WIRE

Waste biorefinery technologies for accelerating sustainable energy processes

Utilizing Renewable Hydrogen in Industrial Heating: A Sustainable Solution

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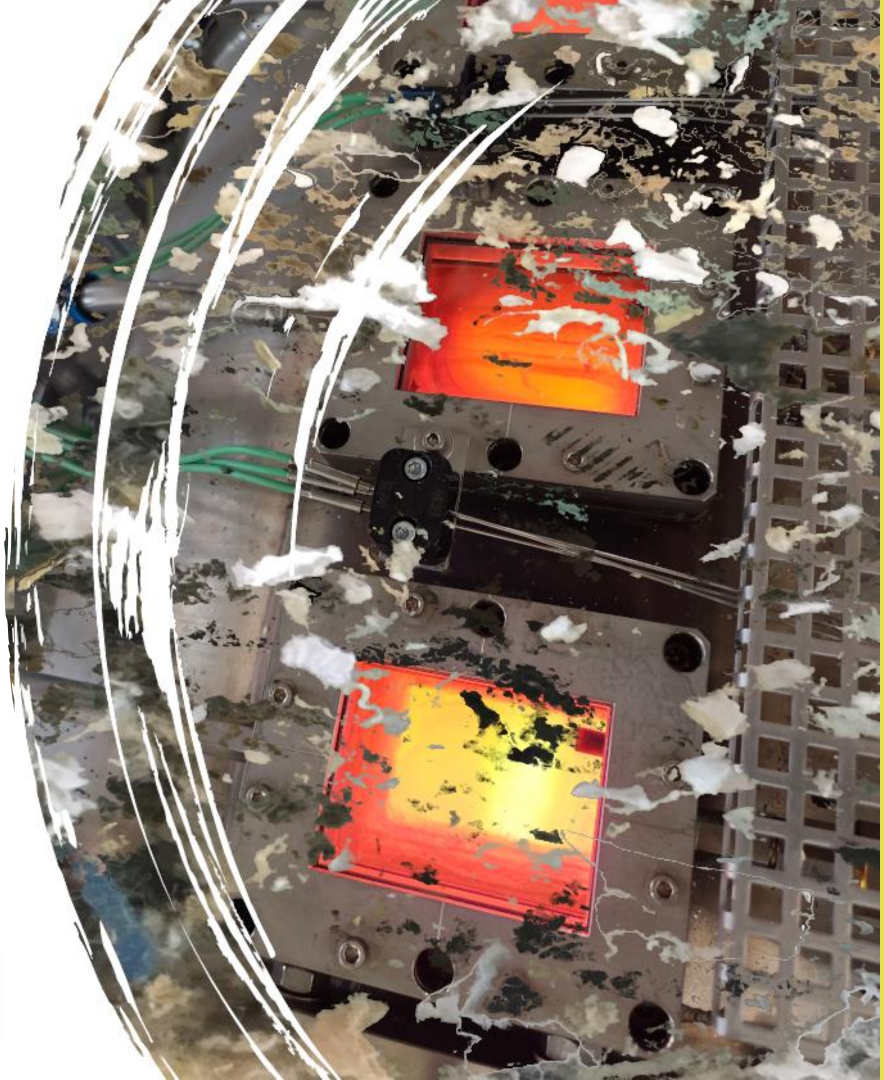
Working Group 3



cost EUROPEAN COOPERATION IN SCIENCE & TECHNOLOGY

Funded by the European Union

Table of Contents

Chair of Gas and Heat Technology

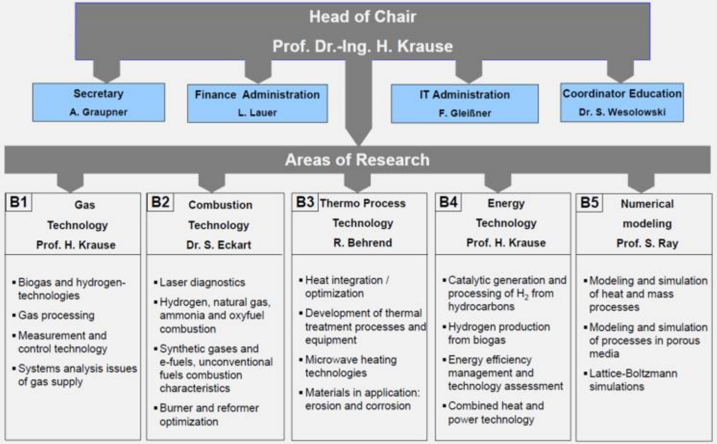
Prof. Dr.-Ing. **Hartmut Krause**

- Combustion technology
- Gas technology
- Energy technology
- Thermo process engineering - furnaces

MOTIVATION

Structure and topics of research

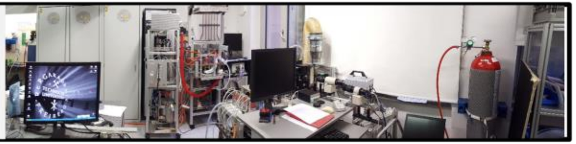
The professorship Gas and Heat Technology is part of the Institute of Thermal Engineering and is assigned to the Faculty of Mechanical Engineering, Process Engineering and Energy Technology. The education and research profile of the professorship is focused on the fields of Gas Technology, Combustion Technology, Thermo Process Technology and Energy Technology.

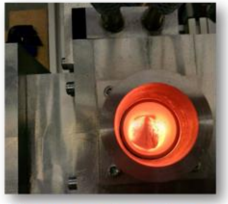


Motivation

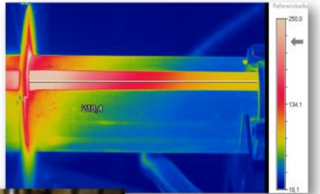
Combustion, Energy and Industrial Furnaces Technology

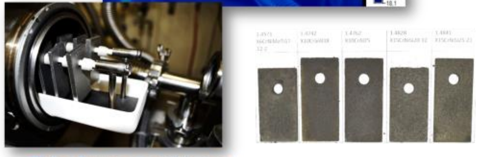
Laboratory





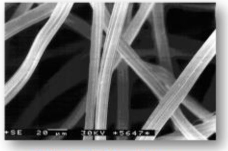
High temperature microwave applicators for glass melting,





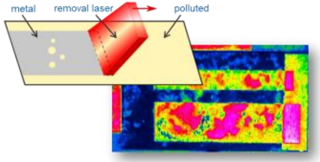
Tube furnaces with controlled atmosphere up to 1600°C for material testing

Plasma flames

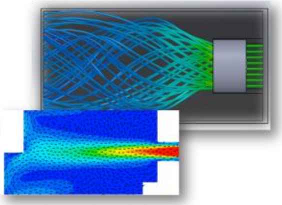


Material testing

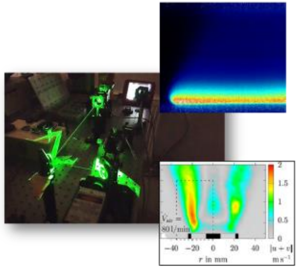
Design and measurement of burners and reformer systems for high temperatures



Surface treatment and reactions



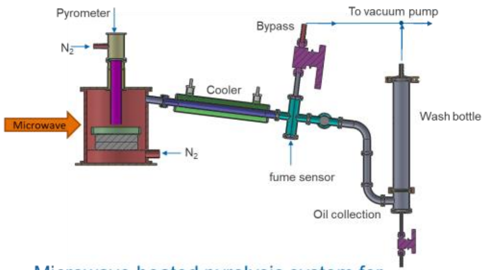
Numerical simulation of combustion and reactive system



Laser diagnostic

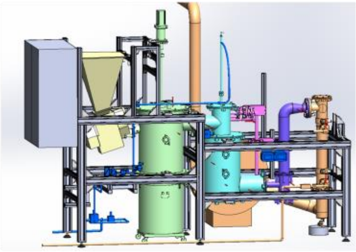
Motivation

Pyrolysis Microwave



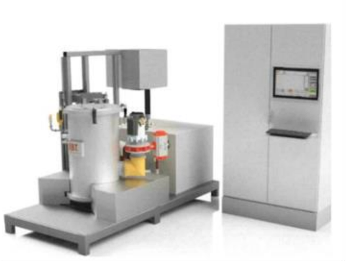
Microwave heated pyrolysis system for CFRP and other polymer based composites

Gasification Combustion



Biomass pyrolysis and gasification systems with low emission burners

Electric/Vacuum



2200°C vacuum/ protective gas/ H_2 furnace for material testing and process simulation

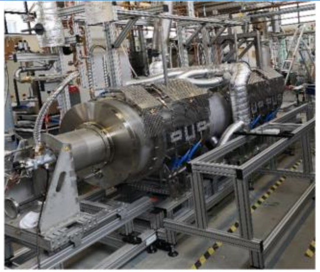
Hybrid/Microwave

600°C combined 2.45 GHz and 5.8 GHz microwave/ hot air heated furnace with large chamber

Combustion Gas/NH3/H2

Measurement of burners and exhaust gas investigations (MS, GC, FTIR, FID, gas analyzer)

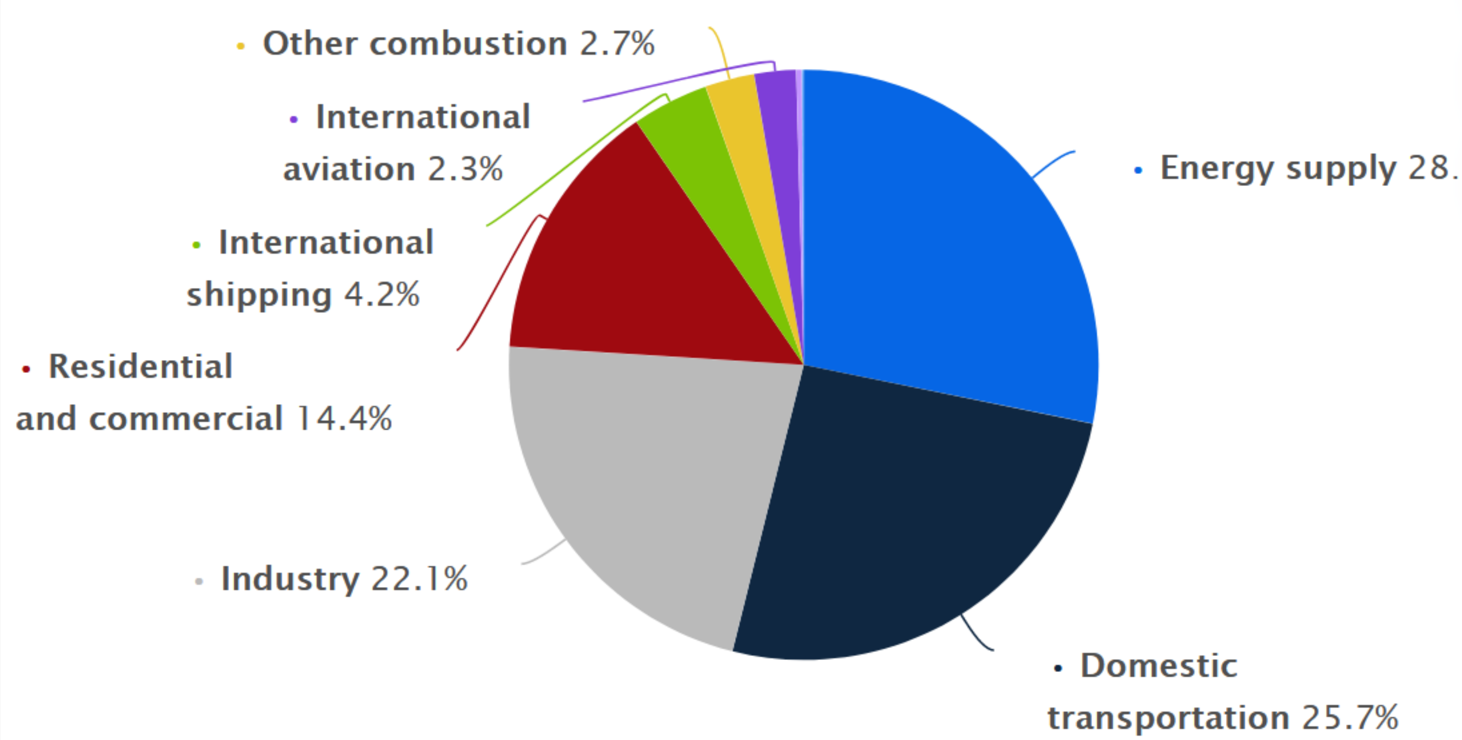
Combustion Gas/H2



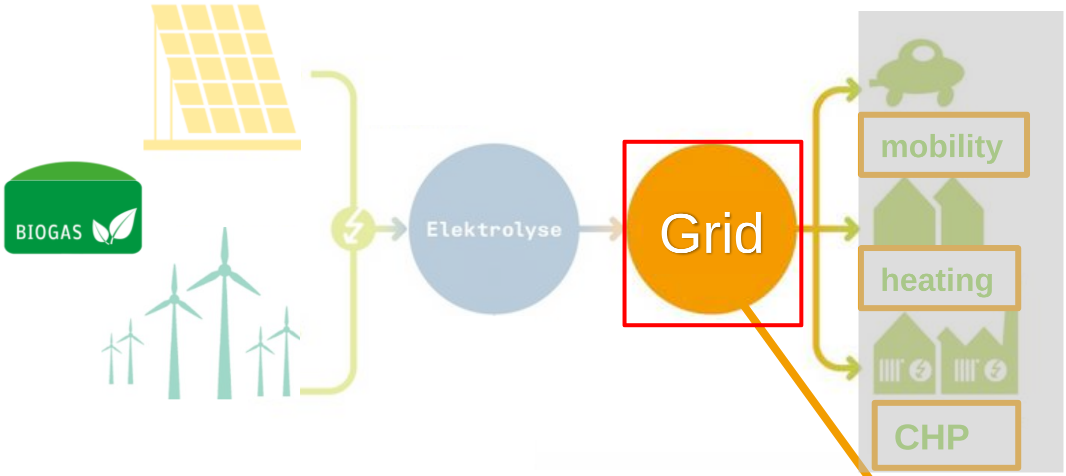
Multistage combustion chamber for fuel and air staging and recirculation (Oxyfuel possible, Hydrogen ready)

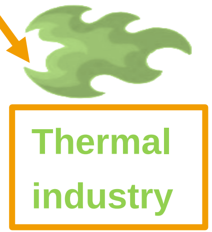
Motivation

Worldwide higher requirements for CO_2 reduction for



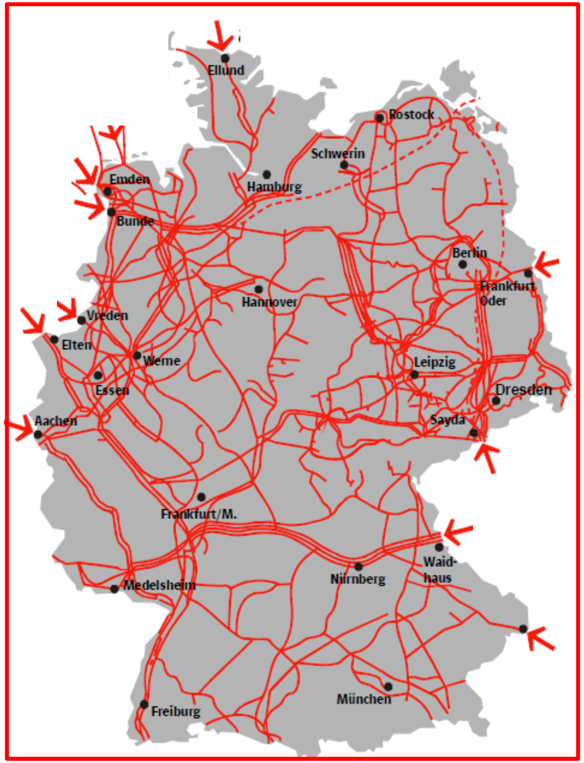
POWER TO GAS





1. Generation of gas from renewable energies
   - Hydrogen and oxygen (from water electrolysis)
   - Methane (from CO_2 and hydrogen)

2. Feeding into the natural gas grid
   - Access to an existing infrastructure for transport and seasonal storage



Motivation - Current developments

Today:

- Running supply structures with H_2 contents up to 10 % Energiepark Mainz (households) since 2018, Stadtwerke Haßfurt (households, commercial).
- Field trials for 20 % H_2 ongoing (Avacon, DVGW)
- Initiative H2vorOrt consisting of numerous municipal utilities is pushing the admixture of H_2 in their own grids up to 20%.
- Distribution grid test field for 100% H_2 in Bitterfeld-Wolfen (H2 grid, H2home since 2019, continued operation until 2025 with significant expansion approved), first H2-cavern in 2025

Short and medium term (< 10 years):

- Germany:
  - In the R&D programme Real Labs of the Energy Transition, the first industrial H_2 supplies are being set up, of which 4 have been launched by 2021
  - 2021: Start of R&D project for the production of GW-class H2-Giga electrolysers
  - R&D technology offensive on hydrogen: production, infrastructure and use
  - By 2024, several large pilot projects will provide green hydrogen
- EU: Numerous national projects of member states are being prepared

Motivation - Current developments

Long-term (> 10 years):

- Natural gas exporters (N, RUS?, Ukraine?) have their own hydrogen supply offers in the conceptual planning stage
- The German government and the European Commission are striving for cooperation with third countries on hydrogen production and supply.
- Numerous studies and potential analyses have been published on this in the middle of the year focus on Africa, South America, etc. Current cooperation agreements concluded with Namibia, Morocco, Chile, Australia,…
- The technology portfolio for production has been expanded to include climate-neutral production methods (blue, turquoise...) in addition to green ones
- There are initial approaches for transport technologies and corridors

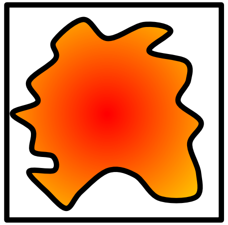
Motivation - Open Questions Burner Technology

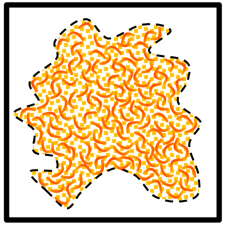
- **Combustion technology:**
  - What changes when hydrogen is used in natural gas burners?
  - Changes in pollutant emissions (focus on nitrogen oxides)
  - Effects of changing flue gas composition on heat transfer
  - Influence on design methods of industrial burners and thermoprocessing plants
- **Safety engineering:**
  - Analysis of hazards in fuel gas supply (leakage rates, materials)
  - Evaluation of findings on flame monitoring
- **Material use in burners and thermoprocessing plants:**
  - Behaviour of burner materials when hydrogen is used
  - Change in condensation potential within assemblies (focus on porous thermal insulation materials, flue gas system)
- **Challenge:** Fuel blends such as low colorific gases, ammonia, DME, e-methanol and metals are also possible

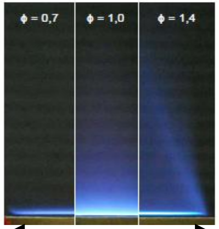
Motivation

MOTIVATION

Turbulent diffusion combustion in industrial plants	Simplification of the models →	Finite sum of laminar flames	Flat flames Investigation →	Investigation of parameters on laminar model burners
Complex simulation		Simplified simulation		experiments







30mm

← Offers the possibility for **scale-up**

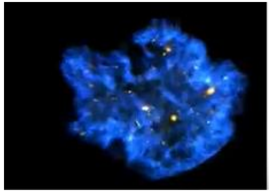
← Provides **validation data**

← Provides **comparative values** for different fuels

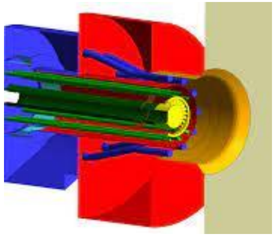
New burner design

simulation

ignition



geometry

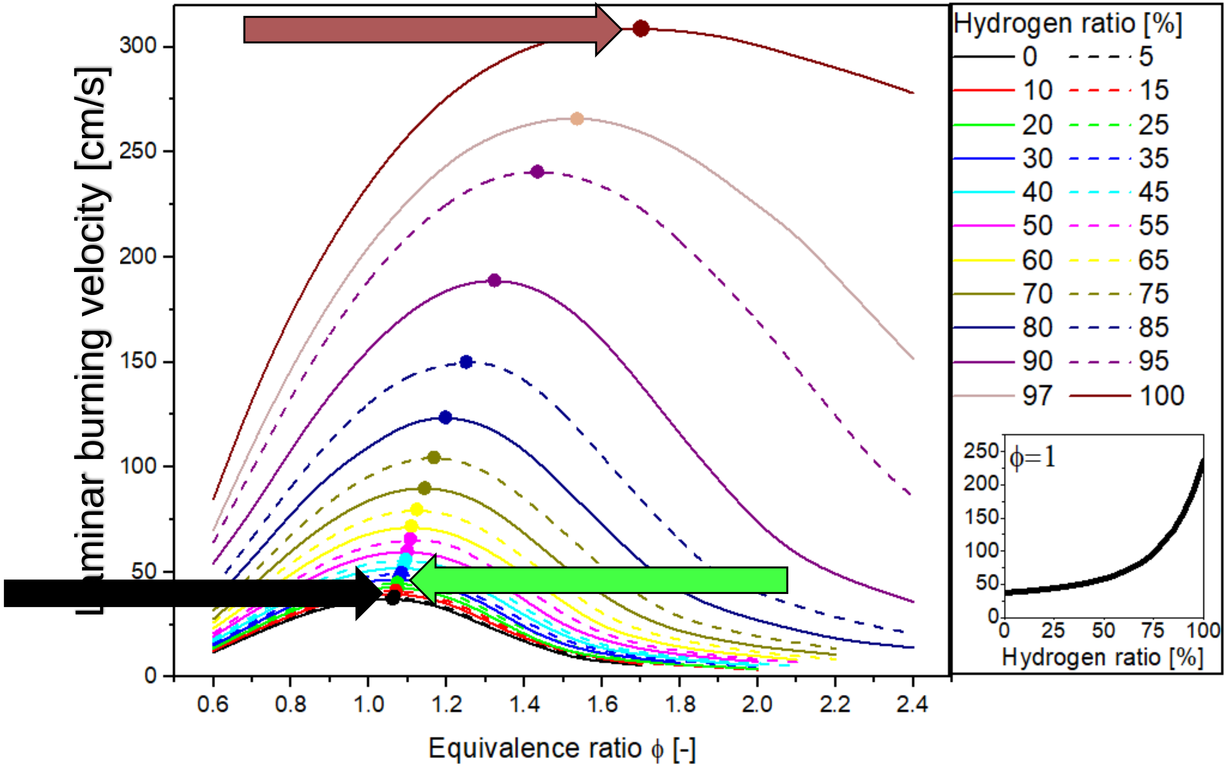


emissions

extinction

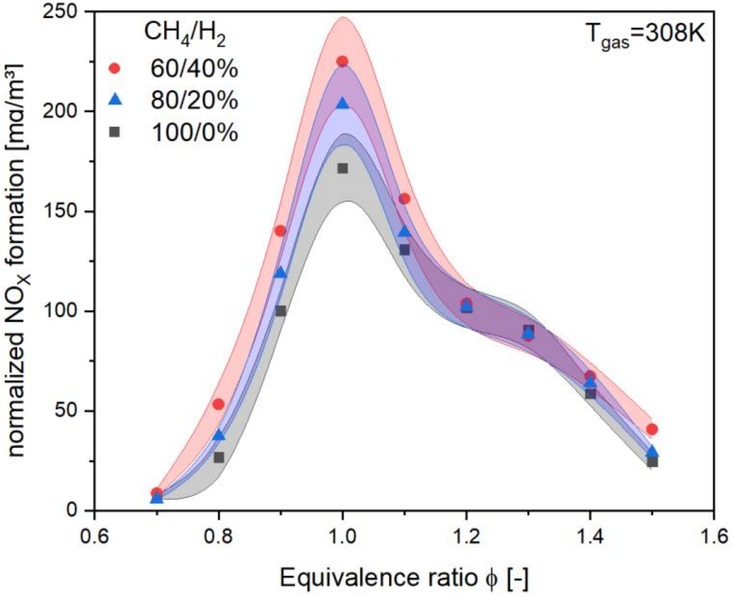
laminar burning velocity

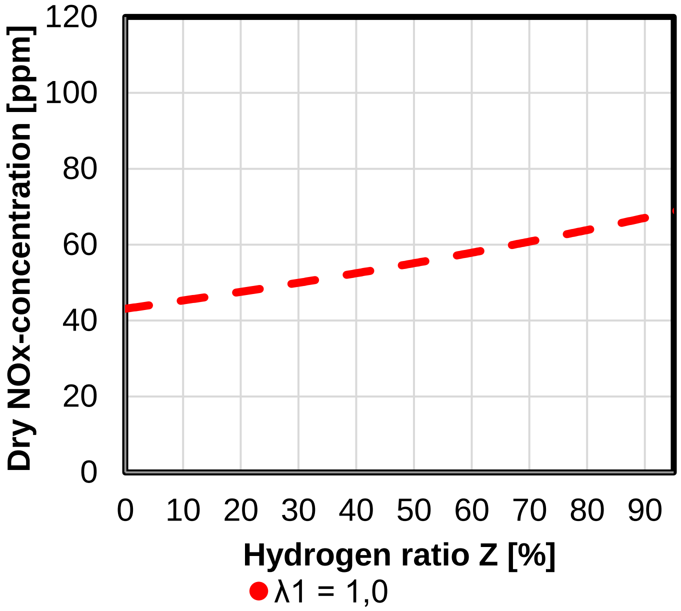
LAMINAR BURNING VELOCITY OF METHANE TO HYDROGEN



Mechanism: Glarborg et al., 2018, Progress in Energy and Combustion Science, 67, 31–68.

NOx- EXHAUSTGAS FOR CH_4/H_2 UP TO 40% HYDROGEN





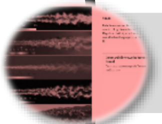
- For values normalized for near residence time and exhaust gas composition, there is a clear trend toward an increase in NOx values with increasing hydrogen content.

→ Burners have to be re-measured and re-developed to minimize NOx

SUMMARY FOR FUNDAMENTALES

Comprehensive parameter study on the non-premixed extinction strain rate

Extensive parameter study on the burning velocity of premixed hydrogen-methane flames



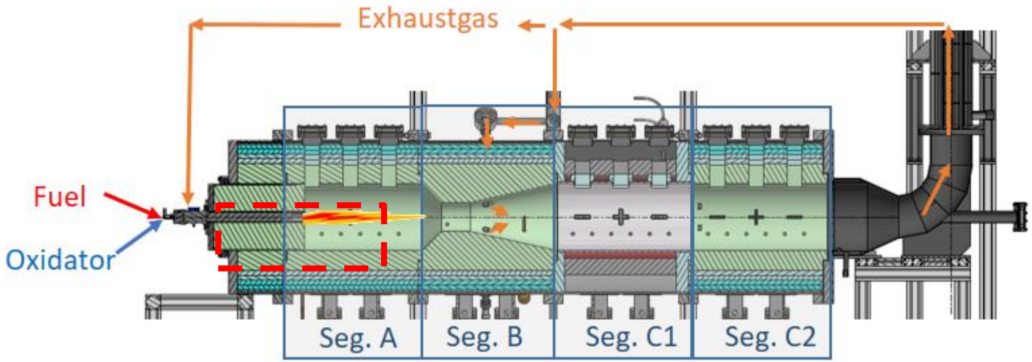
Comparison and evaluation of the prediction accuracy of 11 detailed reaction mechanisms

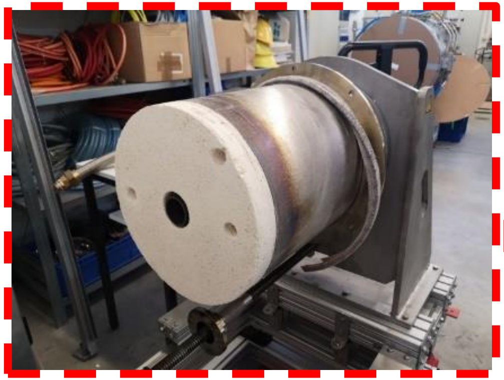
Development of a temperature & equivalence ratio and pressure correlation

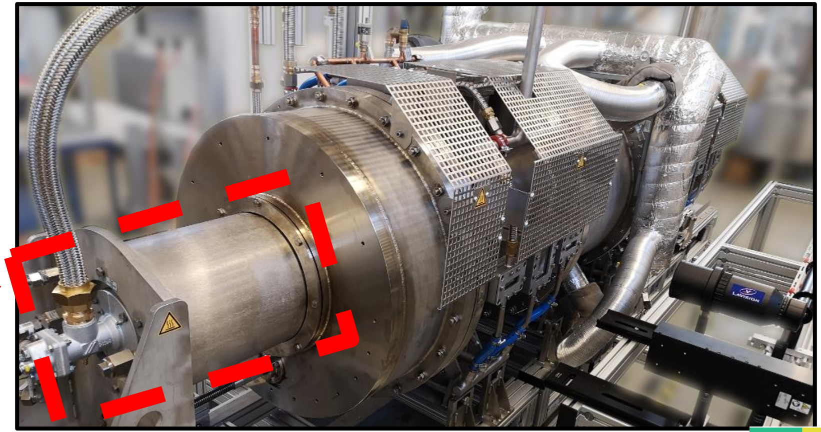
Measurement of nitrogen oxide formation in adiabatic flat flames up to 50% hydrogen

Research object: optically accessible combustion chamber

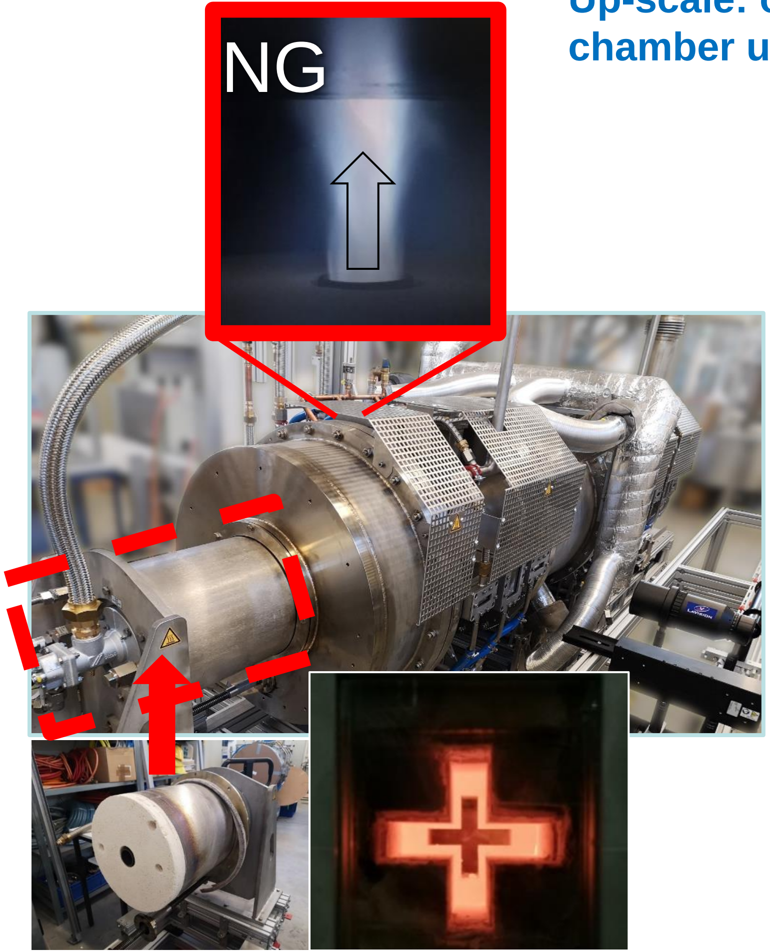
- Diffusion burner
- Multi-stage capability
- Modular design
- Exhaust gas recirculation

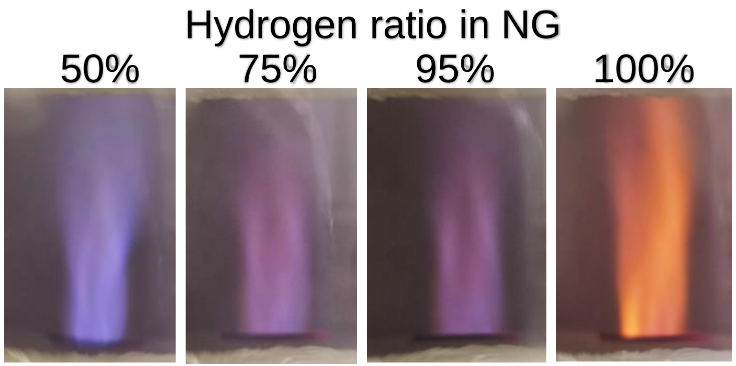






Up-scale: optically accessible combustion chamber up to 50kW





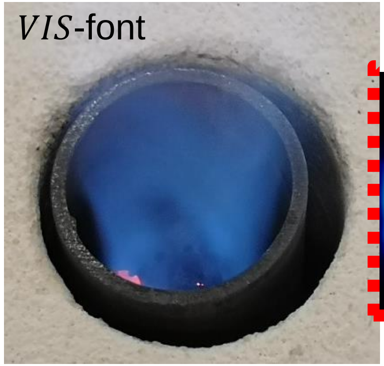
- Exchangeable burner systems up to 50 kW or various industrial applications.
- **Possibility of producing gaseous and liquid**, conventional and renewable mixed fuels by using a gas mixing unit with up to 6 components (CO_2, CO, H_2, N_2, CH_4, O_2) and oxidants (air, N_2, O_2)

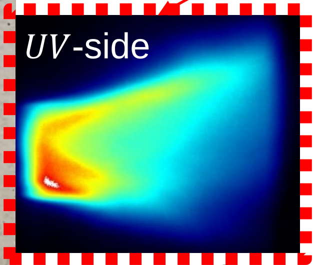
- Possibility of **exhaust gas recirculation and staged air** combustion

Scale-up approach and exhaust gas prediction

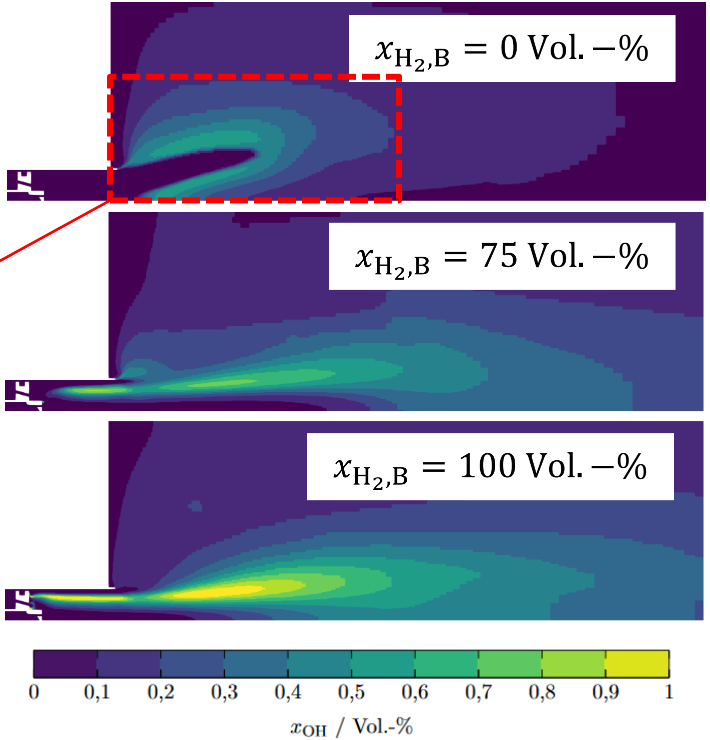
- CFD simulation with Ansys of both combustion chambers
- When using EDC with $x_{H_2,B} < 75$ Vol.$-$% stabilisation flame erroneously at combustion chamber inlet.

- → EDC not possible in advance for all mixtures
- → Simulation methods have to been proved for hydrogen combustion in large scale





$x_{H_2,B} = 0$ Vol.$-$%



Investigation of the Integration of Hydrogen in Thermoprocessing Technology in the Project "TTgoesH2“

Integration of hydrogen as a climate-neutral energy carrier in industrial and commercial thermoprocessing technology

TP1:

ULoBurn
Ultra low emission burners

Development of ultra low emission combustion systems for hydrogen

TP2:

GreCoCon
Green combustion control

Industrial combustion control for high volatile H_2- contents on the basis of flame signals

TP3:

ResInMa
Resistant, innovative materials

Innovative materials for use in hydrogen and its combustion products

GAS- UND WÄRMETECHNISCHE ANLAGEN

DBI GTI Gastechnologisches Institut

IOB Institut für Industrieofenbau und Wärmetechnik

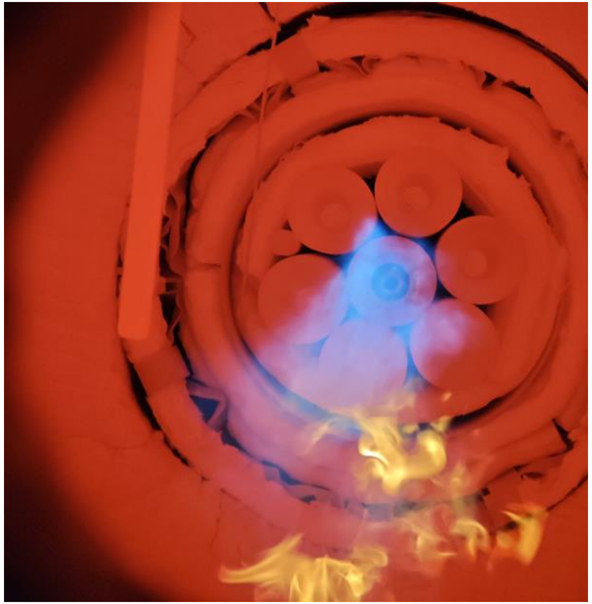
gwi Gas- und Wärme-Institut Essen e.V.

UNIVERSITÄT DUISBURG ESSEN Offen im Denken

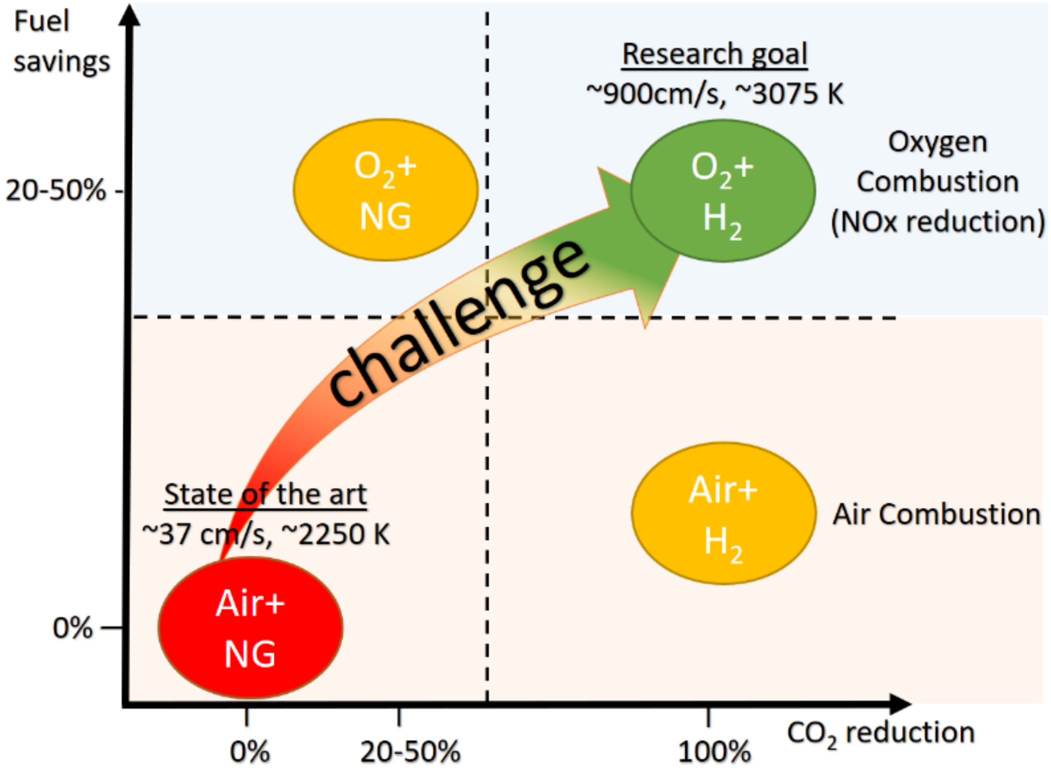
IWT Leibniz-Institut für Werkstofforientierte Technologien

Projects during the last years

CLEAN-Mag - "CO2-neutral production of lightweight magnesiumcomponents made of magnesium".

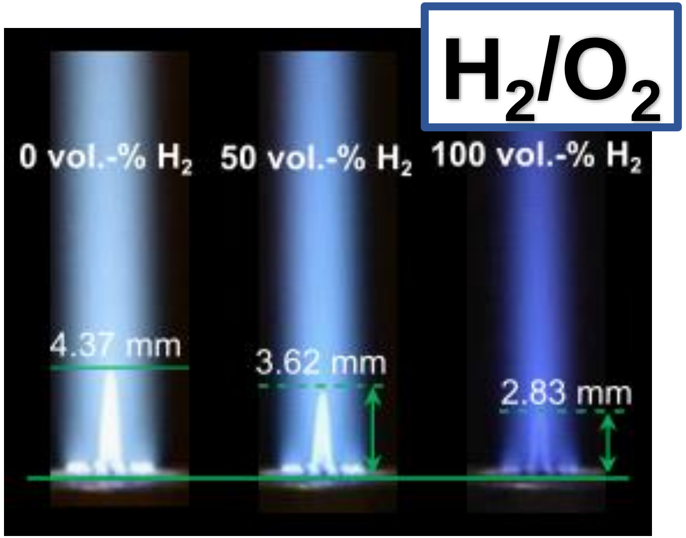
Burner	Flame mode	MILD mode
		

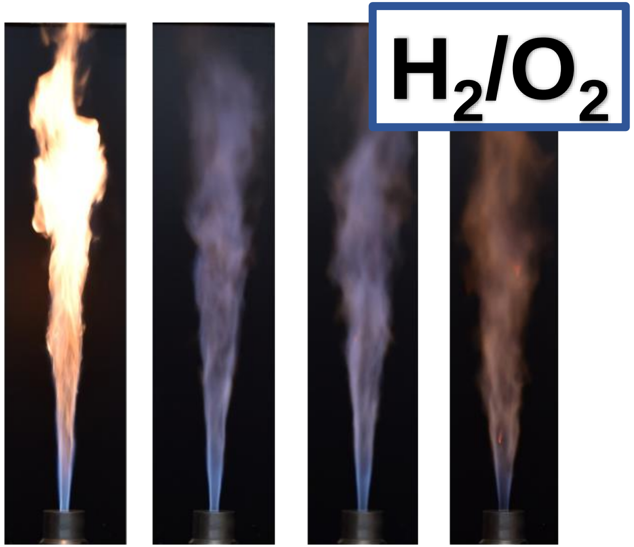
Burner Development and Flame Analysis for oxyfuel combustion



Project MiGWa: "Combined glass melting with microwaves and H2-oxyfuel combustion" of the joint project "KlimPro: CO2 savings in glass production through novel and climate-friendly heating"

- Experiments have been made with laminar premixed and turbulent non-premixed oxyfuel flames, Investigation of Hydrogen-air and hydrogen-oxygen combustion processes (small (0.3kW) to large scale burners (35kW)) were done
- Laser optical (OH/CH/NO-LIF, LDA, PIV, Raman, Rayleigh), heat flux sensors and spectrometers diagnostic were used in flat flames
- Investigation of emission in flames (NO, NO2, CO, CO2), successfully demonstrated NOX reduction with EGR and air staging in H2 flames





Projects during the last years

Use of Hydrogen in Stenter Frame Dryer (Acronym: WasserSTOFF)

MiGWa - KlimPro joint project: CO2 savings in glass production through new production through innovative and climate-friendly heating; TP2: Combined glass melting with microwaves and H2-oxyfuel combustion

SeEWOf - Development of thermoacoustic sensor technology for industrial furnaces to detect flame stability limits when using natural gas-hydrogen mixtures - contributions to flame diagnostics and noise reduction in furnace construction

BioHydroGen - Development of a Hydrogen-generator for biogas

Conclusions for large scale flames

Hydrogen admixture up to 20 %:

- Effects on the design of thermo-processing plants (materials) are negligible.
- Firing systems can largely be adjusted to higher H_2 content
- Open question:
  - Compliance with efficiency targets for combustion systems
  - Compliance with NOx limits
  - Dealing with fluctuating
    → Adaptive combustion control required

Conclution:

- Solutions available in the short term
- In the medium term, developments are required with regard to adaptive combustion control and NOx reduction on combustion systems

R&D needs in thermoprocess technology

Hydrogen up to 100 %:

Effects on the design of thermo-processing equipment (materials) are not negligible, focus on

- Avoidance of condensate formation
- Water vapour resistant materials
- Additional open question:
  - Design principles for low-NOx H_2 burners, safety devices
  - Development of new material systems, coatings
  - Development of adapted firing systems (low-NOx, high-efficiency)

Conclusion:

- Solutions must be developed now (→Project: TTgoesH2)
- Start of developments for H_2 burner systems (lead time approx. 3 - 5 years)
- Evaluation and development of refractory, ceramic and thermal insulation materials (lead time approx. 5 - 8 years)

Conclusions & Outlook

Hydrogen combustion is possible and also feasible on a large scale for industrieal processes.

We currently do research on usage of hydrogen in the glass, metallurgy (magnesium, steel,..), ceramic and textile industry with one project each. As well as on sensoring and material interaction.

Challanges remain:

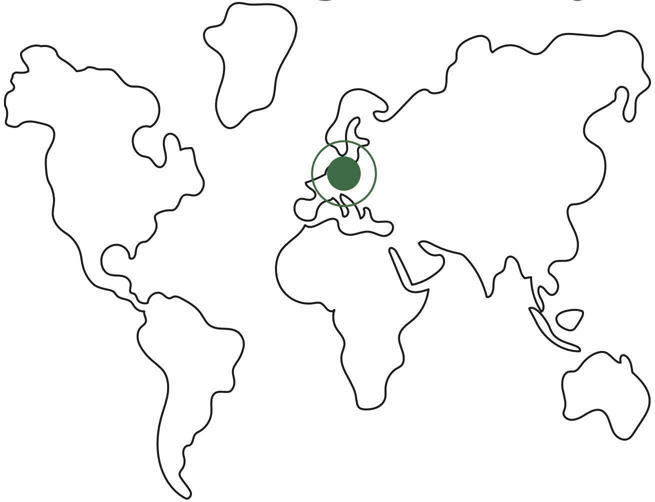
- Renewable generation (nearby)
- Safety concerns of industry and population
- Production quality depends on adapted burners and flue gases
- Material interaction not conclusively clarified

- Avoiding pollutants though oxyfuel H_2 → even more concerns will come

Meet the Team

W I R E

Freiberg, Germany



Dr. Sven Eckart

Head of combustion group

Prof. Hartmut Krause

Chair of gas and heat technology

Team members of the combustion group