upon hydrogen addition
- Increase in NO_x emission
- Shift hot flame zone closer to burner head:
  - **No overheating** of the burner head observed
  - Increase in the **ceramic tube temperature** upon hydrogen addition



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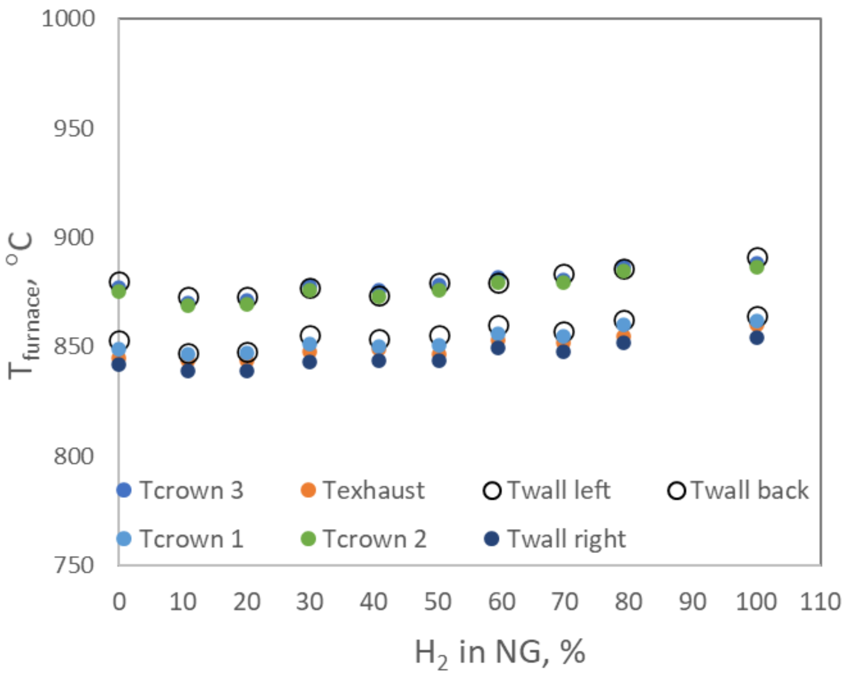
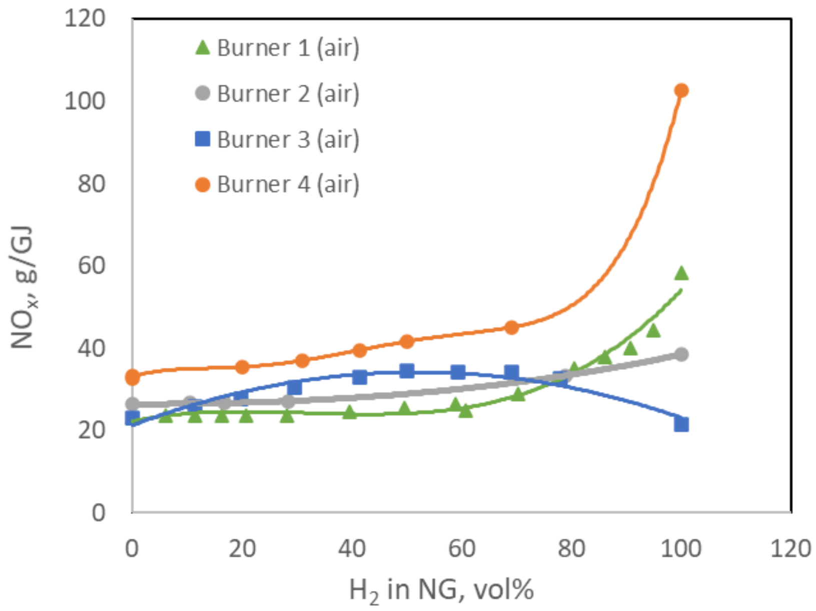
Temperatures measured in furnace upon hydrogen addition to natural gas while keeping the air factor and power constant



- No large differences in the measured furnace temperature observed upon hydrogen addition
- Slight increase of about 20°C when switching from NG to hydrogen combustion
- No substantial changes in the radiation flux were observed when switching to hydrogen combustion

NO_x emission trends upon hydrogen addition (not generic)



Burner no.	Type of burner	Industry
1	Forced Draught Burner	Hot water and steam production/metal
2	Swirl burner	Metal industry
3	High velocity burner	Ceramic/metal industry
4	Hot air burner	Glass industry

- Effect hydrogen blending on NO_x emission depends on burner type
- For burner types no. 1, 2 and 4 an (exponential) increase in NO_x is observed
- In contrast, burner no. 3 initially shows a substantial increase in the NO_x emission upon hydrogen addition followed by a decrease.

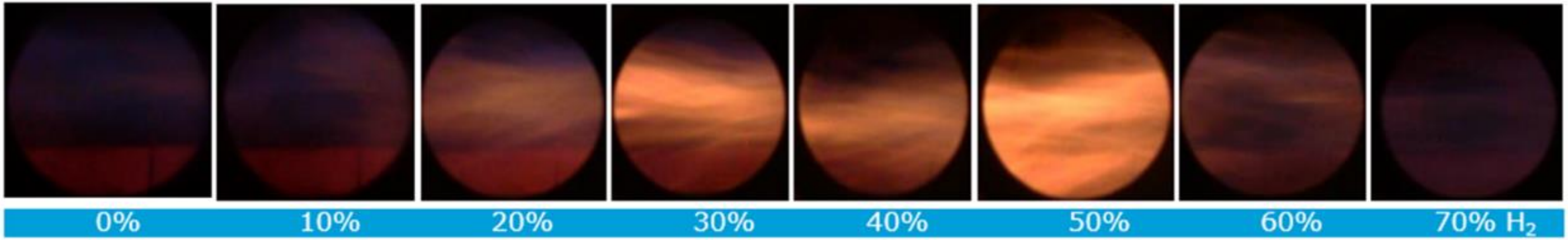
Conclusion NO_x formation/emission depends upon type (not simply one answer)

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



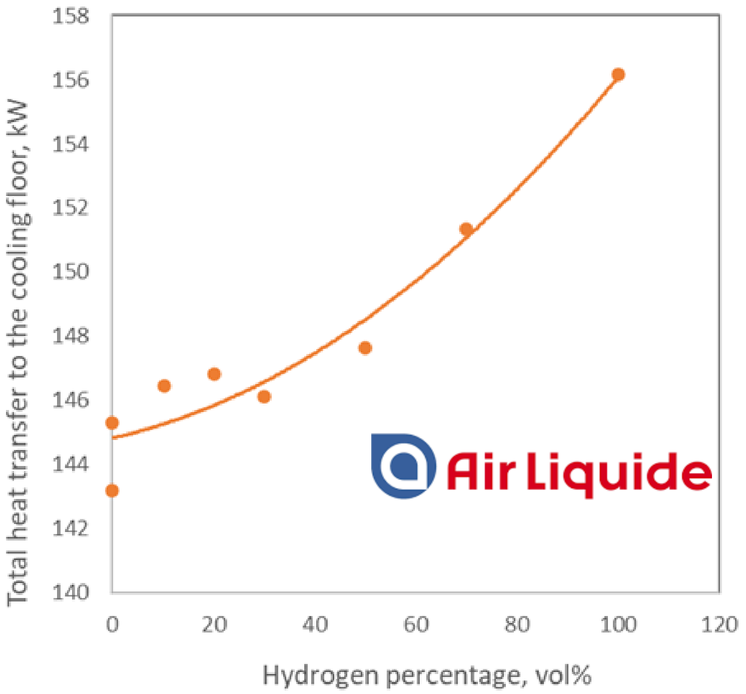
Measurements performed at DNV in a 500 kW furnace using an industrial swirl burner

Oxyfuel combustion ($CH_4/H_2/O_2$)

Advantages oxy-fuel combustion:

- High efficiency
- Low flue gas flows and high concentrations of impurities which makes aftertreatment and CO_2 capture more efficient
- Low NO_x emission

- Results on the ALGLAS Air Liquide burner show excellent combustion behavior for H_2/NG blends ranging from 0-100 vol% H_2



Summary

- The effect of hydrogen blending on the performance of burners strongly depends upon the burner type. Generally hydrogen blending results in:
  - Increase NO_x emission
  - Increase in flame temperature
  - Change in air factor and burner power (installation of fuel adaptive control recommended)
  - Reduction in ionization signal of the flame (replacement of ionization probe by UV detector recommended)
  - Hot flame zone moves closer to the burner tip
  - No large difference in visual flame length
  - No large difference in radiation flux and heat transfer measured for the burners studied
  - Reduction in flue gas flow rate
  - Oven atmosphere changes: higher flame temperature and change in H_2O/CO_2 composition
- Recommended to study lance burners (often used in the ceramic kilns)

Preparing for the future use of hydrogen in the metal industry

What is needed?

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

2. Studying impact switching from natural gas to hydrogen combustion on **product quality** and **refractory material**

Part 2: Using biogas a fuel for heating processes

Gases and compositions

- Fermentation gases (dairy waste, waste water treatment, landfill, “clean” biomass):
  - Methane, CO_2, water
  - Trace: siloxanes, sulphur- and halogen-containing compounds, NH_3, microbiological stuff, phosphines? etc.

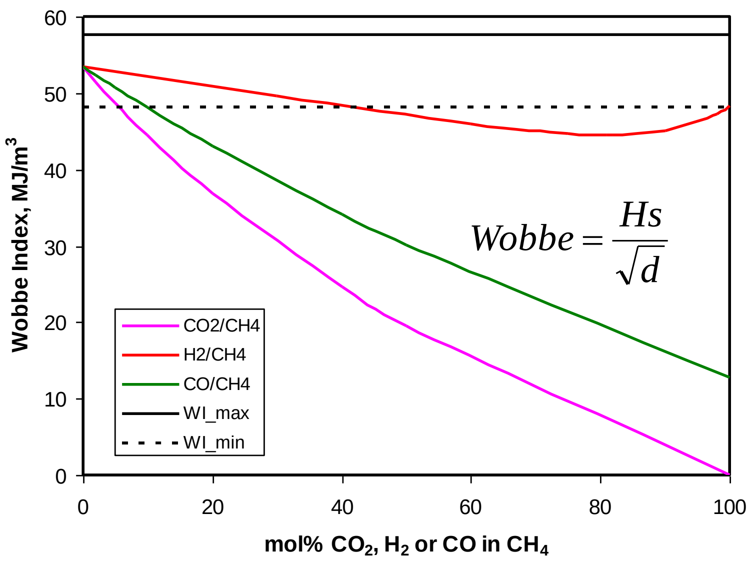
- Gasification (biomass, but also coal):
  - H_2/CO/trace mixtures, can be “methanized” to CH_4/H_2/CO/CO_2/trace mixtures (SNG)
  - Trace: sulphur and halogen species, NH_3, HCN, unsaturated hydrocarbons, etc.

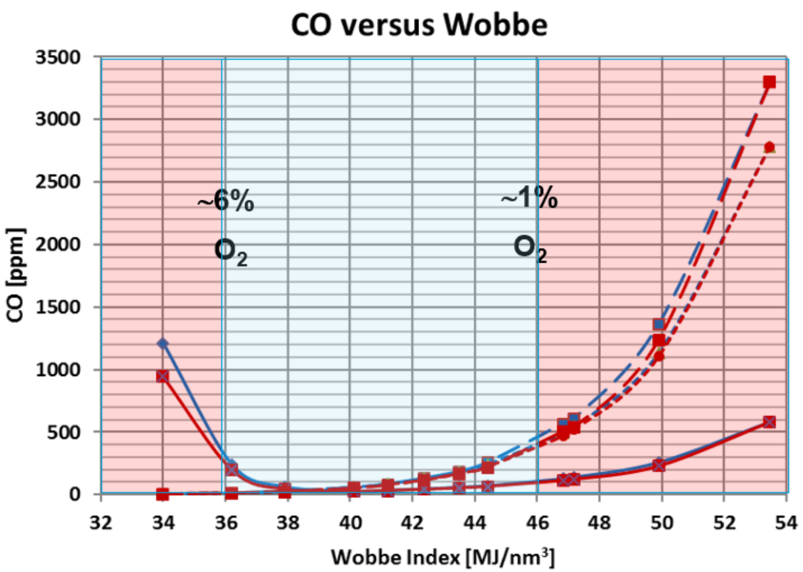
Source Wikipedia

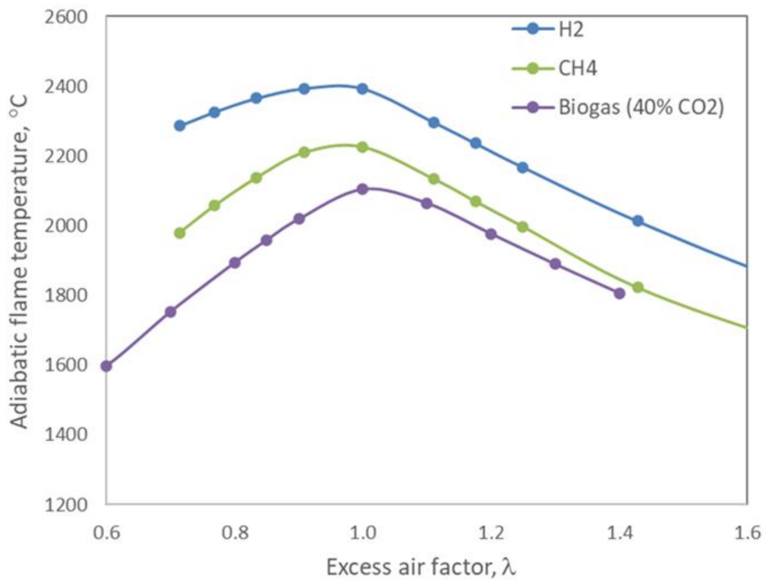
Issues?

- Health: H_2S, CO, HCN, NH_3, phosphine, bugs, silica particles (siloxanes)
- End use:
  - CO_2, CO, H_2 -> flame stability, engine knock, also changes in other emissions (NOx)
  - Siloxanes: silica formation -> health/clogging/worse
  - HCN, NH_3 -> NOx (quantitative)
  - Halogens/sulphur -> HX (dioxines?), SO_x (quantitative)
- Behaviour of end-use equipment with “new” gases can be different compared to traditional distributed (natural) gases
- Installed equipment (including industrial equipment) were designed and/or adjusted for original range of compositions
- Hence, installed appliances put limits on introduction of “new” gases

End Use; effects on thermal input, CO emission and temperature







Fermentation gases

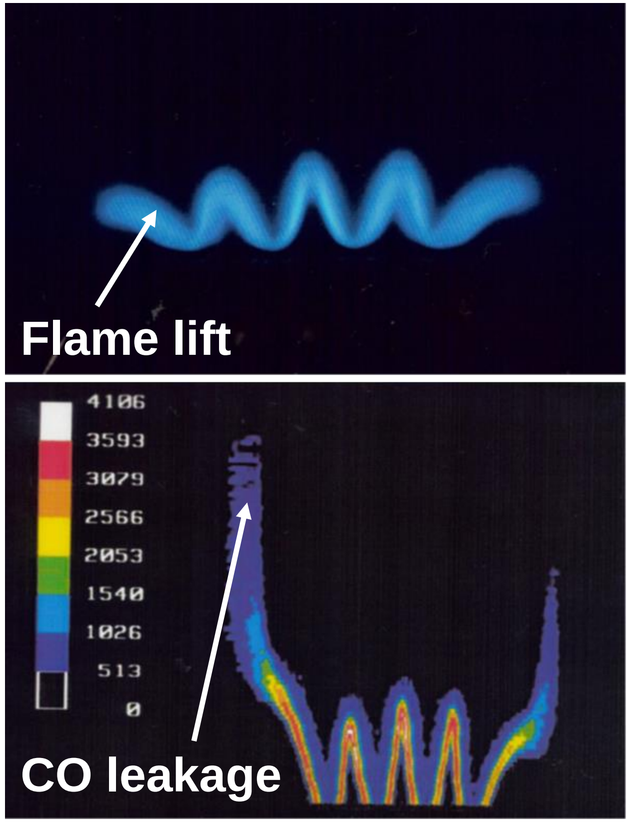
- ✓ CO_2 is a heavy inert, reduces heating value, Wobbe and flame temperature

Gasification: CO/H2-containing gases

- ✓CO, H_2 are low calorific fuels, high temperature
- ✓Density H_2 low

Changes in flue gas composition and flame temperature can affect heat transfer, product quality and NO_x emission

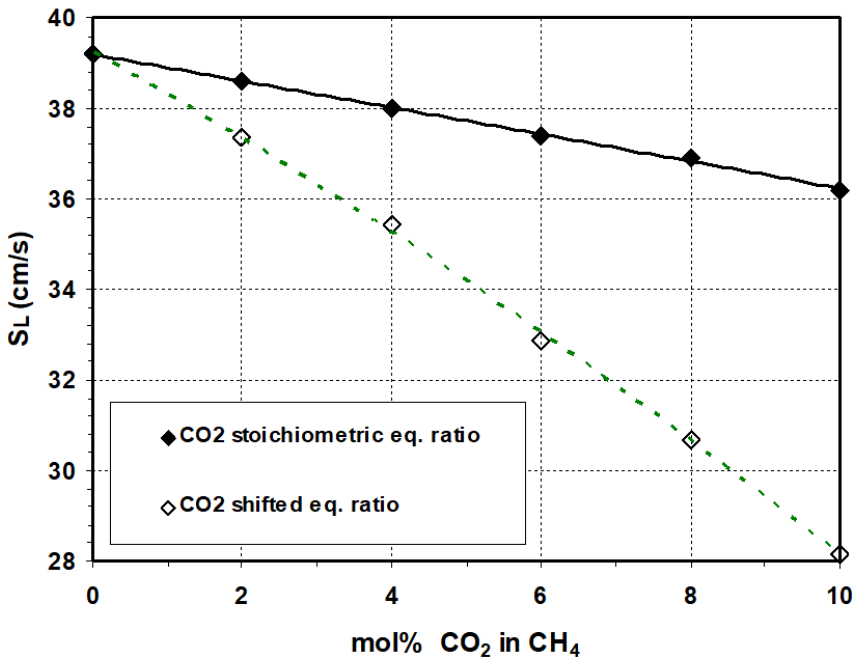
Mixing natural gas with fermentation gas *(CH_4/CO_2)*



DNV developed CO_2 specifications for natural gas: maximum of ~10% CO_2 in Dutch natural gas

Modern lean burn burners (λ=1.2)

- Lower burning velocity leads to flame lift
- (flame no longer stable on burner)
- Lift: CO emissions ("leakage" of fuel)
- Extreme: blow-off, shut down of equipment



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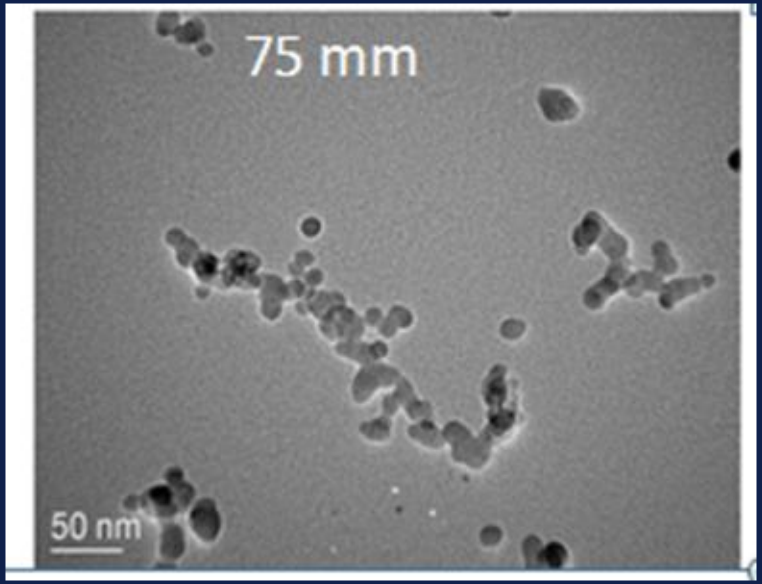
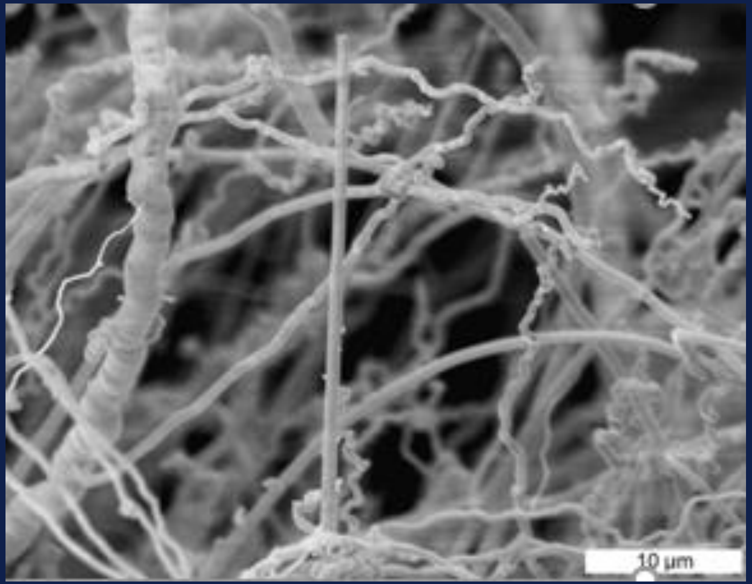
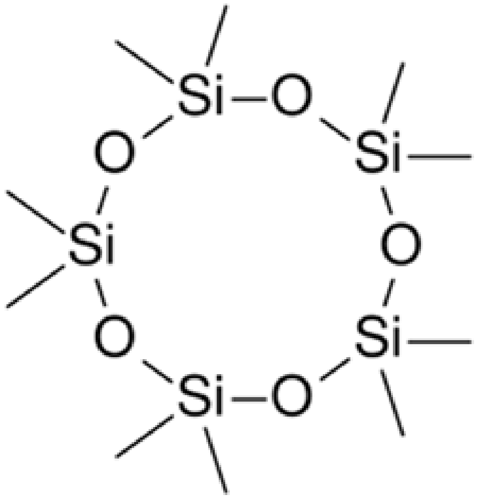
Research effect of presence of siloxanes in biogas and biomethane on performance of gas engines and gas combustion appliances





Introduction

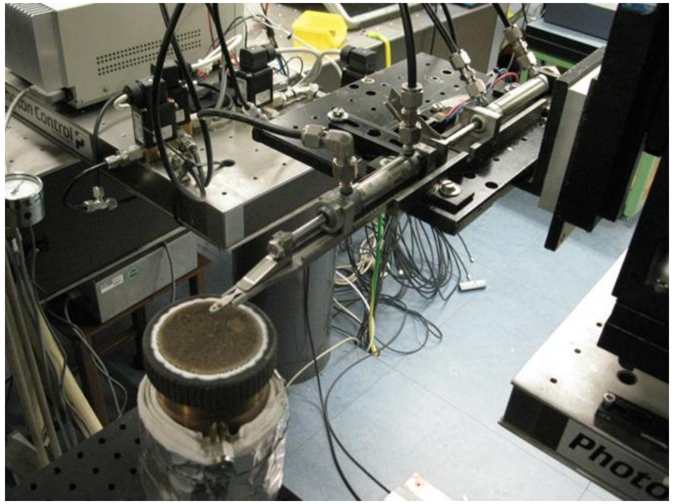


- Siloxanes are manmade organosilicon compounds
- Usually found in gas from landfill and wastewater treatment
- Mostly chemically inert at room temperature (although do biodegrade somewhat)
- Not harmful to living organisms
- Problem?
- Upon combustion, silica (solid SiO_2) is formed, which deposits in combustion equipment and/or is emitted into the environment which can result in health issues

Table 2. Measured siloxane concentrations at selected sites in Europe [2].

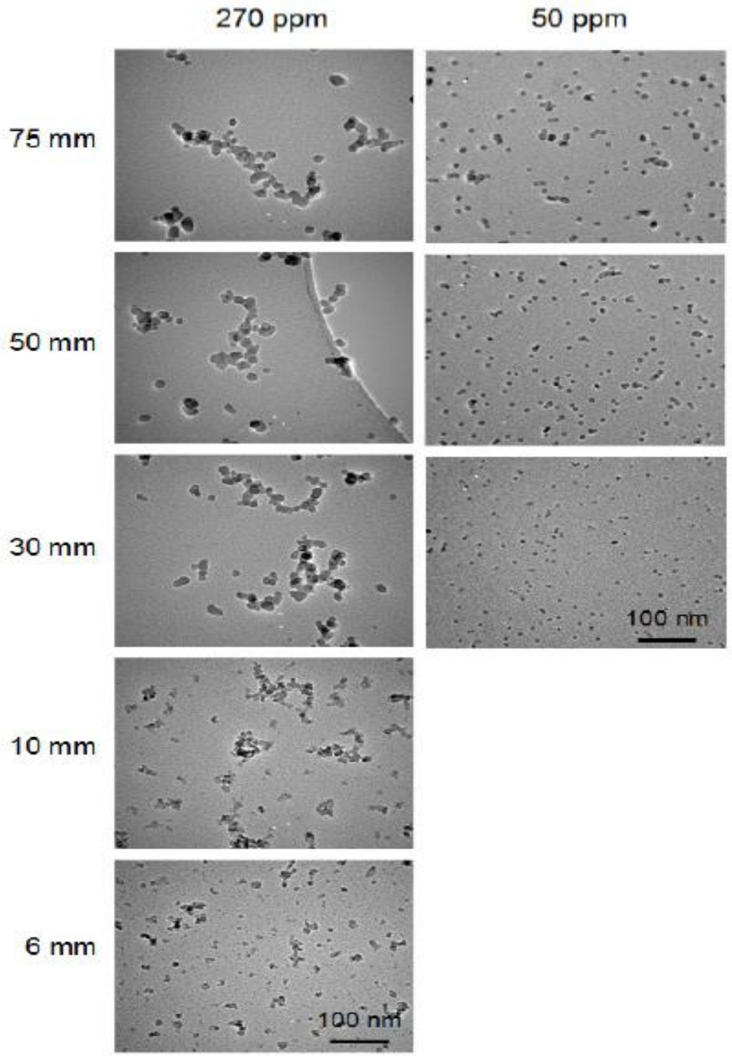
Type	Location	Total siloxane (mg/m^3)
Sewage treatment	Zurich, Switzerland	25.1
Sewage treatment	Neuburg, Germany	59.8
Sewage treatment	Sint-Truiden, Belgium	20.0
Sewage treatment	Trecatti, UK	Up to 400
Sewage treatment	Minworth, UK	Up to 16
Landfill	Berlin, Germany	36.3
Landfill	Augsburg, Germany	4.8
Landfill	Vienna, Austria	9.3

Fundamental research: formation and deposition silica

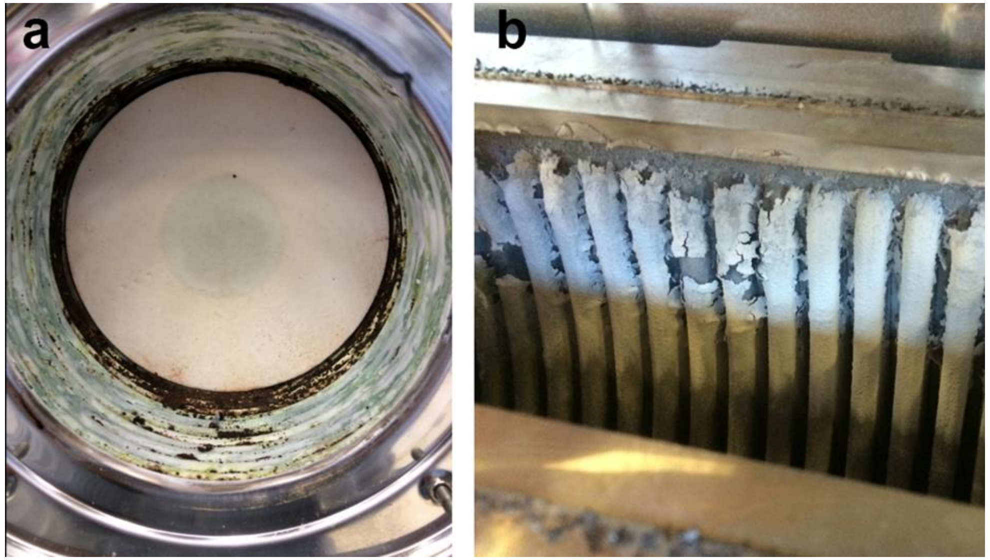


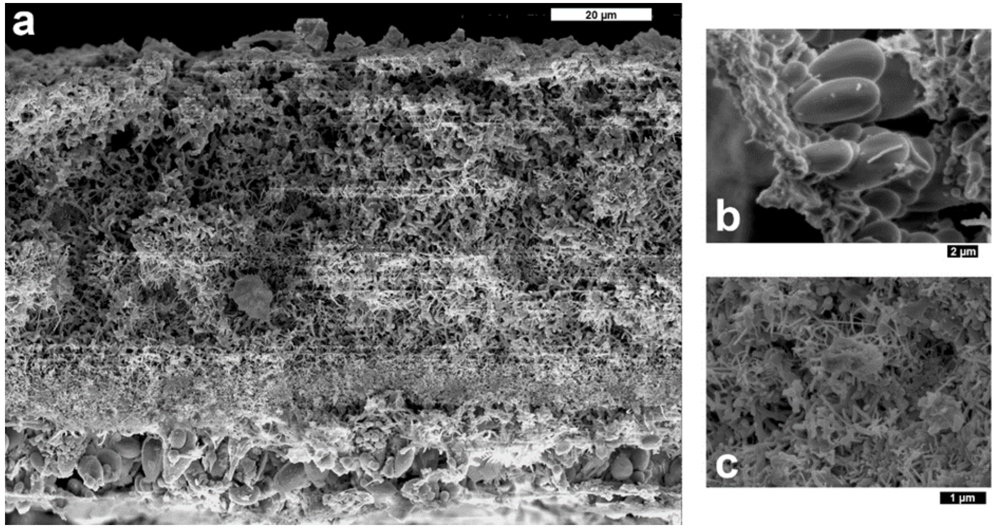
$$C_6H_{18}Si_2O(g) + 12O_2 \rightarrow 6CO_2 + 9H_2O(g) + 2SiO_2(g)$$

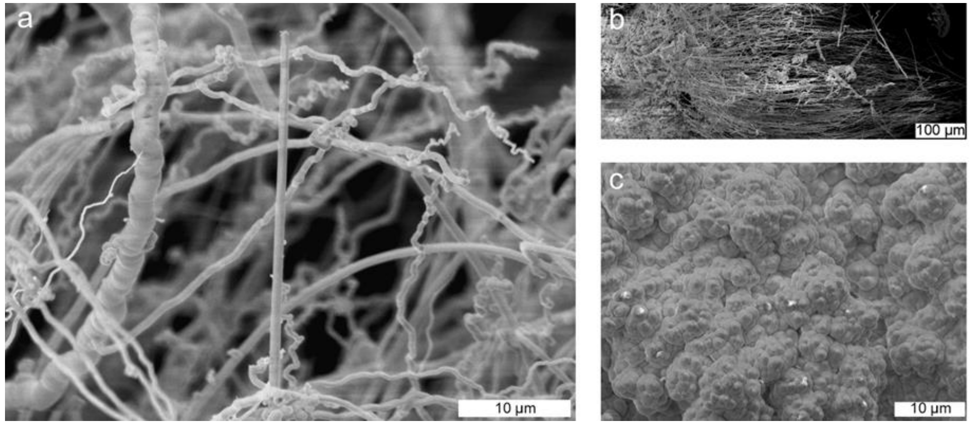
- During combustion siloxanes are oxidized to silica (SiO_2)
- Kinetic mechanism of formation and deposition of silica (SiO_2 is studied)
- Information is used to set-up experimental program and analyses of effect silica deposition on end use equipment

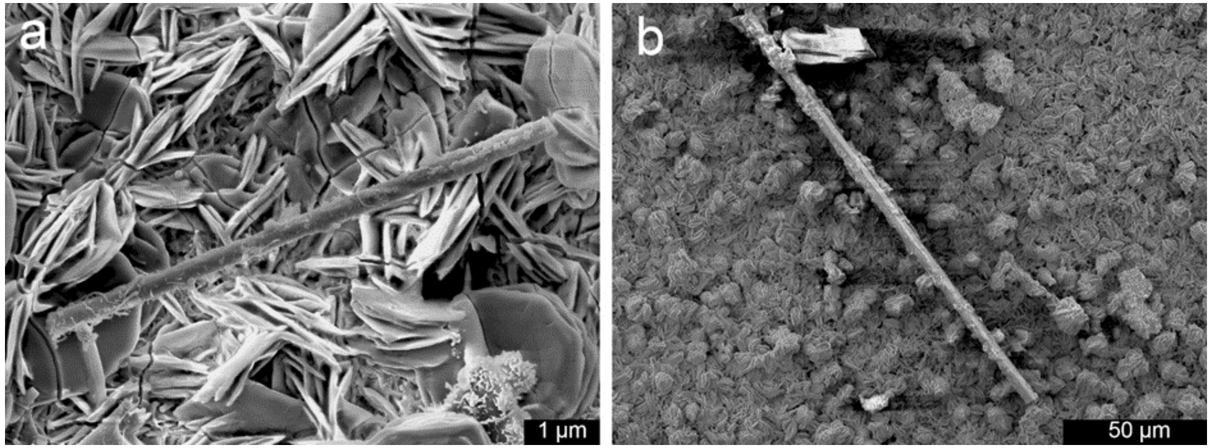


Silica deposition heat exchanger (6 mg Si/m^3)









Summary biogas

- Introduction of biogas gases results in changes in combustion properties
  - Pollutant emission: e.g. CO, NO_x, silica particles
  - Flame stability (flame lift and flash-back)
  - Thermal input and flame temperature (heat transfer changes)
  - Changes in furnace atmosphere
- Fuel adaptive control recommended when using biogases with different CO_2 percentages
- Recommended to remove impurities like siloxanes to maintain product quality
- In the Netherlands the biomethane specification is 0.1 mg Si/m^3

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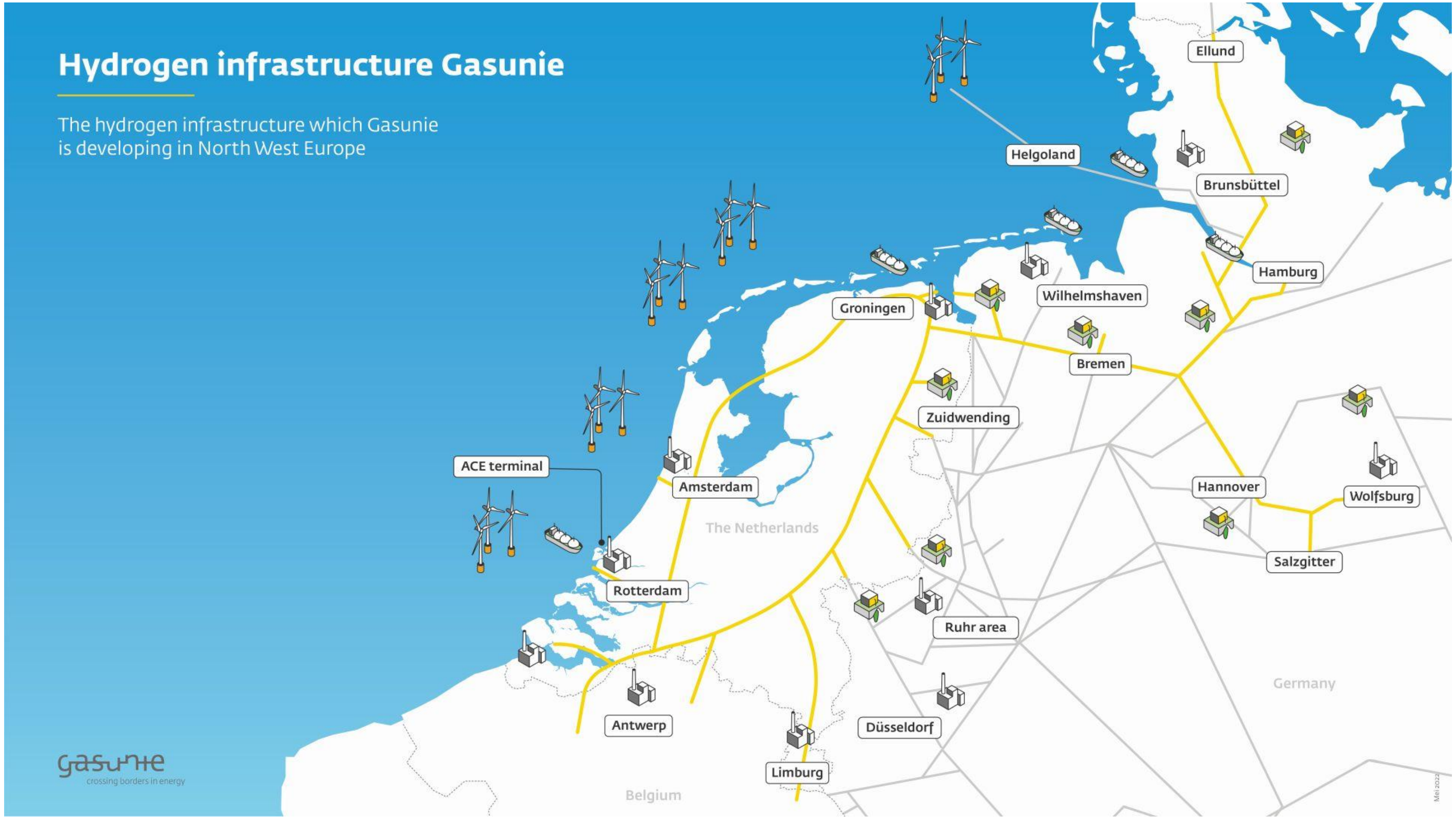
Hydrogen pilot projects

Gasunie's hydrogen backbone



Gasunie, the Dutch gas TSO is in the process of (further) developing a dedicated hydrogen pipeline transmission system including underground storage facilities.

Because of hydrogen becoming more widely available, industrial gas consumers in the Netherlands, Belgium and Germany have expressed their interest in achieving carbon neutrality through green hydrogen.

Hydrogen projects in the industry

With a total available budget of almost €800 million, seven Dutch impactful projects for hydrogen production are subsidised. The projects receive a subsidy from the so-called second wave of IPCEI hydrogen: this wave includes projects aimed at making industry more sustainable. If all projects are realized according to plan, they will together provide a capacity of 1,150 Megawatts of electrolysis for making hydrogen. That is more than a quarter of the 2030 target of the Dutch Climate Agreement.

Apart from the subsidized hydrogen production projects, several Dutch industries have started their own investigations on the applicability of hydrogen in their production processes. Industry sectors that look into switching from natural gas to hydrogen are:

- Potato processing industry;
- Magnesium production industry;
- Ceramics and building material industry;
- Agriculture sector (Greenhouse operators).

An important aspect of the use of hydrogen in the Netherlands is that only pure hydrogen is considered; no blending of hydrogen with natural or bio gas is being pursued.

Domestic use of hydrogen, some pilots

Hydrogen project Stad aan’t Haringvliet:

- 632 homes and utility buildings are foreseen to be connected to a hydrogen distribution grid (the present natural gas distribution system).
- Hydrogen is to be produced by means of electrolyzers running on green power from a nearby wind farm.

In all cases, both industrial and domestic use of hydrogen, safety has the highest priority, but also applicability of hydrogen for specific purposes and required system modifications are key to the success of the pilot projects. DNV is closely involved in finding solutions by doing hands on research and project guidance.

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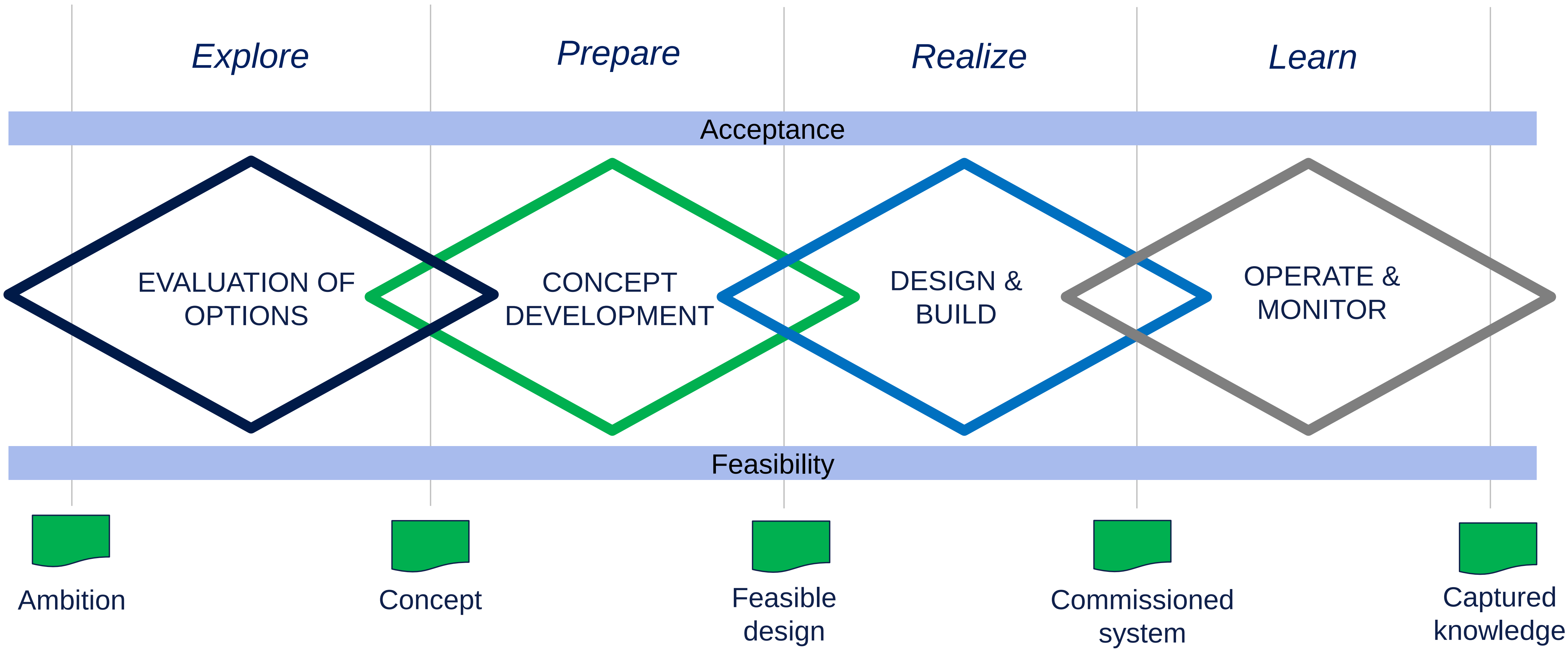
Successfully implementing decarbonization solutions in industry – the 4 stages



Successfully implementing decarbonization solutions in industry – more detail

1 Evaluation of options

- Detailed, prioritized techno-economic overview of the solutions
- In depth techno-economic-environmental feasibility study
- Develop business cases and Project Development Plan
- Stakeholder mapping
- Technology assessment (BAT scan)
- System impact analyses

Explore

2 Concept development

- Functional Specification / Conceptual design
- Inventory of local laws, regulation and permitting
- Define objective of pilot
- Safety & risk analysis studies (TRA / HAZOP / RIE / contour calculation)

Prepare

3 Design & Build

- Engineering concept design (P&ID)
- Safety Studies
- Permitting process
- Bill of Material (BOM) & purchasing support
- Design documentation (QRA, PED, EVD, ATEX)
- Commissioning (FAT, SAT)

Realize

4 Operate and Monitor

- Monitoring performance
- Analysis and discussion of the data
- Organize dissemination activities (PR) / share key results
- Safety aspects evaluation
- Publish the results
- Define next steps

Learn

EXAMPLE - Pilot project Nedmag (magnesium salt mining and manufacturing)

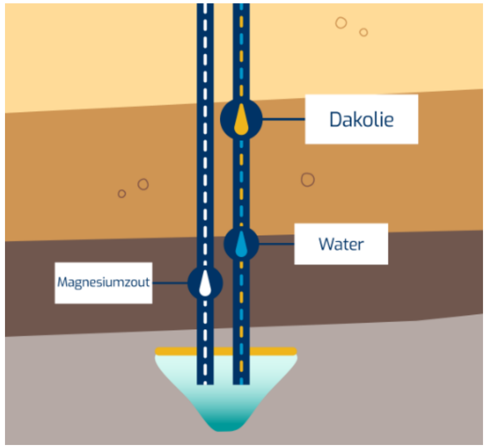
Goal:
to get field experience (pilots) with blending hydrogen in NG and/or switching to pure hydrogen

Nedmag Veendam

Pilot/Demo project thermal oil heating furnace:

- **2MW**
- **0-100% Hydrogen in Natural Gas**

Hydrogen pilot Nedmag



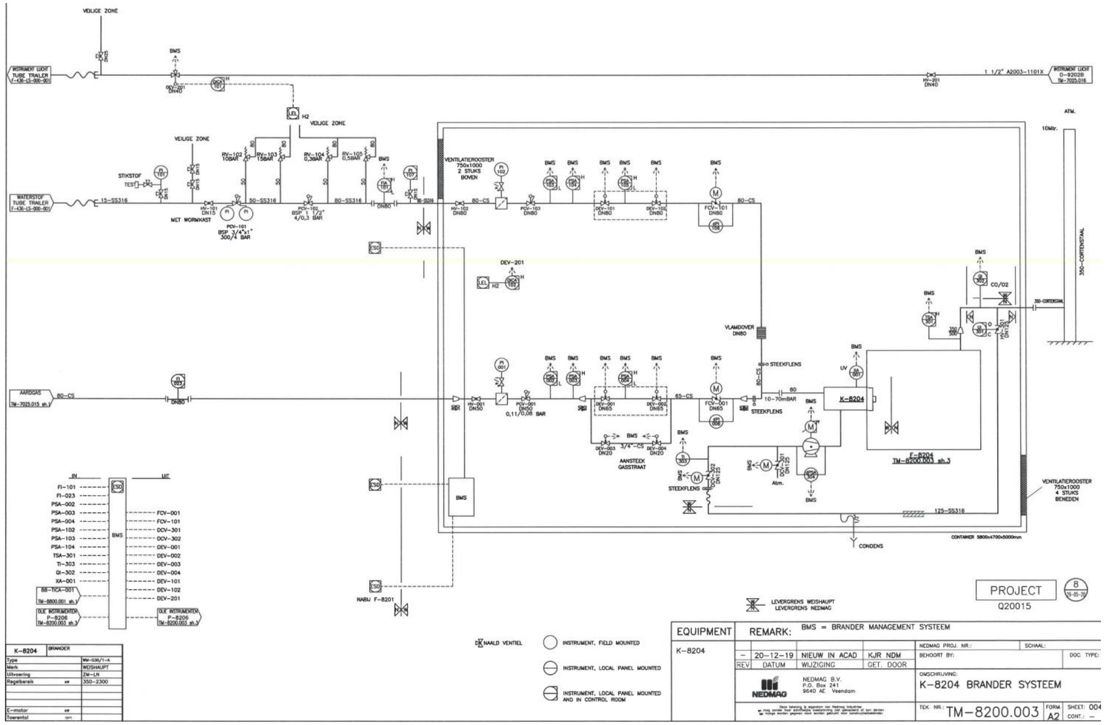
Magnesium salt mining

Parties involved:

- **Nedmag:** Owner installation, PM, applying legal permits, etc.
- **DNV:** Consultancy combustion (theoretical and experimental), engineering and risk assessments (Hazop, TRA, Explosion Safety Document, certification
- **Monarch/Weishaupt:** burner supplier, incl. fuel and combustion air supply
- **Tempco:** Burner Management System, flame detection and safeguarding
- **PMF:** construction of fuel and air supply

A successful implementation/demonstration/pilot of Hydrogen as a sustainable fuel necessitates a **multi-disciplinary** and **independent** approach

Design fuel supply system



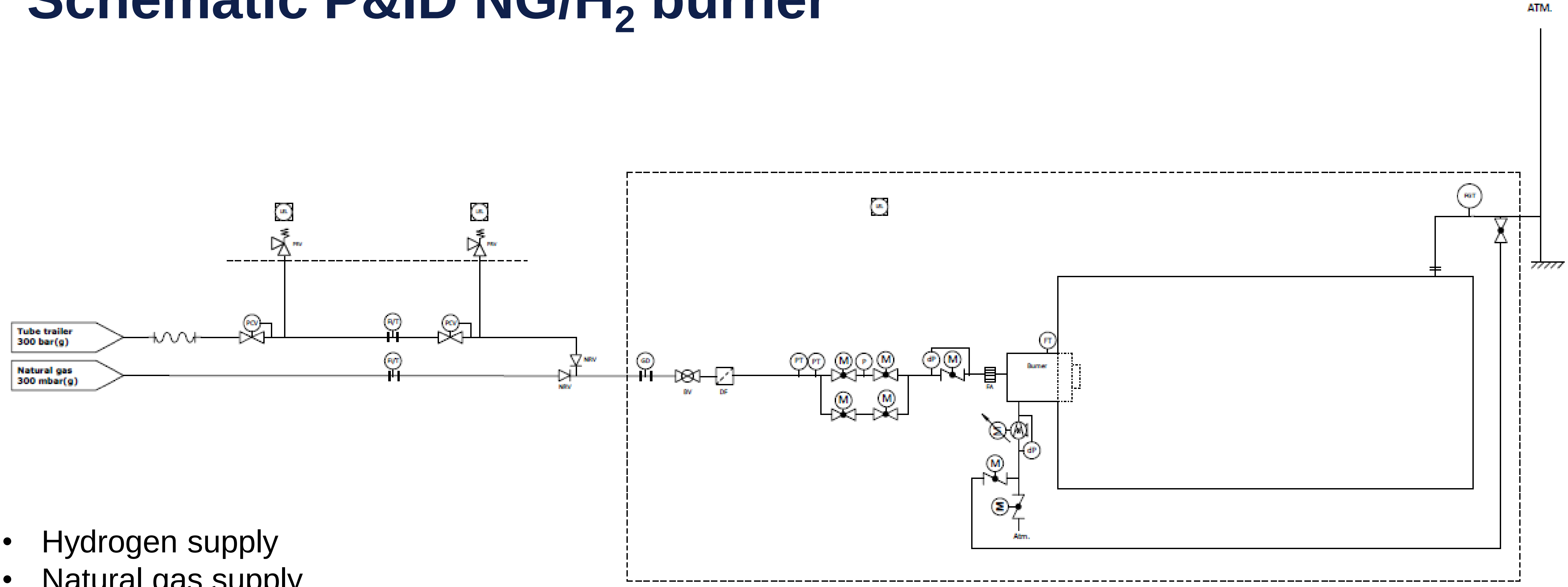
- Power 2 MWth, 180m^3/h NG=> 600m^3/h H_2
- Hydrogen from 300 barg tube trailer
- Two pressure reduction steps (H_2):

  300 barg → 4 barg / 4 barg → 300 mbarg
- Basic design from different participants →

  several Hazops and TRAs with all parties involved
- Next step detailed/final engineering →

  another safety assssment resulted in additional modifications, such as flame arrester, safety blow-off, etc.
- Fuel gas composition derived from NG and H_2 flows → input signal for BMS to optimise combution
- Min. and max flows are safeguarded by BMS
- UV-cell to detect and safeguard hydrogen flame, ionisation does not work. Not needed above 750º C ?

Schematic P&ID NG/H_2 burner



- Hydrogen supply
- Natural gas supply
- Composition derived from flow ratio or gas sensor
- Flame arrester just downstream of burner (UEL H_2 ~ 75% !)
- Fuel adaptive control system beneficiary to optimise combustion efficiency

DNV **‘fuel-adaptive’** burner system –being able to accomodate any conceivable hydrogen/natural gas mixture- is the solution for the **transition period** from NG to H2.

DNV

Example DNV project - Refractory integrity at H_2-rich combustion

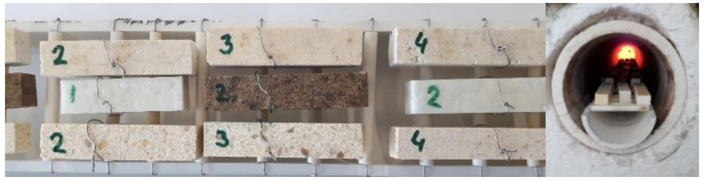
Motivation:

- Change-over from air-gas to oxygen-gas firing led to increased silica crown corrosion (and reduced crown lifetime) as result of the changed flue gas composition

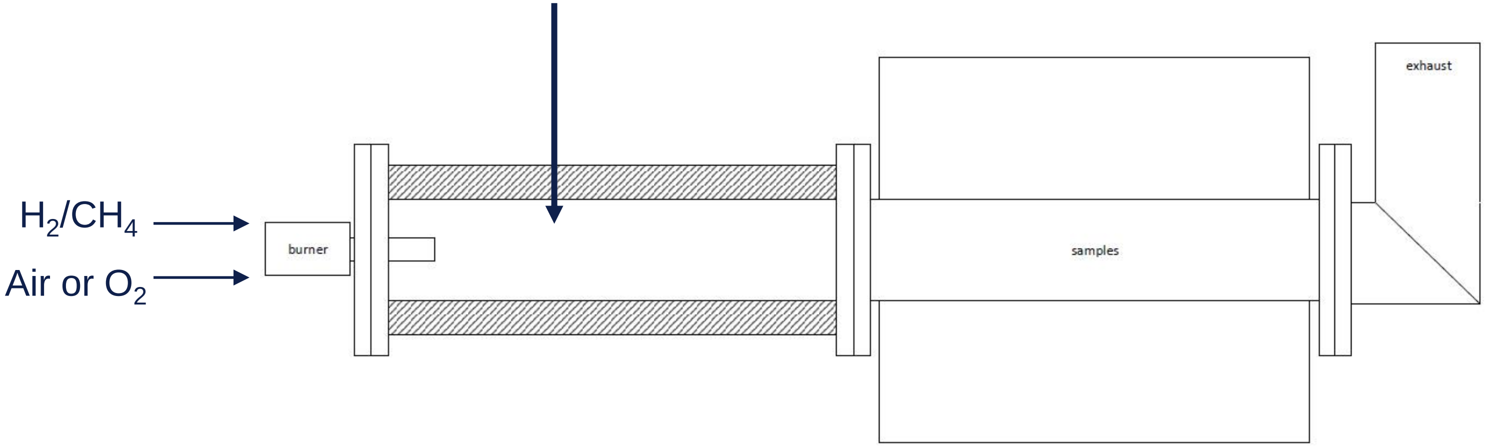
- When (partly) converting from gas- to H_2-firing, a further adjustment of flue gas composition (amongst others [H_2O] and [NaOH]) is expected affecting refractory lifetime

- Selection of appropriate refractory types and process settings requires understanding of the (chemical) interaction between refractory and flue gas resulting from H_2-combustion

Refractory integrity test facility



Injection components to mimic 'real' oven atmosphere



High-temperature tube furnace

Technical specifications

Outer dimensions furnace	920 x 550 x 640 mm (W x D x H)
Switchgear dimensions	600 x 400 x 1400 mm (W x D x H), can vary with additional equipment
Weight	approx. 110 kg
Power rating furnace	approx. 14,4 kW
Power supply furnace	380-415 V, 3/N/PE, 50/60 Hz, fuse protection without earth-leakage breaker
Max. tube diameter outer	120 mm
Heated tube length	600 mm
Length constant temperature +/− 5 K	300 mm after a dwell time of at least 20 minutes at T_{max} -100 K
Heating zones	3
T_{max}	1700 °C
T_{max} in working tube	approx. 1650 °C
T_{max}, vacuum	1400 °C (possible with additional equipment only)
Max. heat-up ramp working tube	200 K/h
Thermocouple type, furnace chamber	type B

Working tube

Material	Ceramic C799
Outer/Inner diameter	120/105 mm
Length	830 mm
Max. heat up ramp	200 K/h
T_{max}	1800 °C
$T_{max, vacuum}$	1400 °C

Electric heaters to maintain desired temperature

Goal material test:

- 24/7 tests with different oven atmosphere (flue gas composition and injection of impurities)

Equipment:

- **Oxy-fuel** burner and **air** burner system (10 kW)
- Air Burner system
- Impurities injection system
- Oven (Electric)
- Ceramic tube
- Adjustments oxy-fuel train

Summary Operation and Maintenance Aspects

- **Gas pipework and valve train capacity**

Depending on Wobbe index of NG substituted for hydrogen, generally 6-10% loss compared to H-gas

- **Impact hydrogen blending on integrity of materials (potential embrittlement)**

Depending on pressure load and materials used

- **Shut-off system tightness**

Installations that are gas-tight with natural gas may not be sufficiently tight for a blend containing hydrogen.

- **Flame detection**

Flame shape and flame length may change (position scanner), no ionization

- **Significantly higher upper flammability limit**

H2 has a significantly higher upper flammability limit ~ 76% vol.), check whether the gas line between the shutoff valve and burner must be purged after the burner has been shut down

- **Significantly higher laminar flame speed**

The high flame velocity may cause resonance and generate noise depending on the burner design

- **Vibrations and pulsations due to the higher flow velocities for hydrogen**

Vibration risk proportional to gas density times velocity squared, no significant change. 30m/s max. with regard to erosion due to particles.

- **Metering and gas analysis**

Some meters need (re)calibration, Turbine meters better than Ultrasonic regarding drift behaviour

- **Safety aspects: inspections, operation and certification**

Standards for industrial thermoprocessing equipment do not contain any reference to hydrogen yet. Therefore, for the time being, the safety and operability of all hydrogen burning equipment should be assessed on a case-by-case basis in cooperation with the governing local, regional and national authorities.

Thanks you for your attention

Questions?

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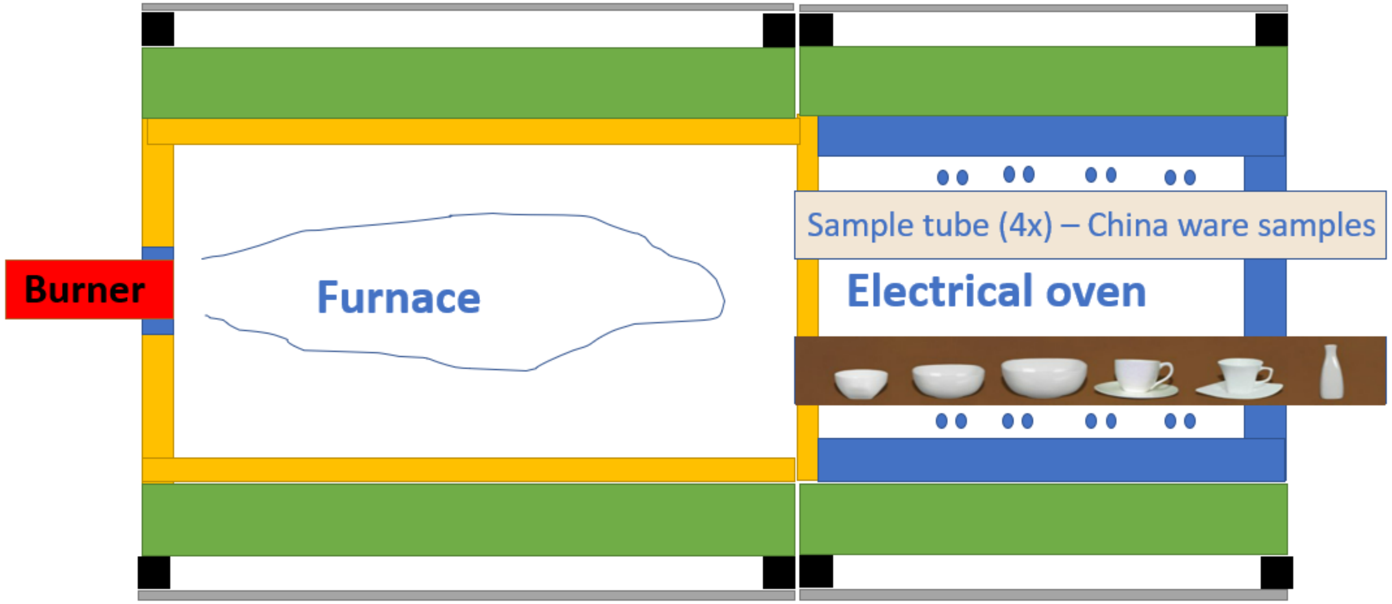
DNV

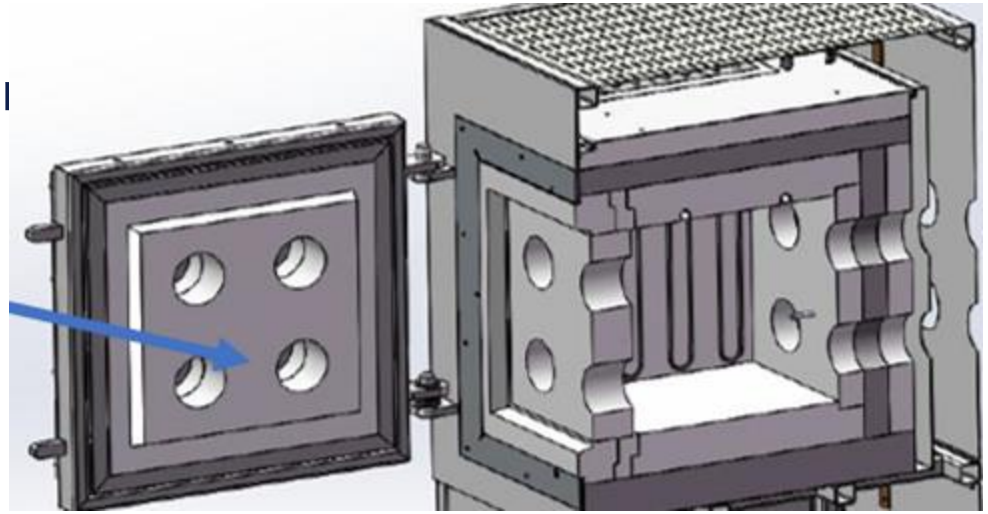
Experimental assessment of influence of hydrogen on chinaware quality possible in refractory test facility

- Chinaware samples can be baked in refractory test facility (max.1600ºC)

- Influence of hydrogen on product quality can be assessed experimentally

- Process parameters (Temperature-Time, etc.) to be determi in cooperation with VISTA ALLEGRE

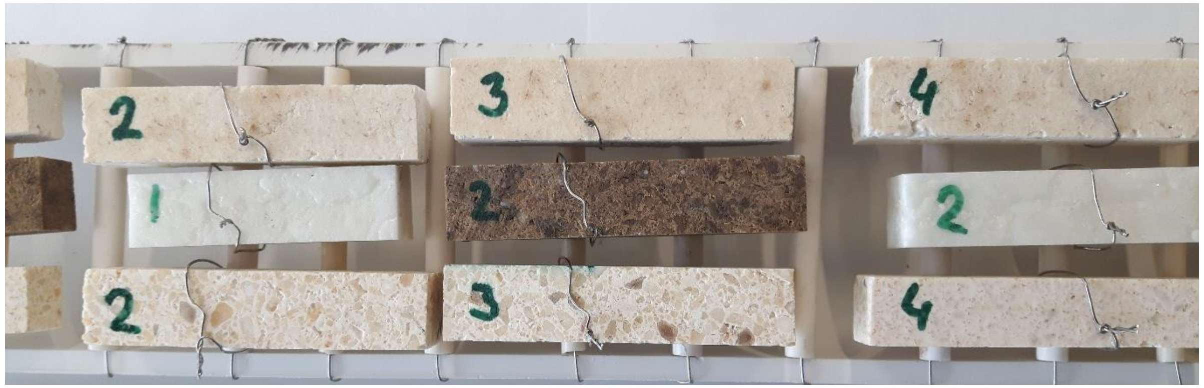




Refractory integrity at H_2-rich combustion

Results/Deliverables:

- Experimental facility for long-term testing of refractory material exposed to flue gas with varying oxidation state ([O_2], [CO]), aggressive species ([NaOH], [SO_x]), and water concentration
- Analysis of the corrosion products and temperature range of chemical corrosion dependent on above-mentioned parameters for a series of (silica) refractory types



Future development: Experimental assessment of the influence of fuel gas composition on product quality