Gas Turbine Combustion of Alternative Fuels

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DLR

Content and Outline

- Introduction: Why do we need alternative fuels? What kind of alternative fuel exists?
- Combustion fundamentals
  - Combustor requirements
  - Classification of flames
  - Flame stabilization
  - Combustor concepts
  - Pollutant formation – NO_x
  - Chemical and physical characteristics of alternative fuels
  - Technical Challenges related to alternative fuels – example H_2
- GT combustion systems
- Studies of GT combustors using alternative fuels
- Examples of GTs using alternative fuels

Why do we need alternative fuels?

→ Decarbonizing gas turbines for power generation

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Carbon Capture

Natural gas (NG)/ liquefied natural gas (LNG)

Carbon capture & Storage (CCS)

Blue / turquoise hydrogen

Carbon removal from exhaust (CCUS)

Alternative Fuels

Renewable power

Green **Hydrogen**
→ direct use

Hydrogen derivatives

Biomass

Biofuels

What kind of Alternative Fuels exists?

Renewable power

↓

Green **Hydrogen**
→ direct use

↓

Hydrogen derivatives

- E-Ammonia
- E-Methanol
- PtL / e-fuels
    - Synthetic Heating oil / Diesel

Biomass

↓

Biofuels

- Biogas
- Bio-Methanol
- Bio-Ethanol
- HEFA*
- FAME**
- HVO***
- Wood gas
- *Pyrolysis oil*

* Hydroprocessed Esters and Fatty Acids; ** Fatty acid methyl ester; *** Hydrogenated / hydrotreated vegetable oils

Combustion fundamentals
Combustor requirements

- High combustion efficiency (“complete” combustion)
- Wide stability limits (including combustion instabilities, lean blow out, emissions at part load, etc.)
- Low pressure loss
- Reliable ignition
- Suitable temperature profile @ outlet → system efficiency & turbine lifetime
- Low emissions
- Design for minimum costs and ease of manufacturing
- Durability
- Maintainability

Combustion fundamentals
Types / shape of flames

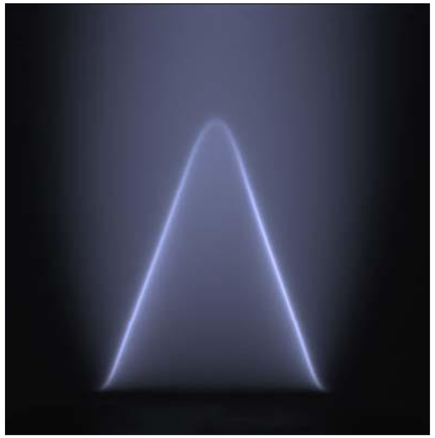
	laminar	turbulent
non-premixed (flame glow: soot formation under rich conditions and oxidation)		
premixed		
	+ quiet + steady state	+ power - noise

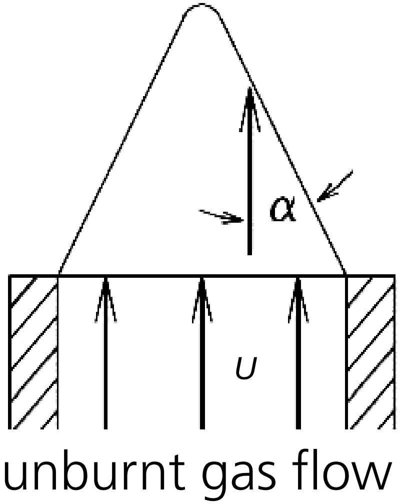
Combustion fundamentals
Types / shape of flames

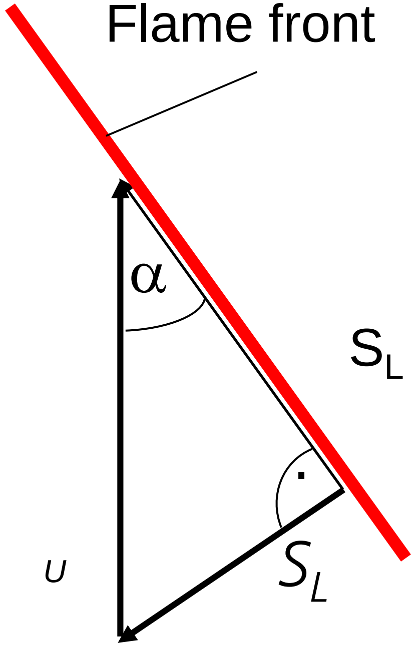
	laminar	turbulent	
non-premixed (flame glow: soot formation under rich conditions and oxidation)			+ safety + reliability - soot - NO_x
premixed			+ less pollutants - risk of flashback

Stabilisation of the flame – laminar flames

- Example Bunsen burner: max. speed u







$S_L = u \sin \alpha$

u = *volume flow / area*

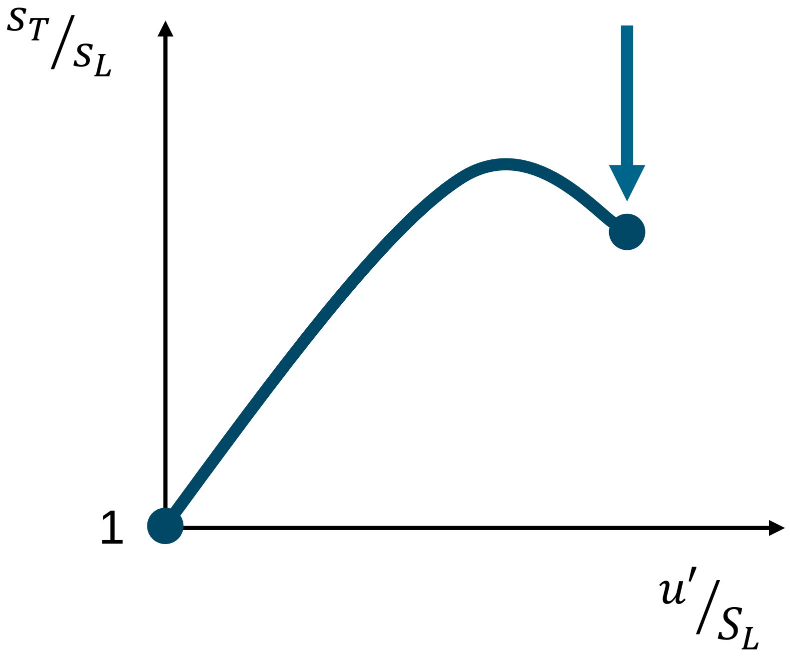
Flame stabilises where

Flame velocity S_L = Incoming flow velocity perpendicular to the flame front

Combustion fundamentals
Flame stabilisation - Turbulent flame

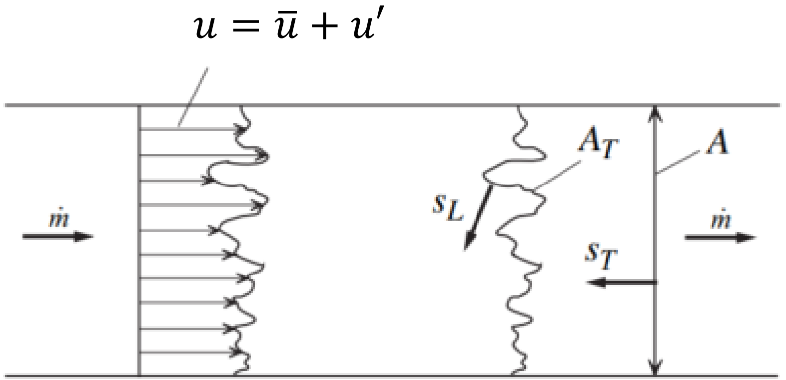
- Example Bunsen burner

Flame extinction due to excessive turbulence



→ Increase in **power density by increasing the flame area:**

$$10 < s_T/s_L < 20$$



$$A_T/A = s_T/s_L$$

For Bunsen burner flame:

$$A_T/A \propto u'/s_L$$

Indices:
T... turbulent *L*... laminar

According to Damköhler from [Peters, N.: Turbulent Combustion, Cambridge University Press, 2000]

Flame stabilisation (self-sustained combustion)**:**

Specific generation of flow areas in which there is a balance between flow velocity and flame velocity

- Areas with
  - low velocity → diffusive transport of temperature and intermediate products
  - **Small and large-scale recirculation of hot exhaust gas & intermediate products** → diffusive and convective return transport of temperature and intermediate products

Combustion fundamentals
Burner concepts

- Which burner concepts do you know?

→ Flame holder: bluff body, baffle disc

→ **Swirl stabilised burner**: swirled pipe or annular flows

→ **Jet-stabilised burner**

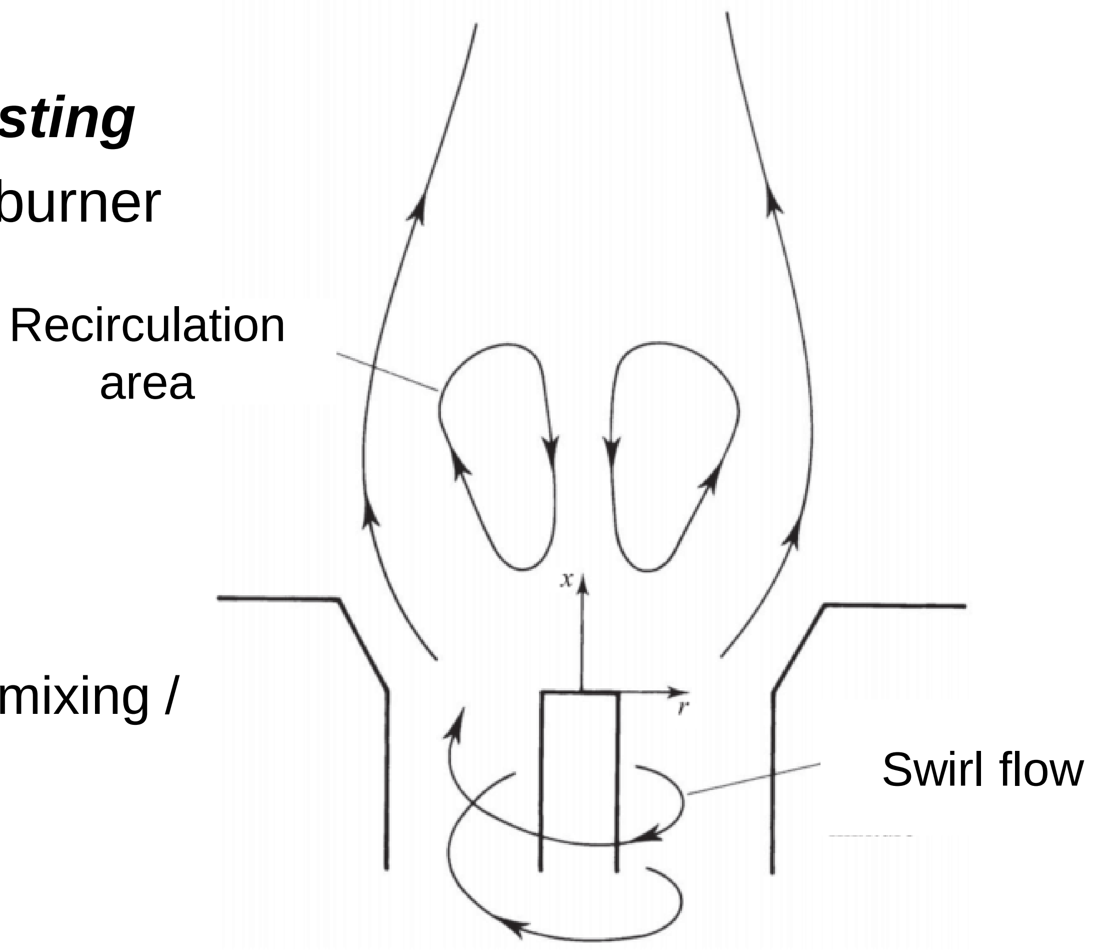
→ **Micromix combustor**

Combustion fundamentals
Burner concepts - Swirl stabilised burner systems

- Principle: ***swirling flow*** creates a ***wide bursting flow*** with intensive backflow / mixing in the burner outlet

- Advantages:
  - Short, compact burnout
  - High specific power densities
  - Less temperature peaks - depending on premixing / mixing quality

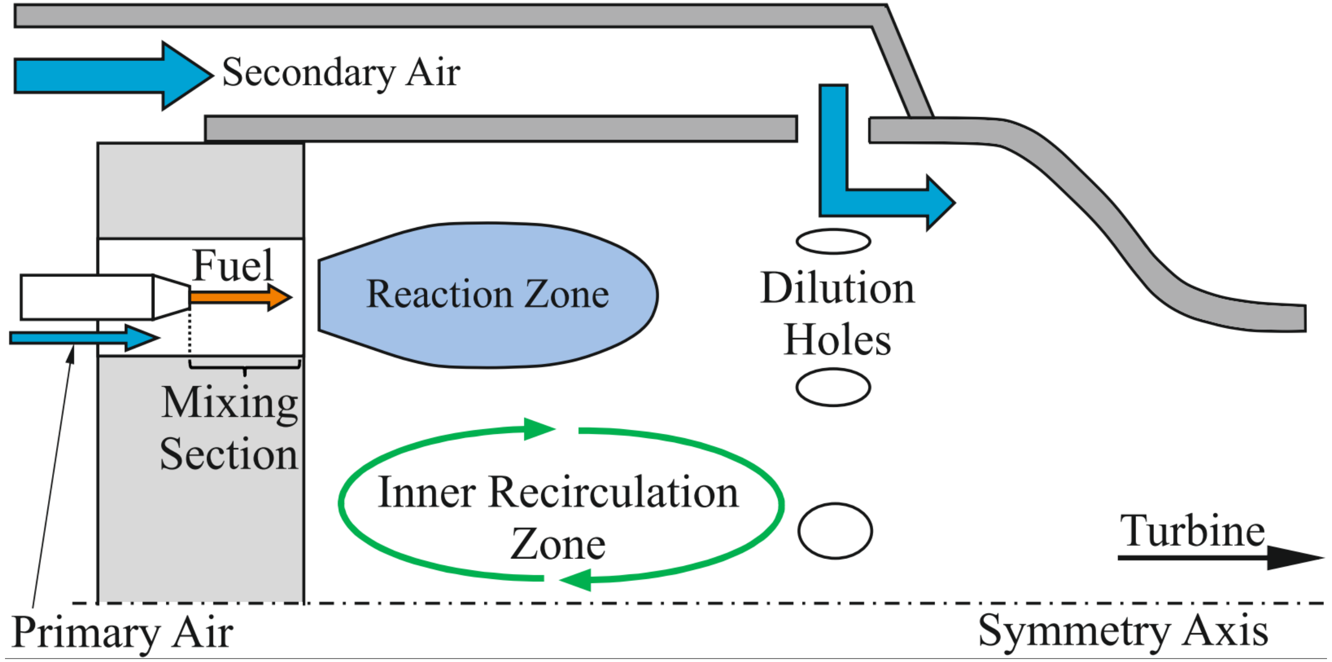
- Disadvantage:
  - Higher risk of flashback (fuel flexibility)



from Turns, S.: An Introduction to Combustion, McGraw Hill, 4th edition, 2021

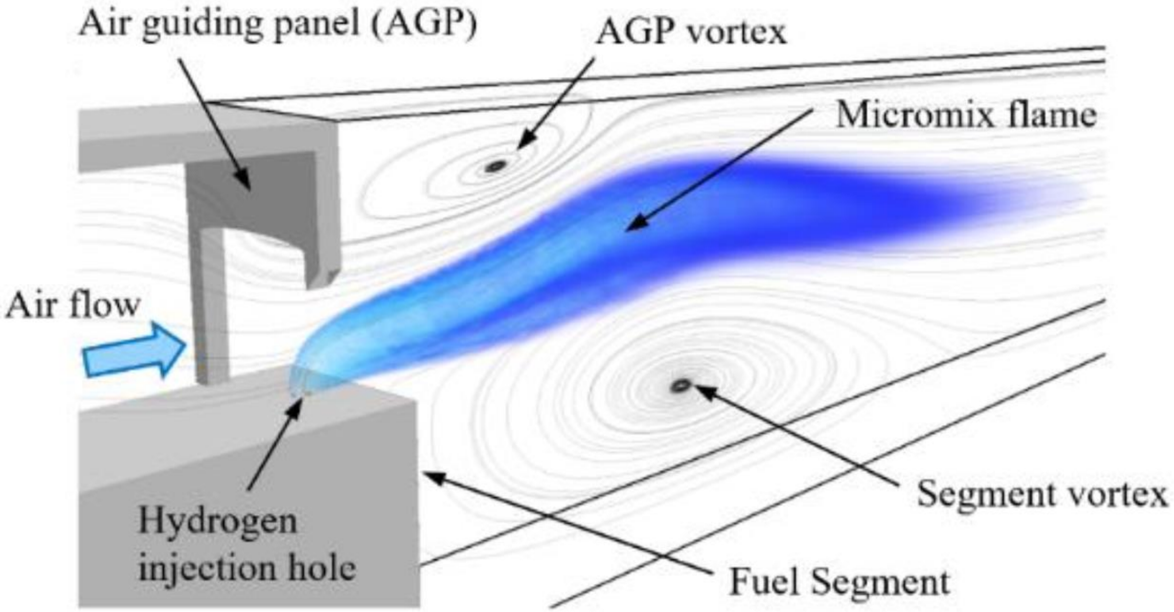
Combustion fundamentals
Burner concepts - Jet-stabilised burner systems

- Principle: ***Fuel and air jets*** arranged in a circle ***with high momentum***, untwisted and partially premixed create a ***distributed reaction zone*** through intensive mixing
- Advantages:
  - No temperature peaks
  - Fuel-flexible (→ hydrogen)
  - Low flashback risk
  - Suitable for high inlet temperatures
  - Wide operating range
- Disadvantage:
  - Likely higher burnout volume



Combustion fundamentals
Burner concepts – Micromix combustor

- Principle: Large number of **miniaturized non-premixed-type flames** with jet in cross flow based fuel injection and air guiding panel forming **a inner and outer vortex pair**
- Advantages:
  - Fuel-flexible (→ hydrogen)
  - Low flashback risk
  - Reduced residence time
  - Suitable for high inlet temperatures
- Disadvantage:
  - Larger combustion volume



S. Aoki et. al., DEVELOPMENT OF HYDROGEN AND MICROMIX COMBUSTOR FOR SMALL AND MEDIUM SIZE GAS TURBINE OF KAWASAKI, Proceedings of ASME Turbo Expo 2024, June 24-28, 2024, London, UK, GT2024-121073

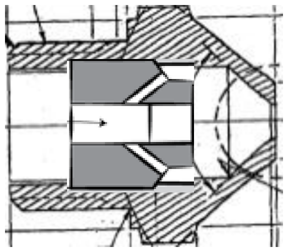
Combustion fundamentals
Liquid fuels – fuel treatment

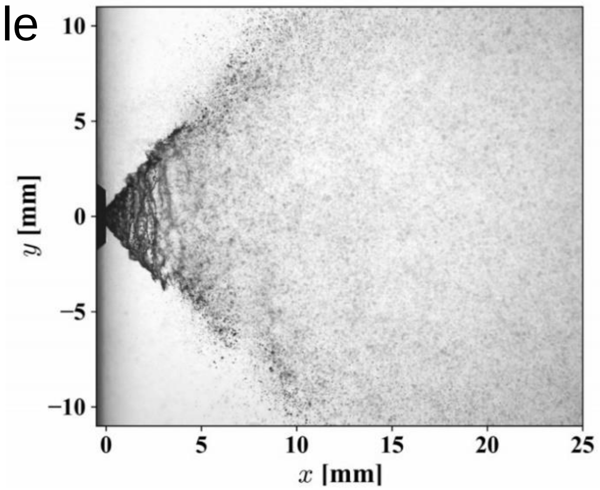
Combustion in the homogeneous gas phase

- Atomisation: Optimisation of the mixing and evaporation behaviour by increasing the surface area
  - Primary / secondary decay of the spray
- Vaporisation

→ Complex subject area: analysing the processes
  - – in the liquid phase and
  - – at the boundary layers of the phases
  - – Additionally: turbulent flow field

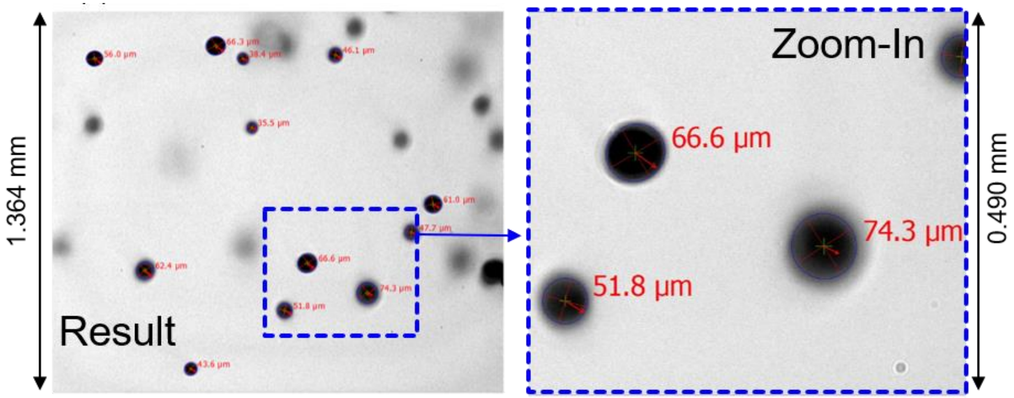
Delavan nozzle





Yin, Z., et al. "Experimental Investigations of Superheated and Supercritical Injections of Liquid Fuels." ASME. *J. Eng. Gas Turbines Power*. April 2021; 143(4): 041016

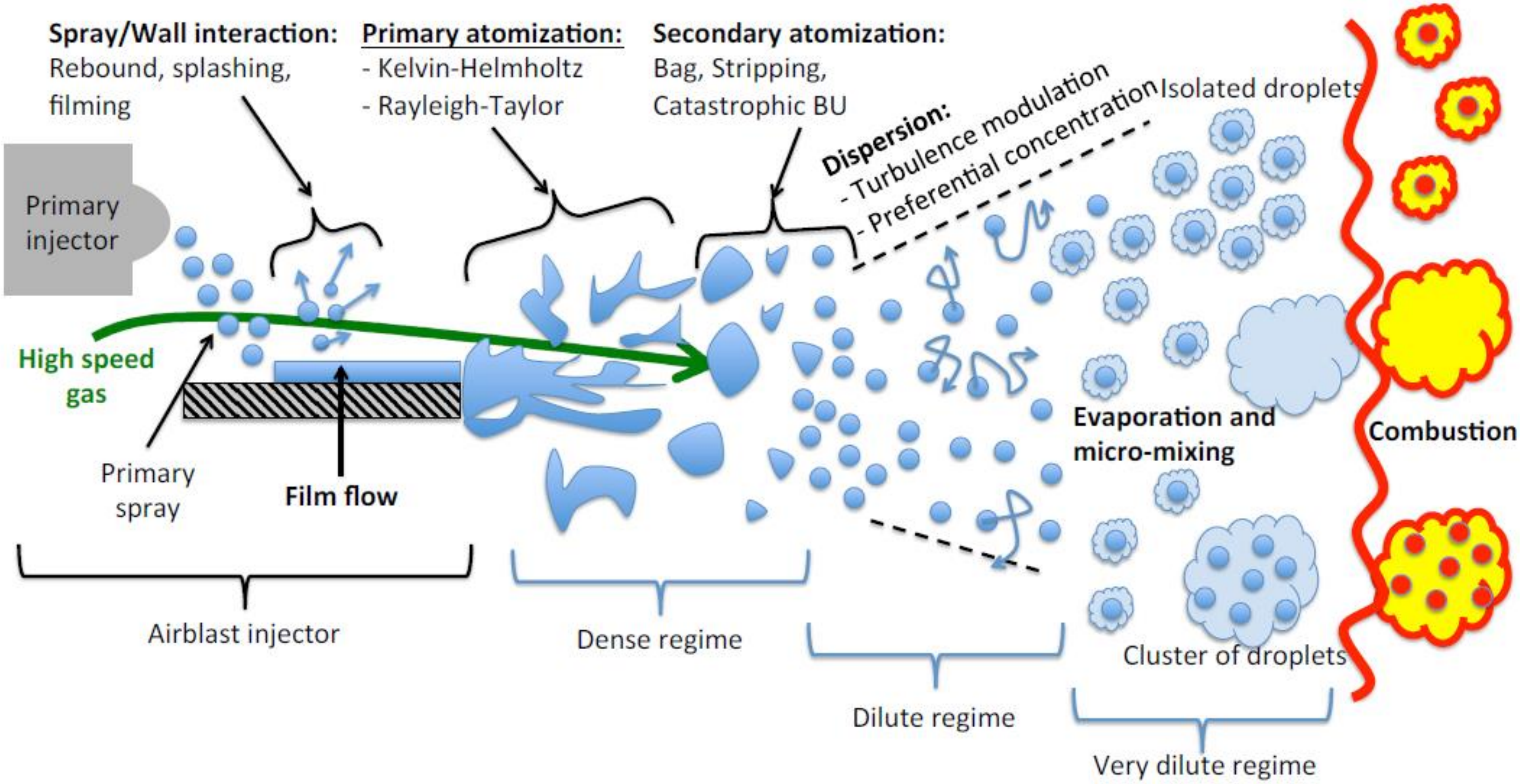
Laser shadow imaging with a remote microscop



Combustion fundamentals
Liquid fuels – fuel treatment

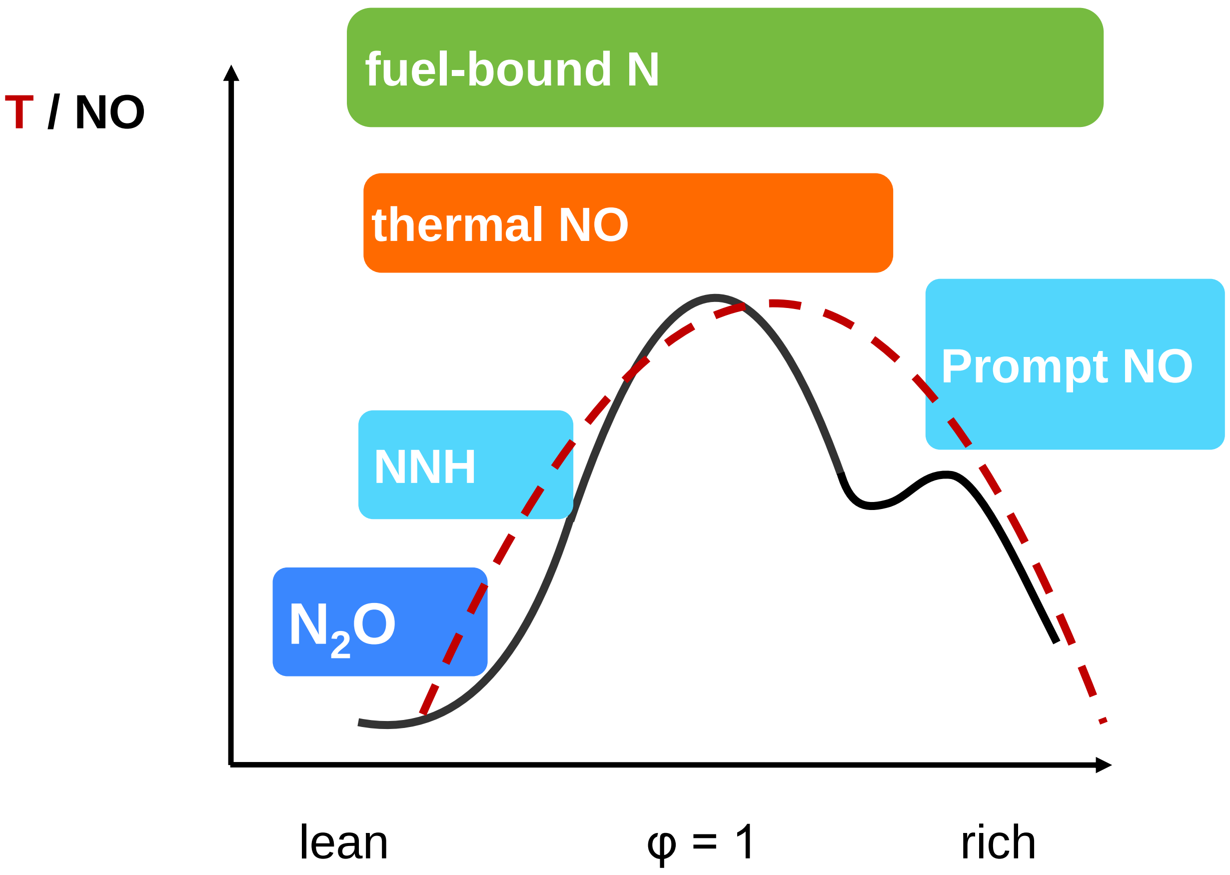
DLR-VT: Pressure Swirl Injector using JetA1 (0.5 g/s)

Combustion fundamentals
Liquid fuels – fuel treatment / film layer

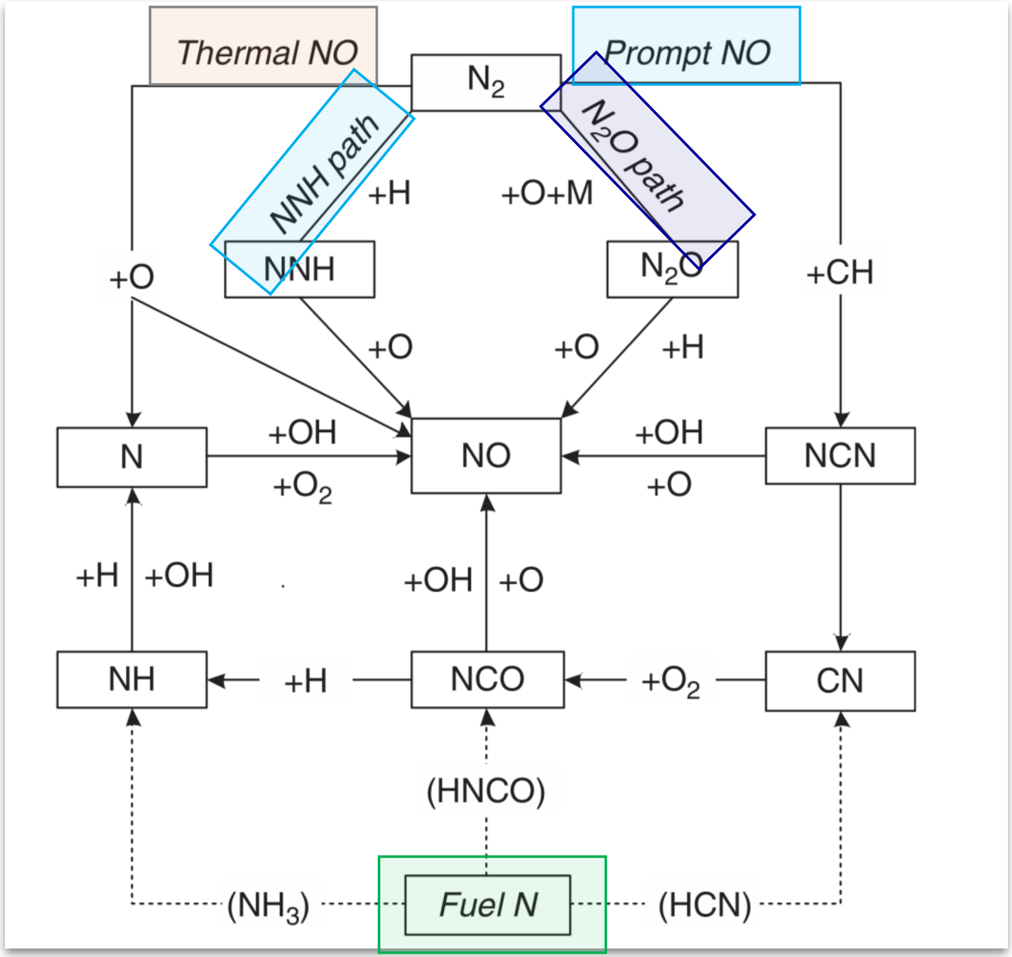


Quelle: Koch, R., Karlsruher Institut für Technologie - Institut für Thermische Strömungsmaschinen - Forschung - Forschungsschwerpunkte - Zerstäubung (kit.edu)

Combustion fundamentals
NO_x - emissions

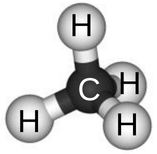


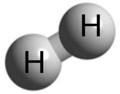
Own illustration, based on Joos, F., Technische Verbrennung, Springer-Verlag, 2006

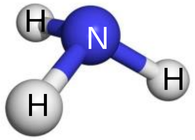


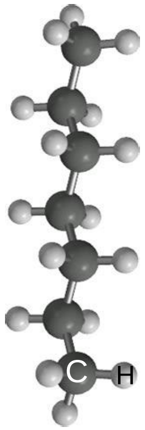
Lieuwen, T.C., Yang, V., Gas Turbine Emissions, Cambridge University Press, 2013

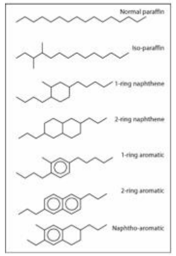
Combustion properties of alternative fuels

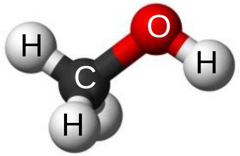








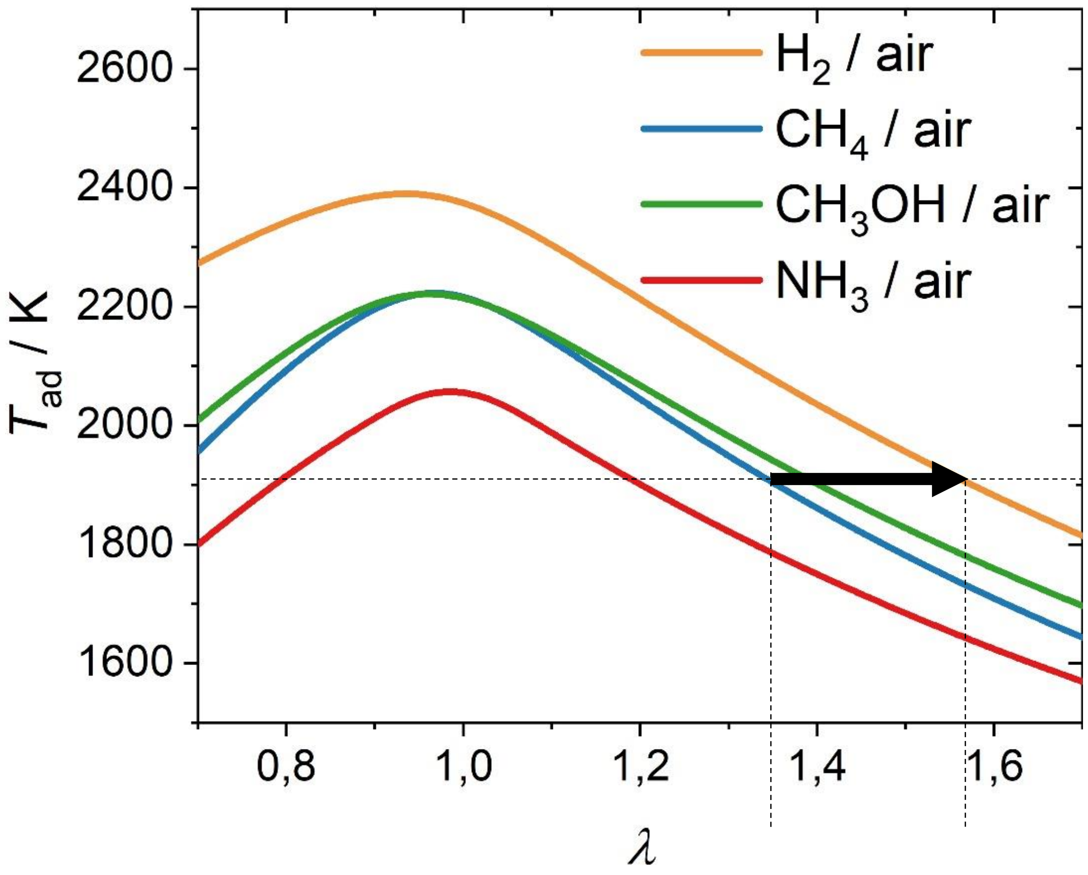


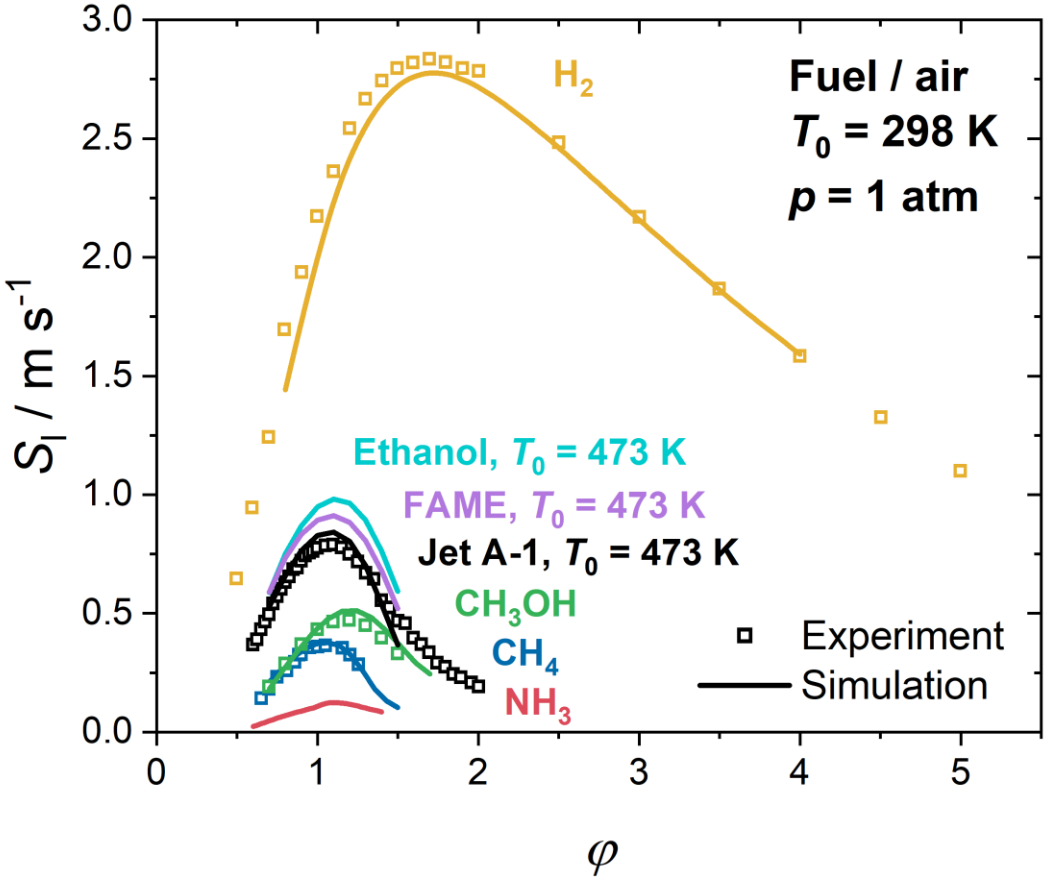


	Methane	Hydrogen	Ammonia	Diesel	Methanol	HVO
LHV [MJ/kg]	50	120,1	18,8	42,5	19,7	44
Flammability limit [equival. ratio / vol.%]	0,5 - 1,7 / 5-14,3	0,1 - 7,1 / 4-75	0,63 - 1,4 15-28	0,6-5,5	0,55 - 2,9 6-36	0,6-7,5
Auto-ignition temperature [K]	810	844	924	498	743	477
Minimum ignition energy [mJ]	0,28	0,011	8	0,24	0,14	-
Density (g/L)	0,657	0,082	0,77	830	787	770-790

Combustion properties of alternative fuels

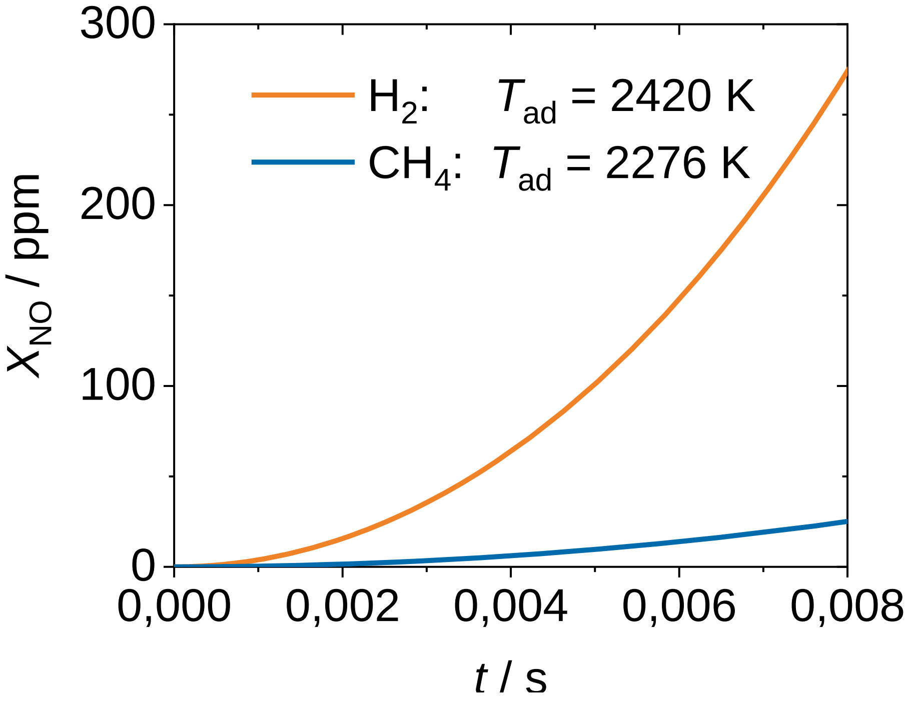
Adiabatic flame temperatures & flame speeds





Combustion properties of alternative fuels
Example: Hydrogen

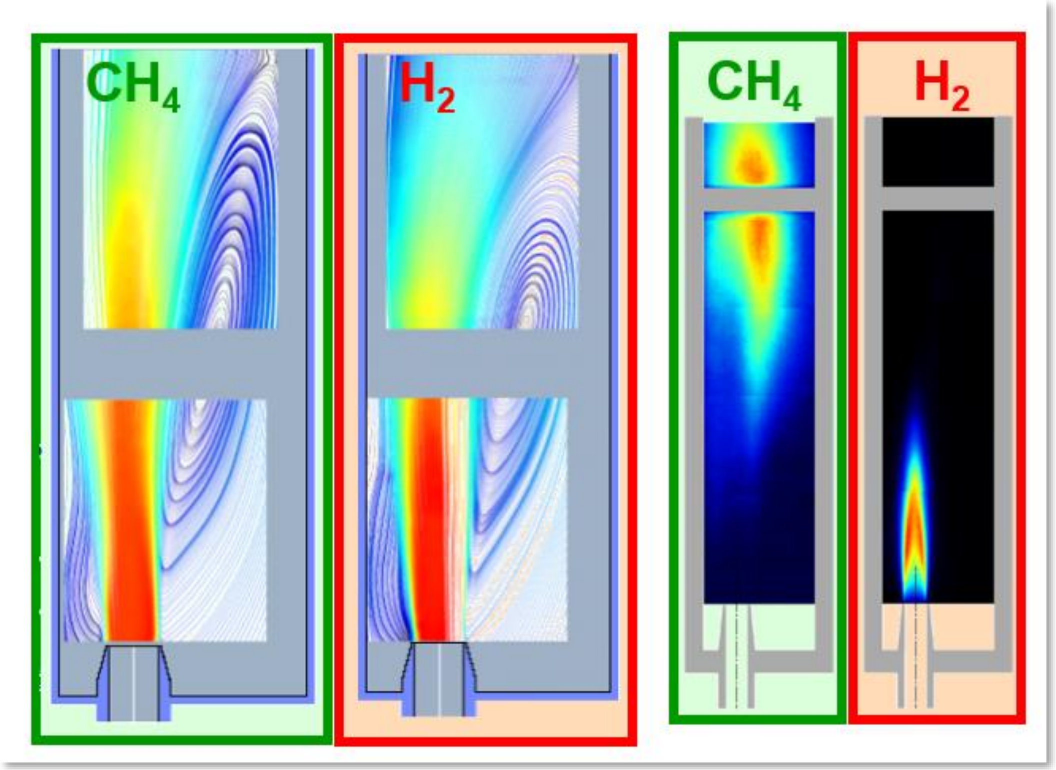
- Adiabatic flame temperature increases with hydrogen
- Temperature (and residence time) have a strong effect on thermal NO_x formation



$T_0 = 400\ \mathrm{K}, p = 1\ \mathrm{atm}, \lambda = 1$

Combustion properties of alternative fuels
Example: Hydrogen

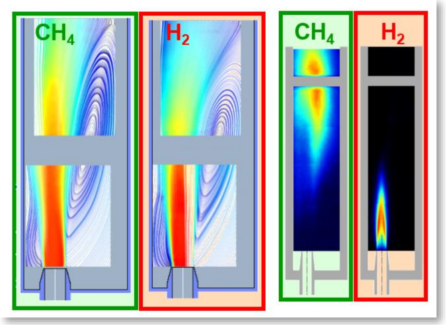
- Adiabatic flame temperature increases with hydrogen
- Temperature (and residence time) have a strong effect on thermal NO_x formation
- In principle, NO_x formation can be hindered by leaner premixed combustion and / or reduced residence time
- But chemical kinetic effects like
  - increasing burning velocities and



[2] [3]

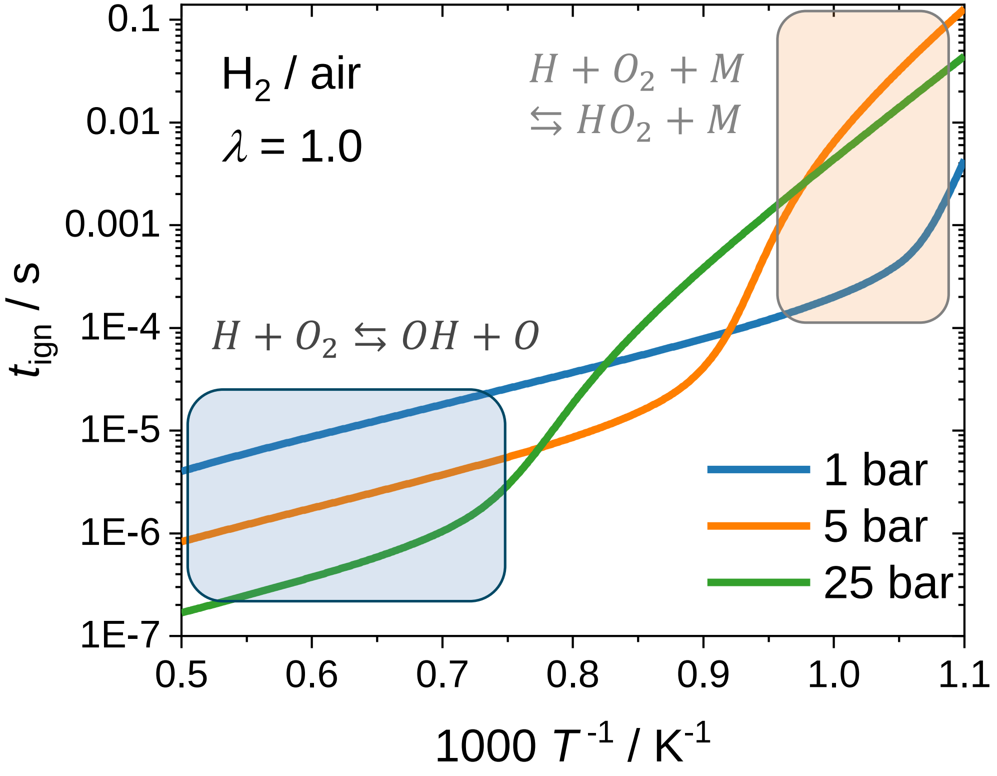
[2] Lammel et al., Investigation of Flame Stabilization in a High-Pressure Multi-Jet Combustor by Laser Measurement Techniques, Proc. ASME Turbo Expo 2014, GT2014-26376
[3] Lammel et al., Experimental Analysis of Confined Jet Flames by Laser Measurement Techniques , J. Eng. Gas Turbines Power 134 (2012) 041506

Combustion properties of alternative fuels
Example: Hydrogen



- Adiabatic flame temperature increases with hydrogen
- Temperature (and residence time) have a strong effect on thermal NO_x formation
- In principle, NO_x formation can be hindered by leaner premixed combustion and / or reduced residence time
- But chemical kinetic effects like
  - increasing burning velocities and
  - pressure effect on ignition delay time

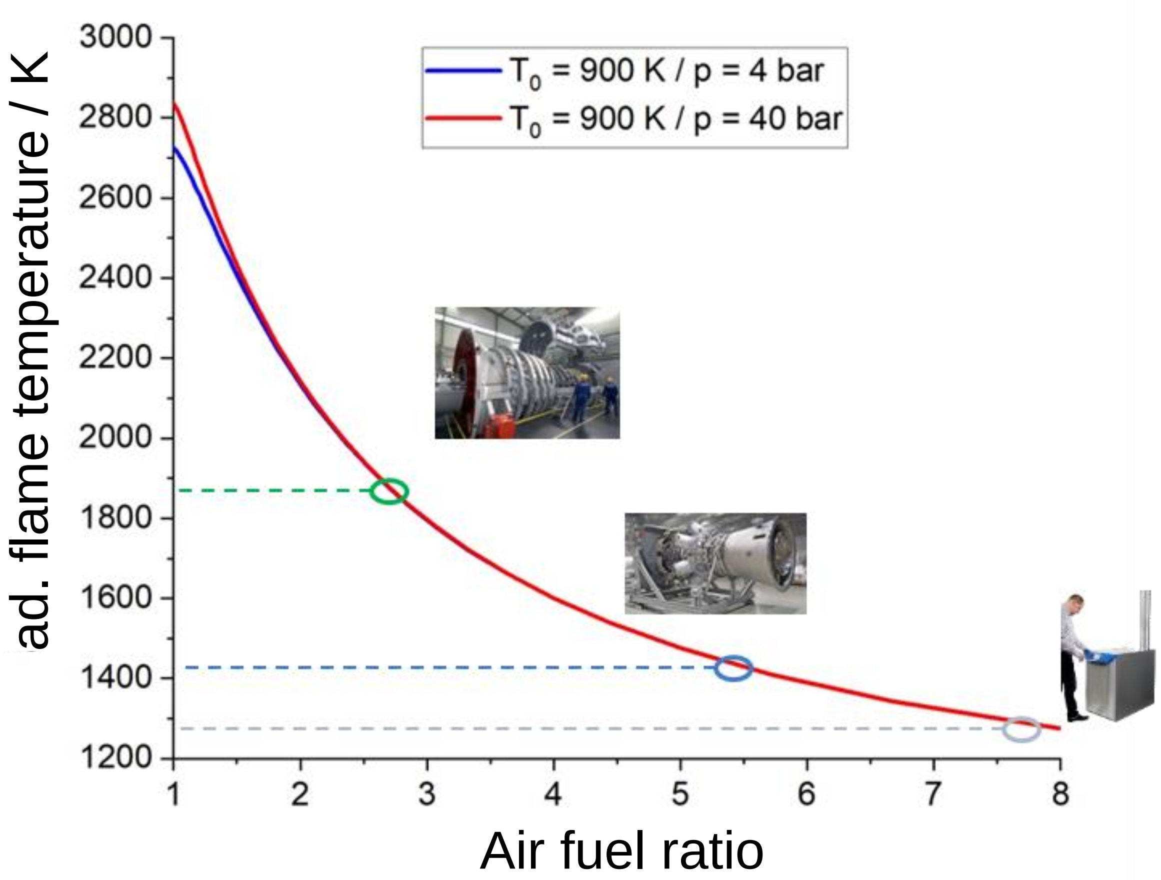
  has to be considered in combustion systems to prevent flash back



www.dlr.de/VT/mechanisms

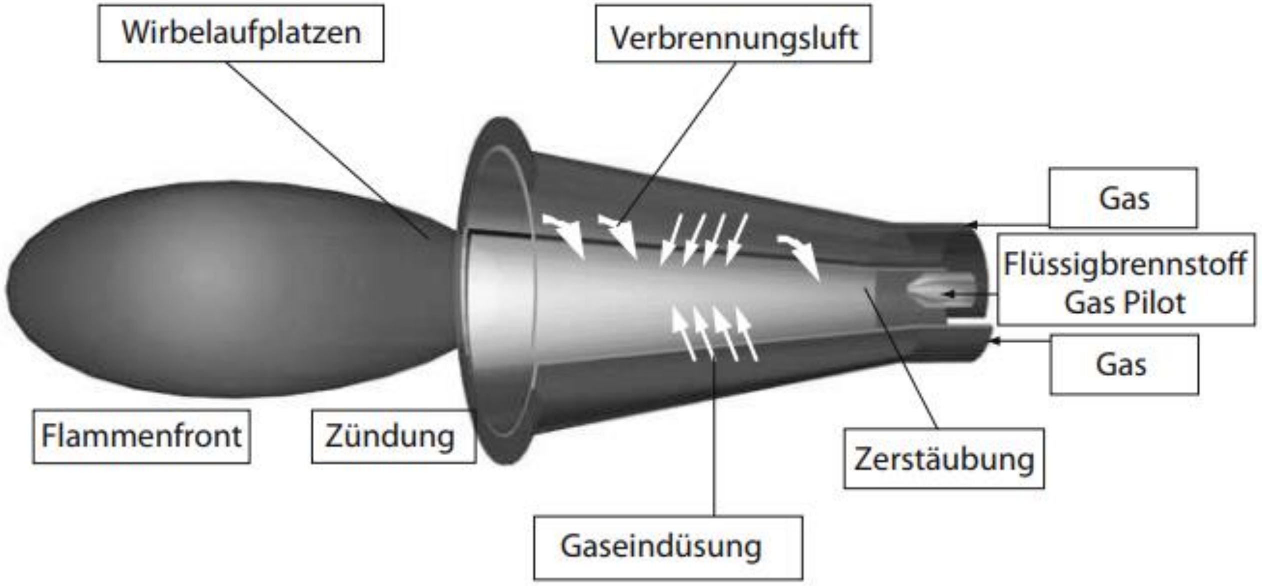
Combustion properties of alternative fuels
Different challenges depending on gas turbine size

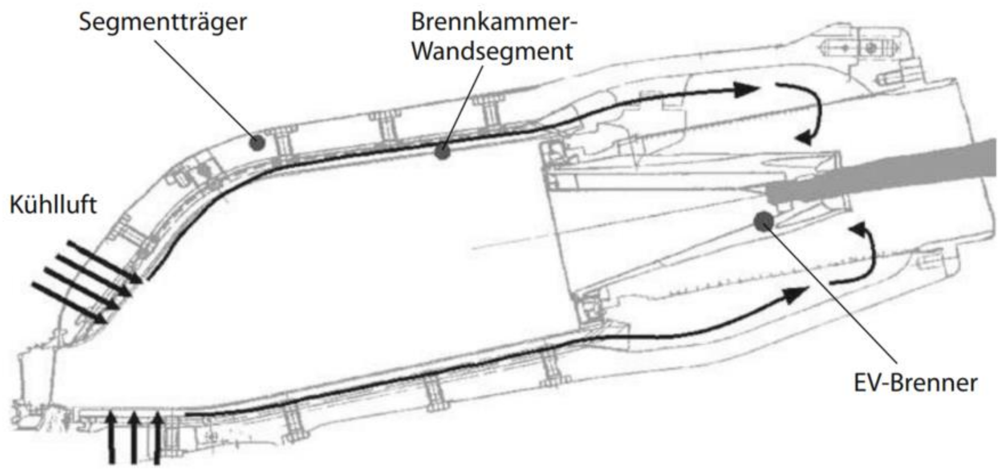
- Efficiency of heavy duty gas turbines depends on high combustion temperature → reduced residence time could be an option for low NO_x emissions
- Industrial gas turbines could benefit from lean premixed combustion systems with high air / fuel ratios
- Very small gas turbines (recuperated cycles) face the challenge of combustor inlet temperatures higher than self ignition temperature of hydrogen / air mixtures



GT combustion systems
Lean combustion of gaseous fuels - DLE

- Ansaldo Energie – GT 26: EV Burner



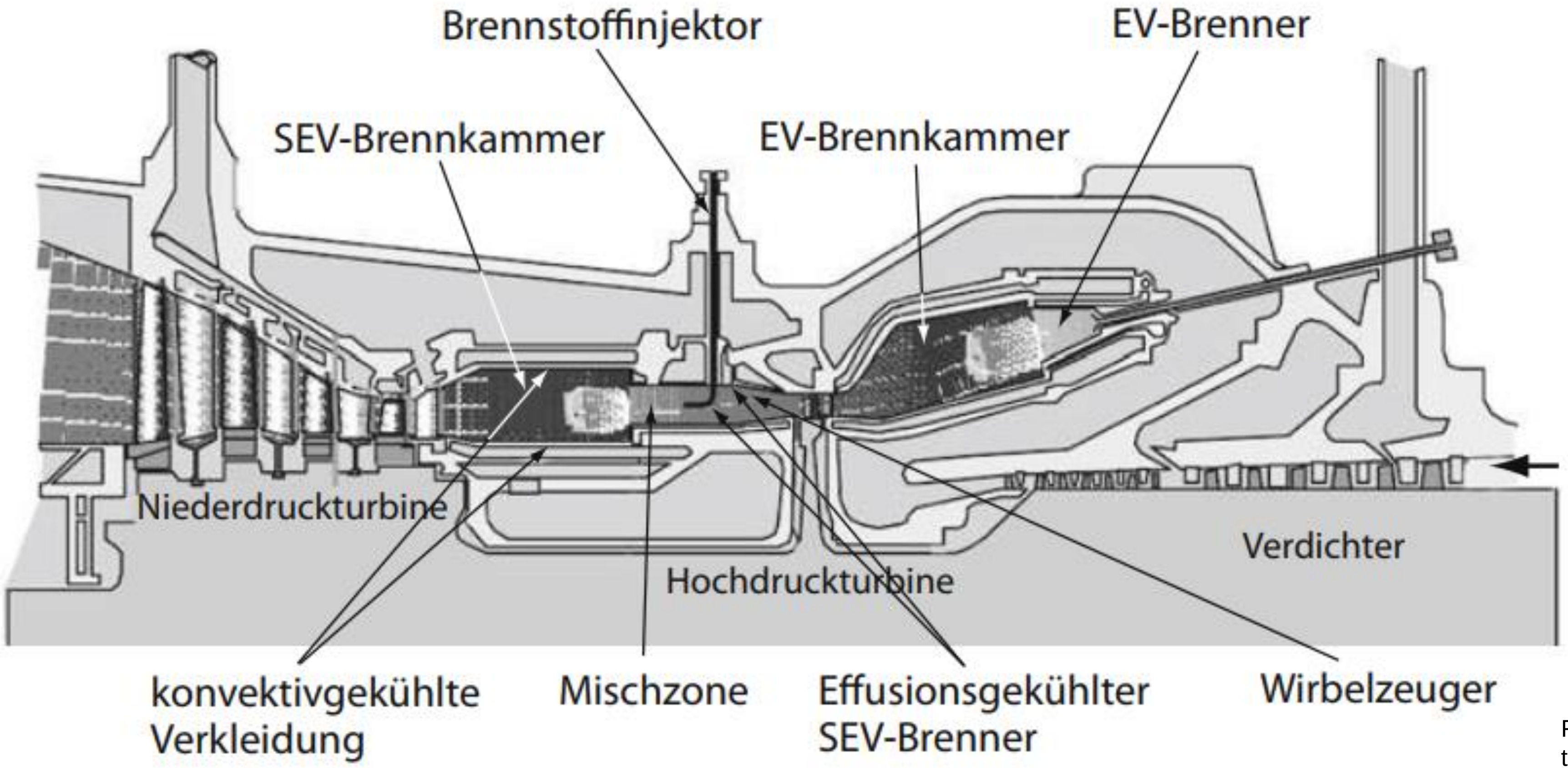


From: Lechner, C., Seume, J., Stationary Gas Turbines, 2nd edition, Springer, 2010

Closed convective cooling (cast iron with cooling fins)

GT combustion systems
Lean combustion of gaseous fuels - DLE

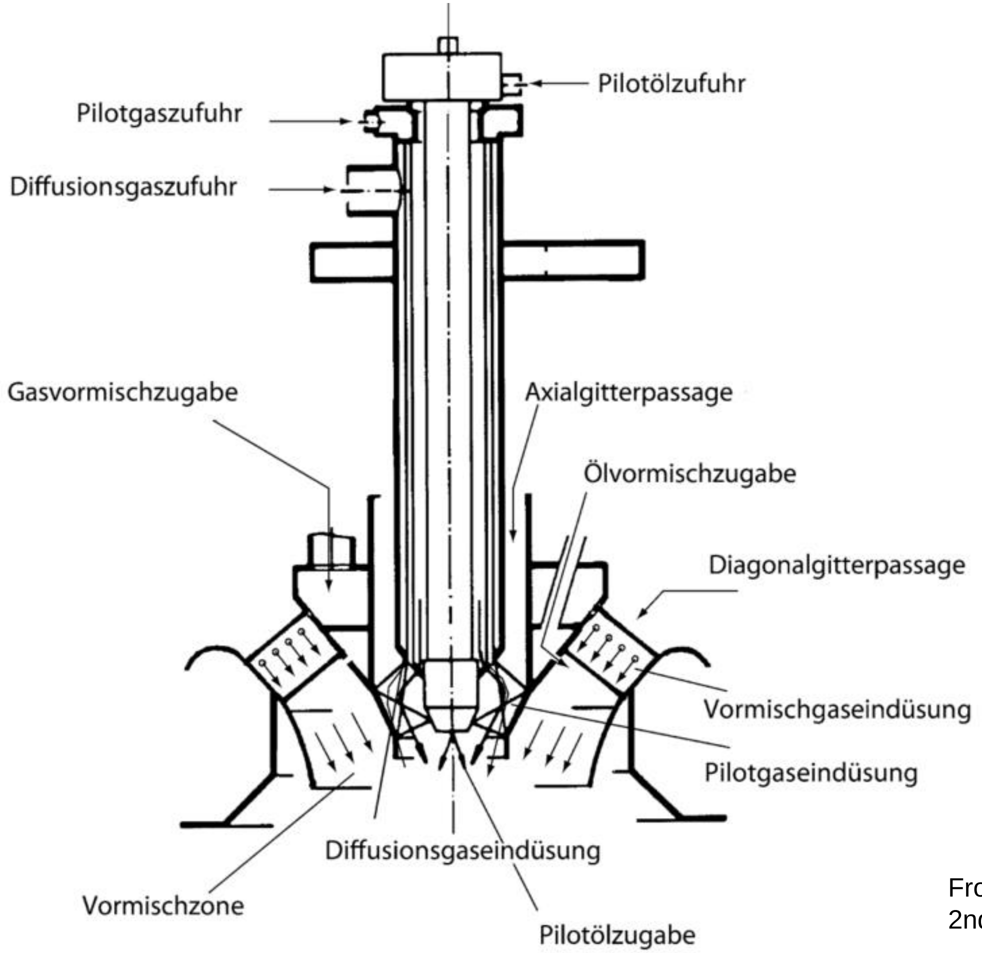
- Ansaldo Energie – GT 26: Special case: two-stage combustion chamber with high-pressure turbine in between



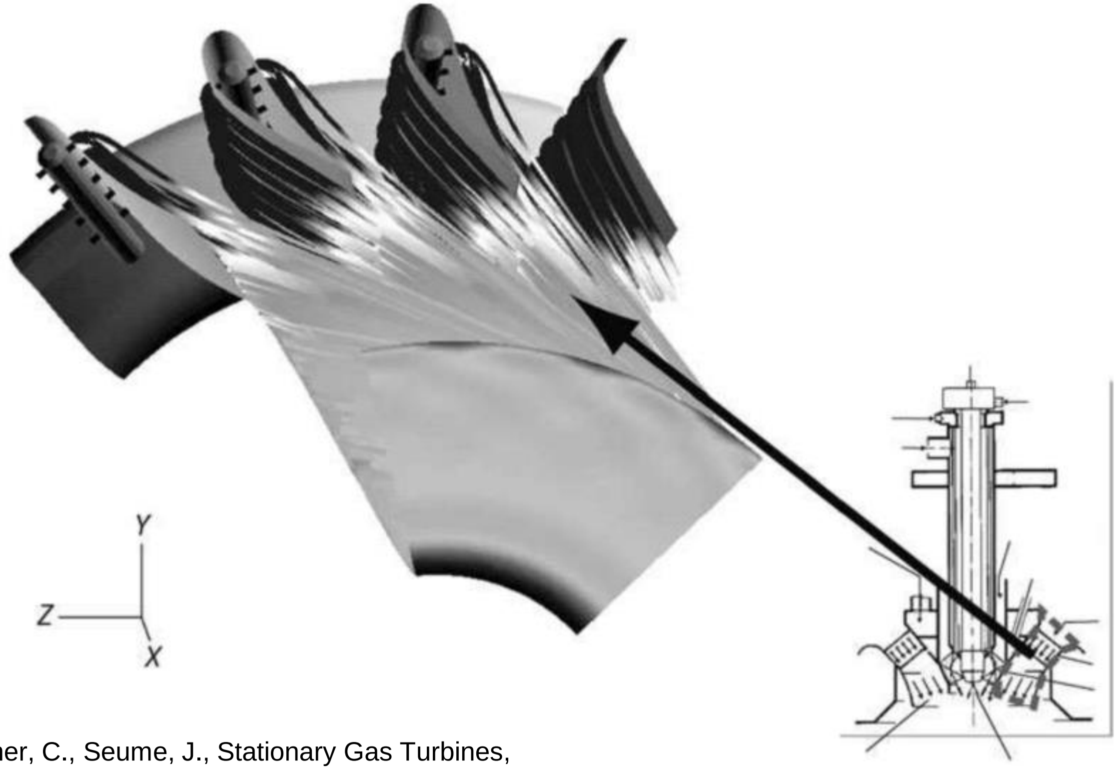
From: Lechner, C., Seume, J., Stationary gas turbines, 2nd edition, Springer, 2010

GT combustion systems
Lean combustion of gaseous fuels - DLE

- Siemens - Hybrid burner HR3



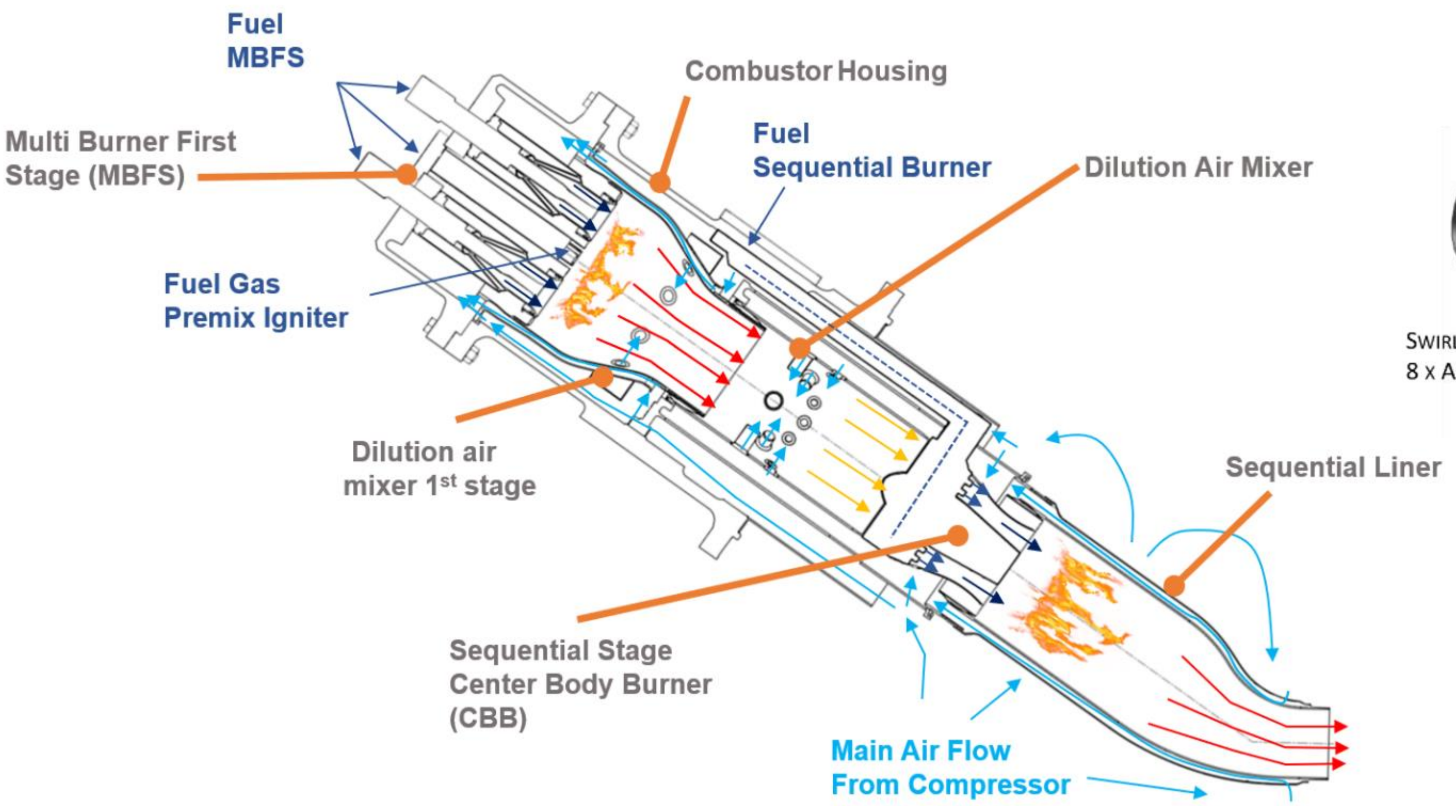
Fuel-air mixture in the diagonal grid passage of the HR3 burner

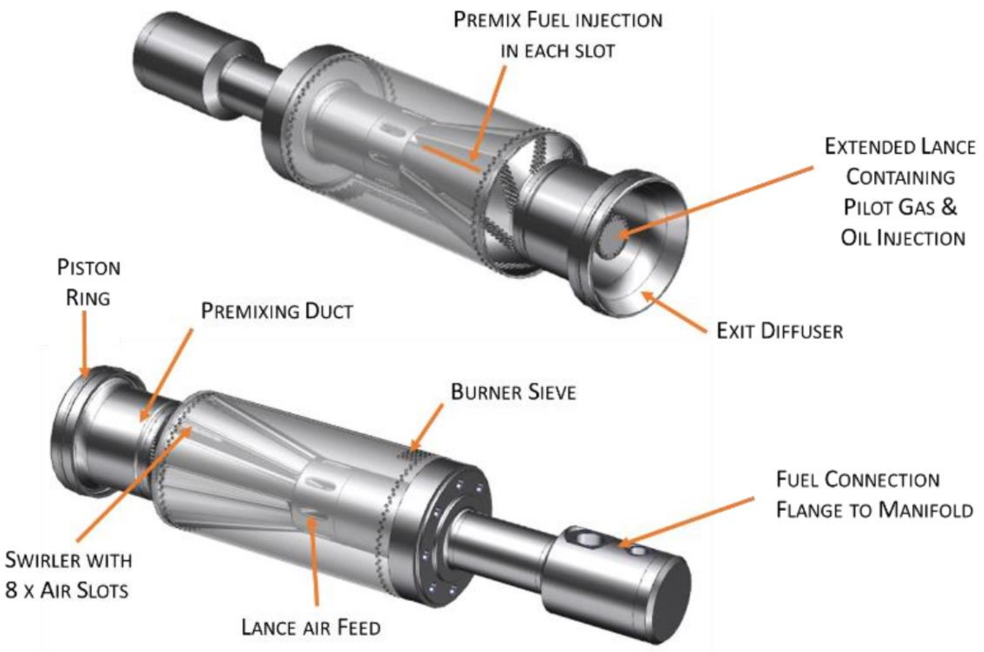


From: Lechner, C., Seume, J., Stationary Gas Turbines, 2nd edition, Springer, 2010

GT combustion systems
Lean combustion of gaseous fuels - DLE

- Ansaldo Energia – GT 36

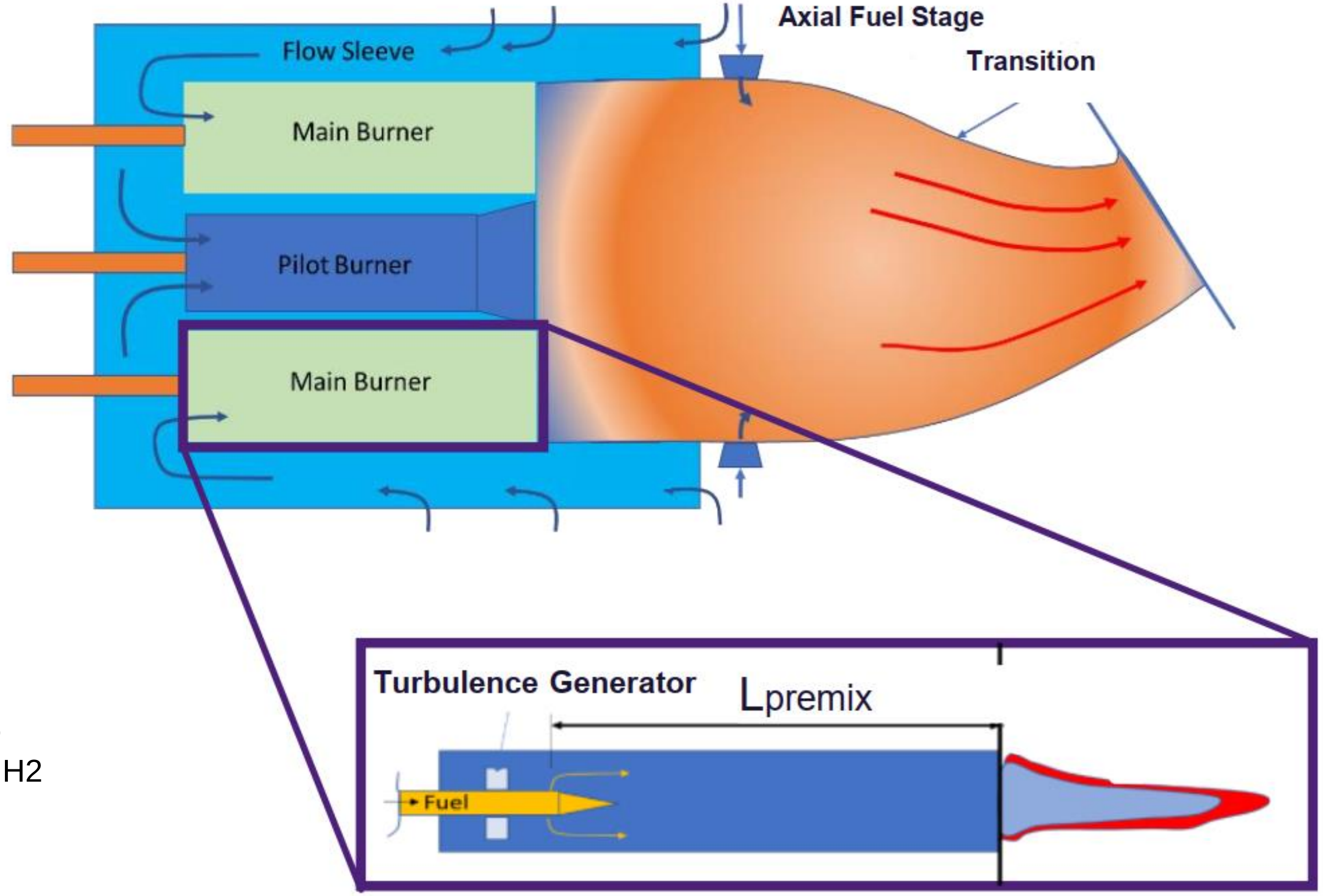




D. Pennell et. Al., GT36 FIRST STAGE DEVELOPMENT ENABLING LOAD AND FUEL (H2) FLEXIBILITY WITH LOW EMISSIONS, Proceedings of ASME Turbo Expo 2023, June 26-30, 2023, Boston, Massachusetts, USA, GT2023-103568

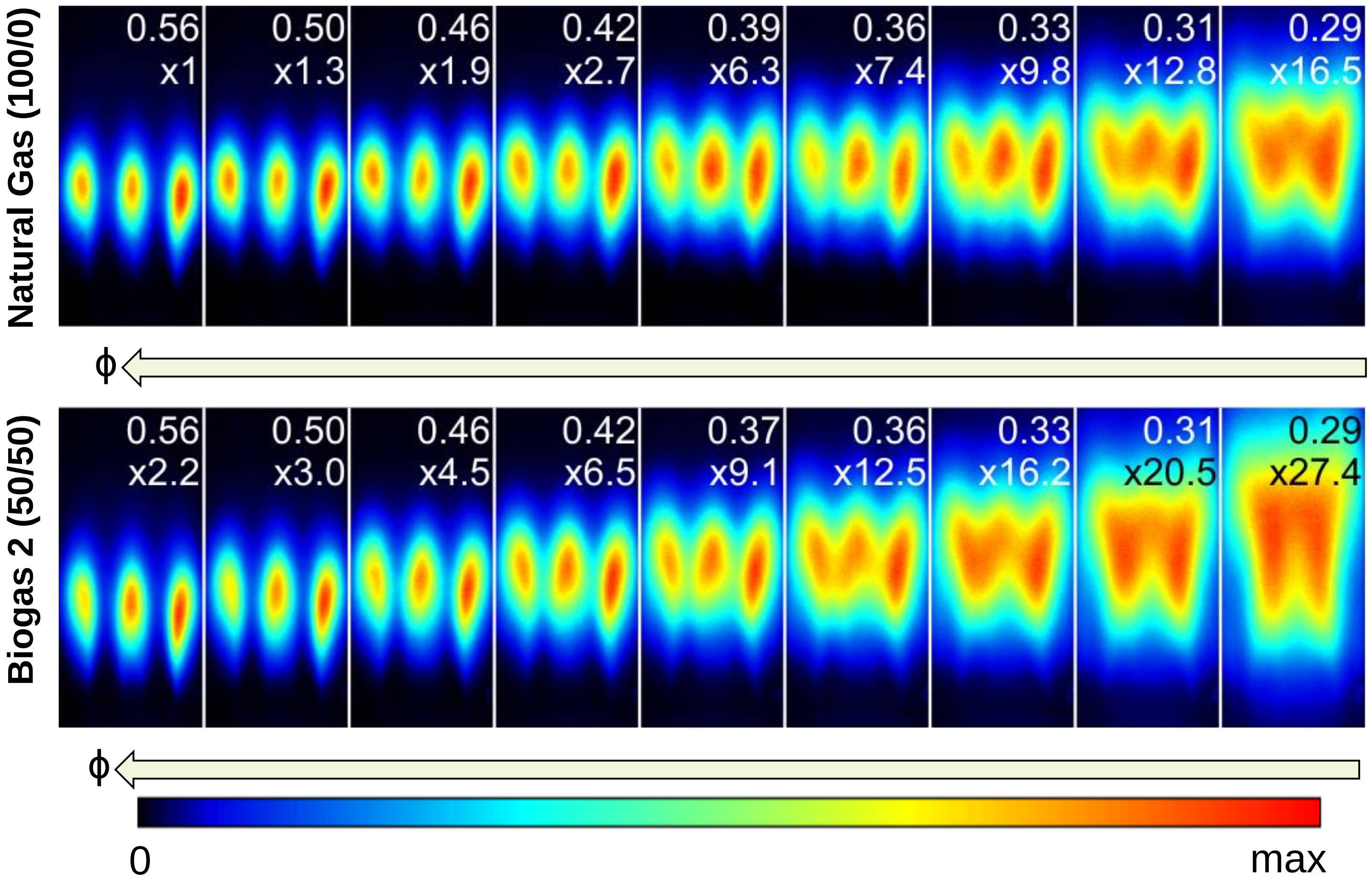
GT combustion systems
Lean combustion of gaseous fuels - DLE

- Siemens – Advance combustion technology with jet-stabilized burner with axial stage



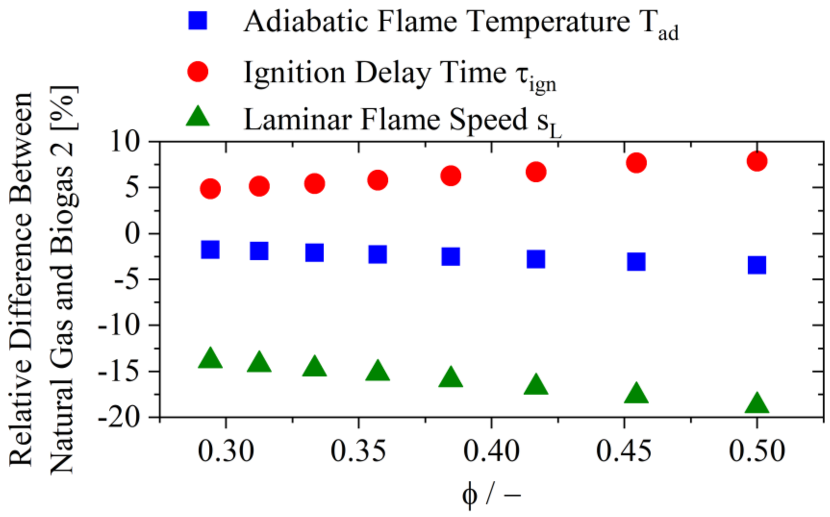
N. Parsania et. al., HYFLEXPOWER PROJECT: DEMONSTRATION OF AN INDUSTRIAL POWER-TO-H2-TO POWER ADVANCED PLANT CONCEPT WITH UP TO 100% H2 IN AN SGT-400 GAS TURBINE, Proceedings of ASME Turbo Expo 2024, June 24-28, 2024, London, UK, GT2024-124016

Studies of GT combustors using alternative fuels
Biogas - Flame Shape - Jet stabilized burner



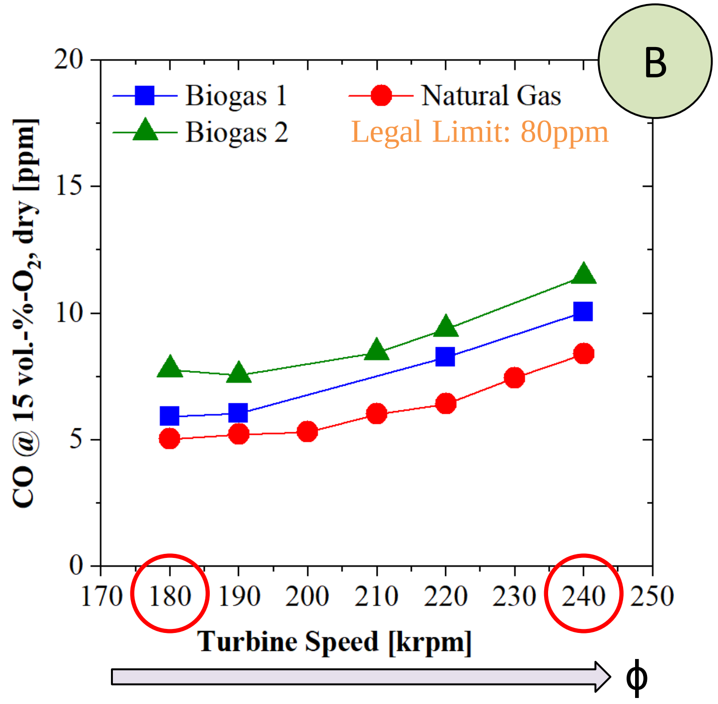
H. Seliger-Ost et al., (2021) *Experimental Investigation of the Impact of Biogas on a 3 kW Micro Gas Turbine FLOX®-Based Combustor.* Journal of Engineering for Gas Turbines and Power, 143 (8), 081020. American Society of Mechanical Engineers (ASME). doi: 10.1115/1.4049927. ISSN 0742-4795

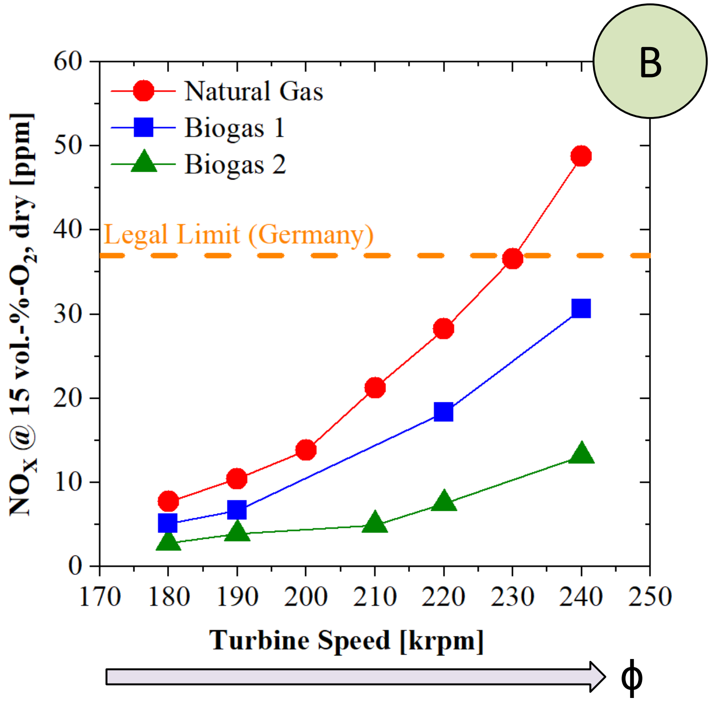
- With decreasing ϕ
  - Flame transforms from single flame to distributed flame regime
  - Influence of CO_2 admixture increases
    →leads to an even more distributed flame

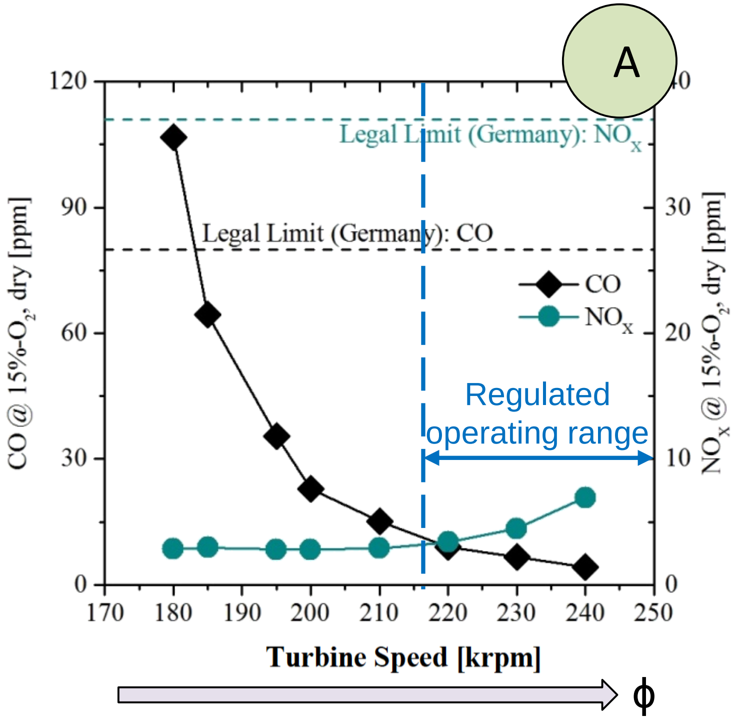


Studies of GT combustors using alternative fuels

Biogas – Emissions of MGT - Jet stabilized burner







- Similar trends as for atmospheric conditions
- Very low CO emissions
- NO_X emissions with natural gas slightly exceeds legal limit

→ Slight adjustment of air split necessary (Δϕ≈0.05)

- Split adjustment can achieve CO and NO_X levels below the legal limit

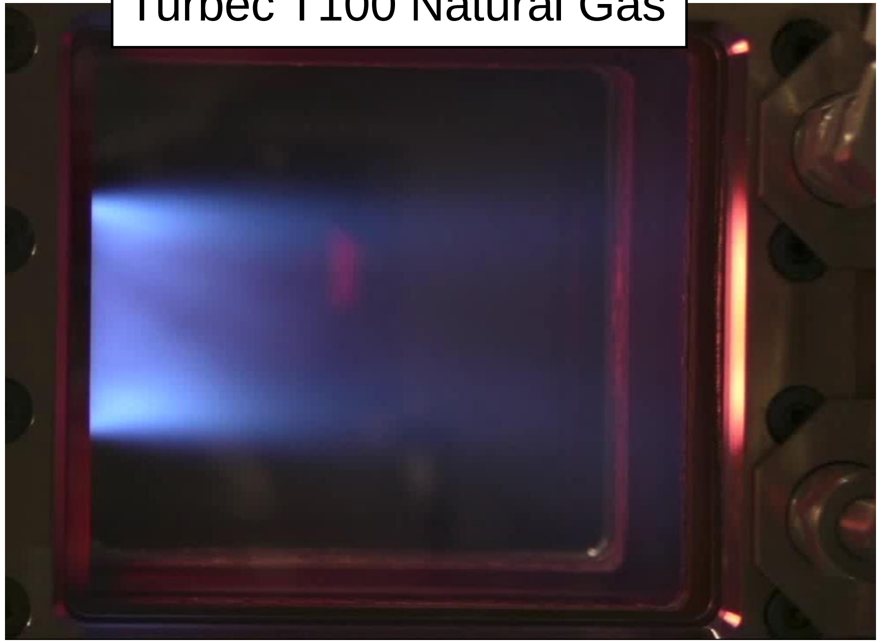
H. Seliger-Ost et al., (2021) *Experimental Investigation of the Impact of Biogas on a 3 kW Micro Gas Turbine FLOX®-Based Combustor.* Journal of Engineering for Gas Turbines and Power, 143 (8), 081020. American Society of Mechanical Engineers (ASME). doi: 10.1115/1.4049927. ISSN 0742-4795

Studies of GT combustors using alternative fuels

Wood gas – Flame shape

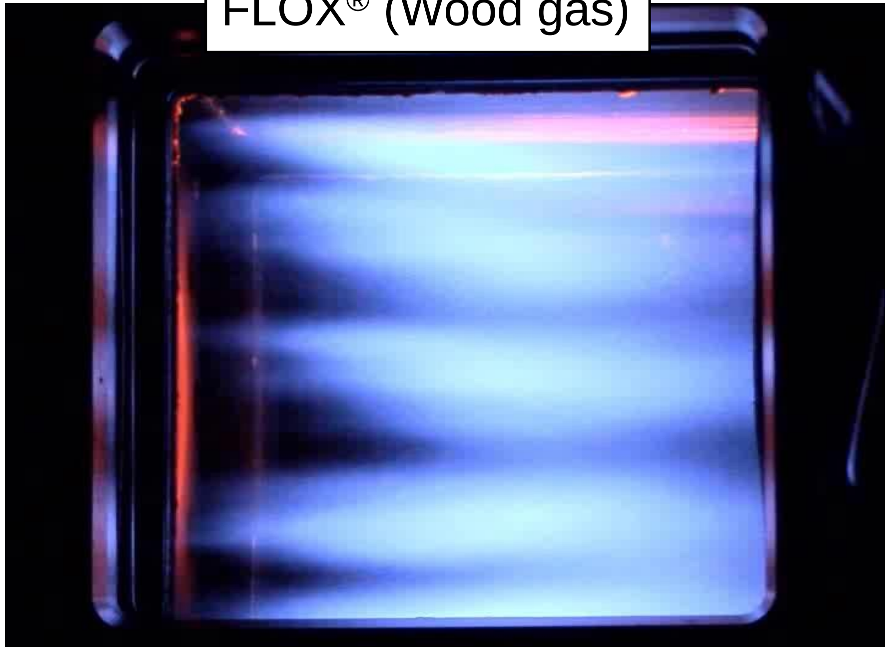
- Engine test with optical combustion chamber

Turbec T100 Natural Gas

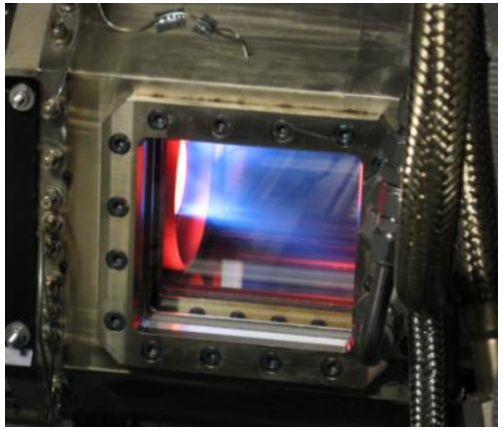


ca. 90 % rotational speed

FLOX® (Wood gas)

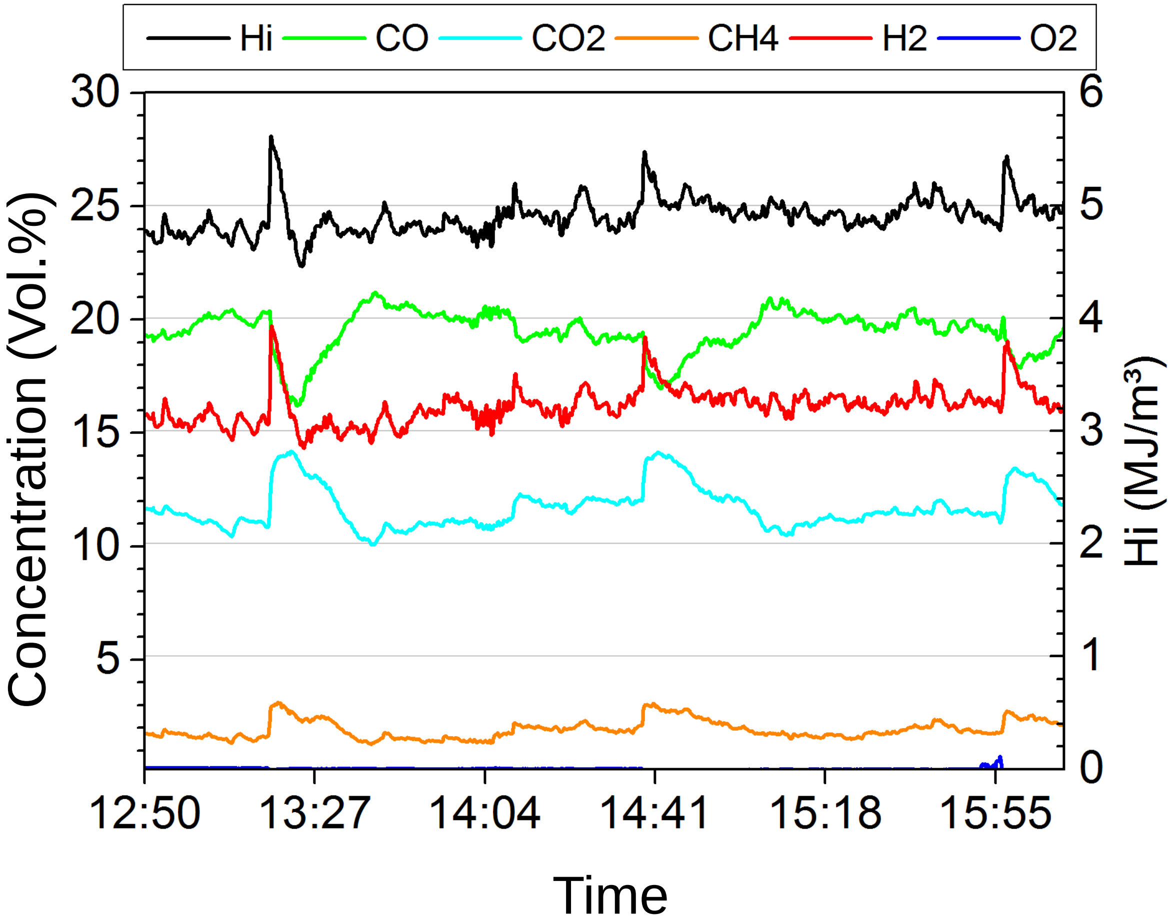


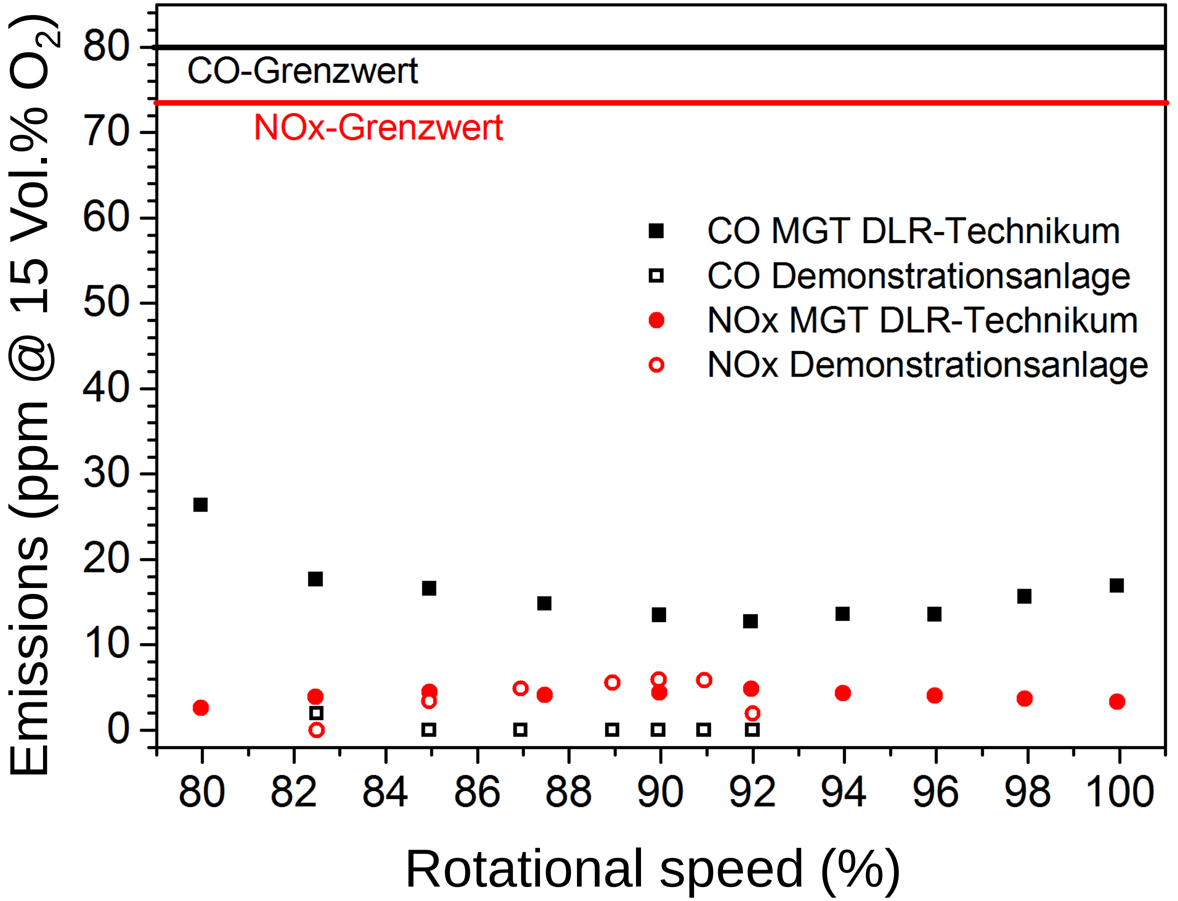
90 % rotational speed



T. Zornek (2017) Betrieb einer Demonstrationsanlage bestehend aus Biomassevergaser und Mikrogasturbine. 7. Statuskonferenz „Bioenergie: Flexibel und integriert in die nächste Epoche“, 2017-11-20 - 2017-11-21, Leipzig

Studies of GT combustors using alternative fuels
Wood gas – Emissions of MGT - Jet stabilized burner

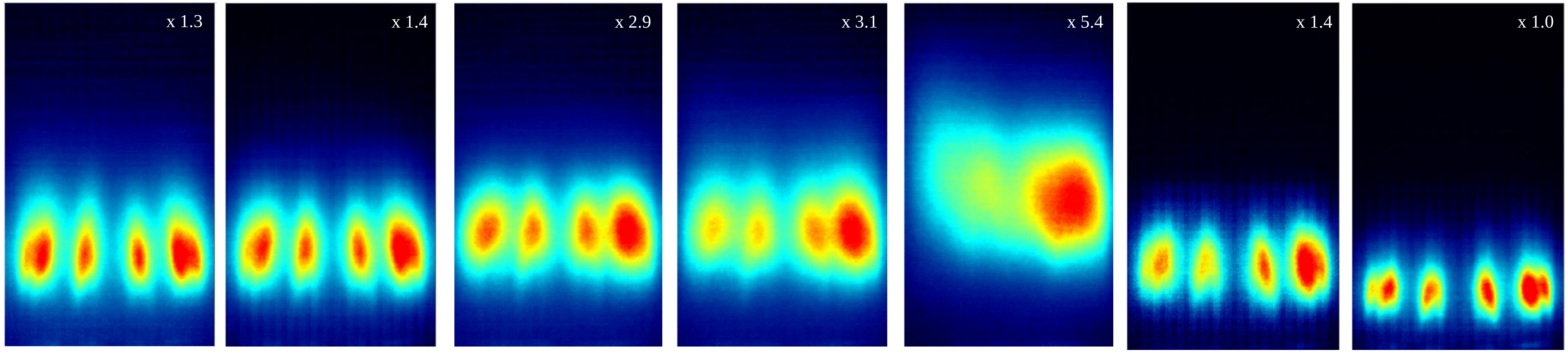




T. Zornek (2017) Betrieb einer Demonstrationsanlage bestehend aus Biomassevergaser und Mikrogasturbine. 7. Statuskonferenz „Bioenergie: Flexibel und integriert in die nächste Epoche“, 2017-11-20 - 2017-11-21, Leipzig

Studies of GT combustors using alternative fuels
Fuel flexibility – from syngas to natural gas to hydrogen

- <u>Flame shape and position - Jet stabilized burner:</u>



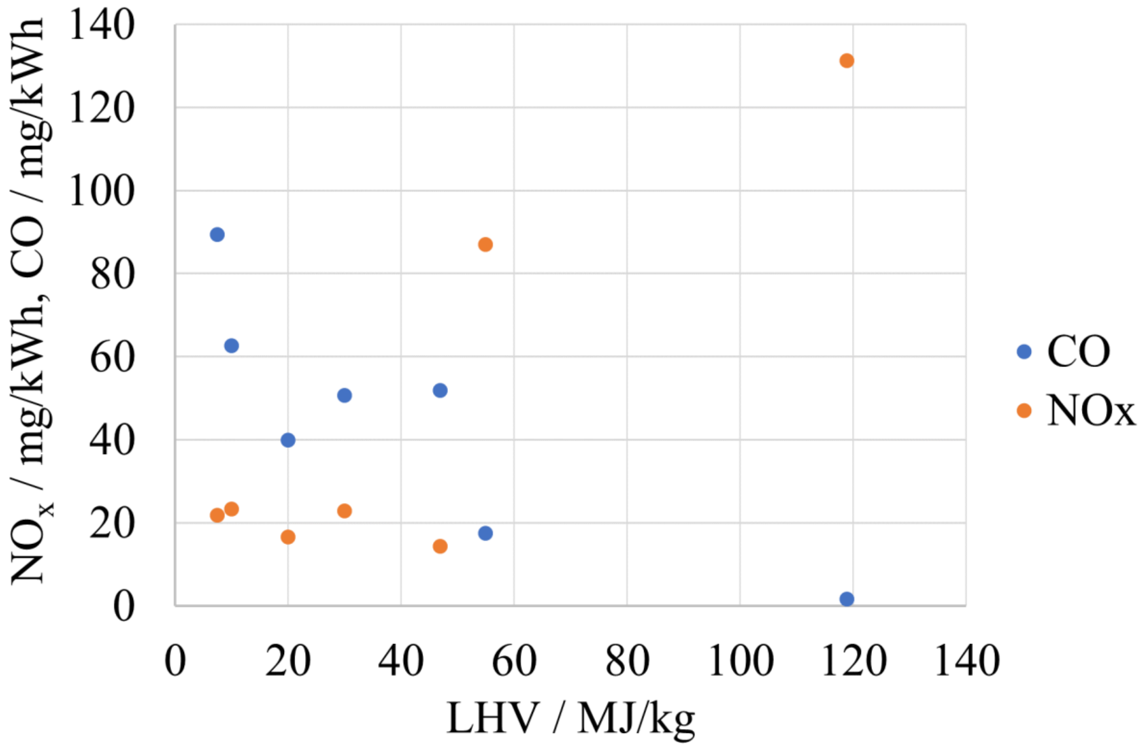
syngas	syngas/NG	syngas/NG	syngas/NG	NG	NG/H_2	H_2
7.45 MJ/kg	10MJ/kg	20MJ/kg	30 MJ/kg	47 MJ/kg	55 MJ/kg	119 MJ/kg
$\lambda = 2.6$	$\lambda = 2.6$	$\lambda = 2.6$	$\lambda = 2.6$	$\lambda = 2.6$	$\lambda = 2.6$	$\lambda = 2.8$
P = 75 kW	P = 80 kW	P = 80 kW	P = 80 kW	P = 80 kW	P = 80 kW	P = 80 kW
mf_{air2} = 85 g/s	mf_{air2} = 85 g/s	mf_{air2} = 85 g/s	mf_{air2} = 85 g/s	mf_{air2} = 0 g/s	mf_{air2} = 85 g/s	mf_{air2} = 85 g/s

- Lifted flame for all mixtures, no flashback observed
- Stable combustion for all fuels, except natural gas (instabilities at some burner air numbers)

M. Hohloch et. Al., Experimental investigation of the fuel flexibility of a jet stabilized syngas micro gas turbine combustor under atmospheric conditions, 31. Deutscher Flammentag, september 27-28, Berlin

Studies of GT combustors using alternative fuels
Fuel flexibility – from syngas to natural gas to hydrogen

- Emissions - Jet stabilized burner:



- Order of LHV values corresponds to order of OH* chemiluminescence images
- Highest CO emissions for syngas
- Zero for pure hydrogen
- Increasing NO_x emissions for high hydrogen content
- Emissions indicate that optimal operation range differs for each fuel composition

→ proven by variation of burner air number

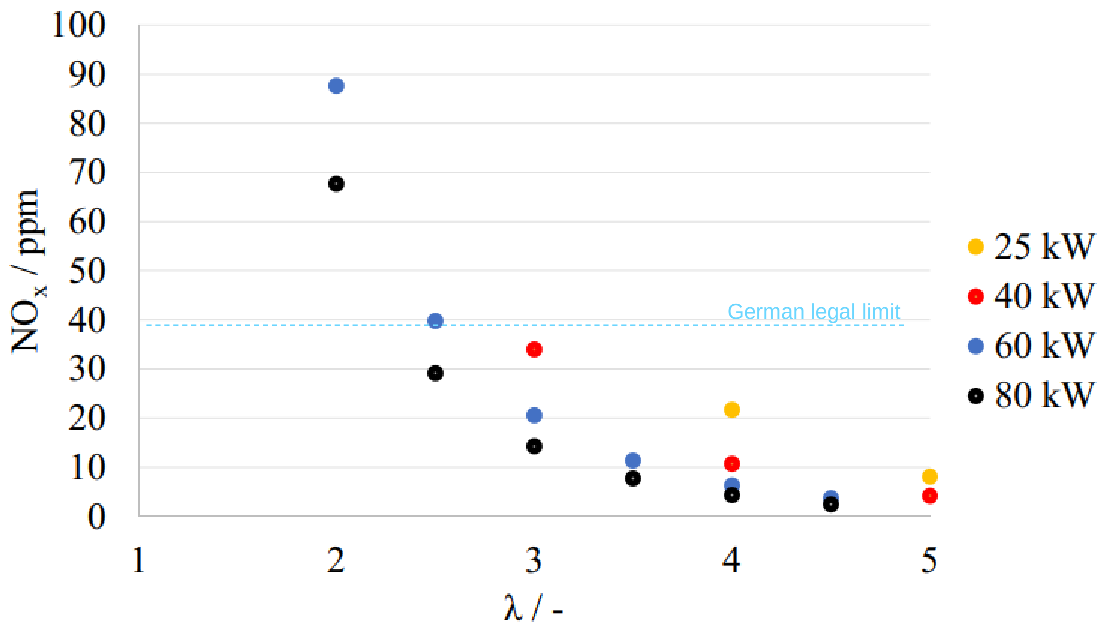
→ especially for hydrogen optimal range at higher burner air number, reaching single digit NO_x values

M. Hohloch et. Al., Experimental investigation of the fuel flexibility of a jet stabilized syngas micro gas turbine combustor under atmospheric conditions, 31. Deutscher Flammentag, september 27-28, Berlin

Studies of GT combustors using alternative fuels
Hydrogen – variation of thermal power and burner air number

NO_x emissions @ 15 vol.% O_2

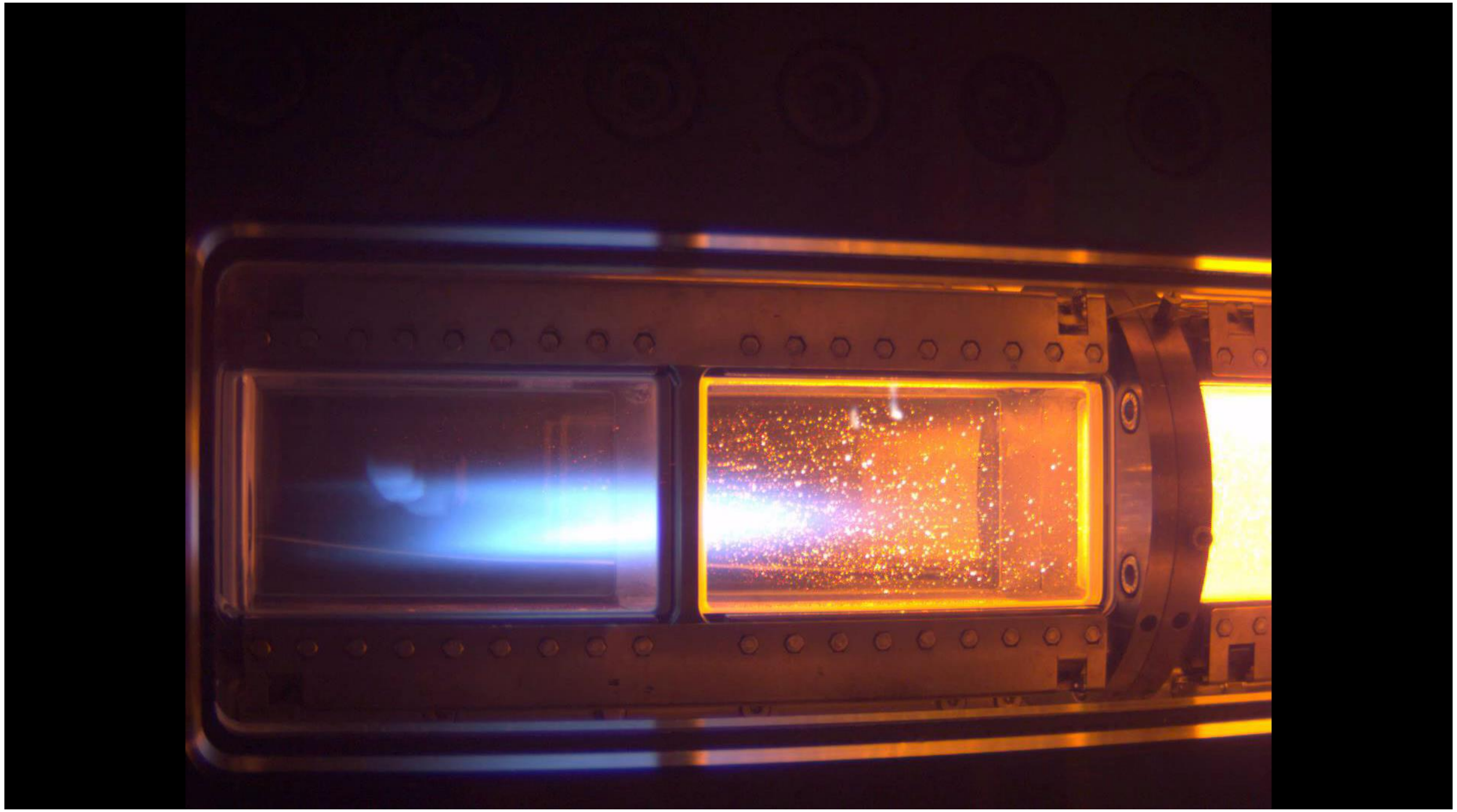
- High NO_x emissions at rich conditions
- Decreasing NO_x emissions with increasing λ
- NO_x emission increase with decreasing thermal power input
  - Lower velocities
  - Less distinctive recirculation zones lead to less homogenous temperature field
  - Hot spots and higher peak temperatures



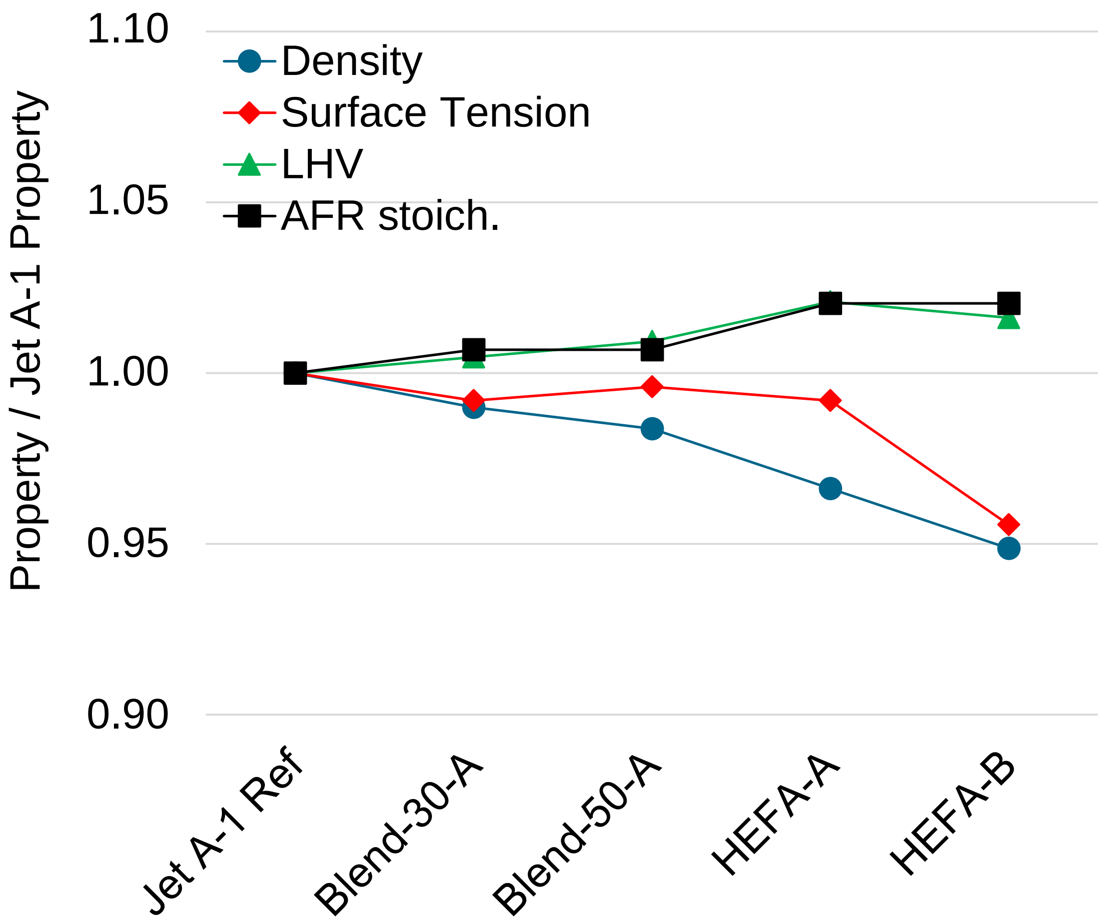
M. Hohloch et. Al., EXPERIMENTAL ANALYSIS OF THE HYDROGEN CAPABILITY OF A FUEL FLEXIBLE JET STABILIZED SYNGAS MICRO GAS TURBINE COMBUSTOR UNDER ATMOSPHERIC CONDITIONS, Proceedings of ASME Turbo Expo 2023, June 26-30, 2023, Boston, Massachusetts, USA, GT2023-103418

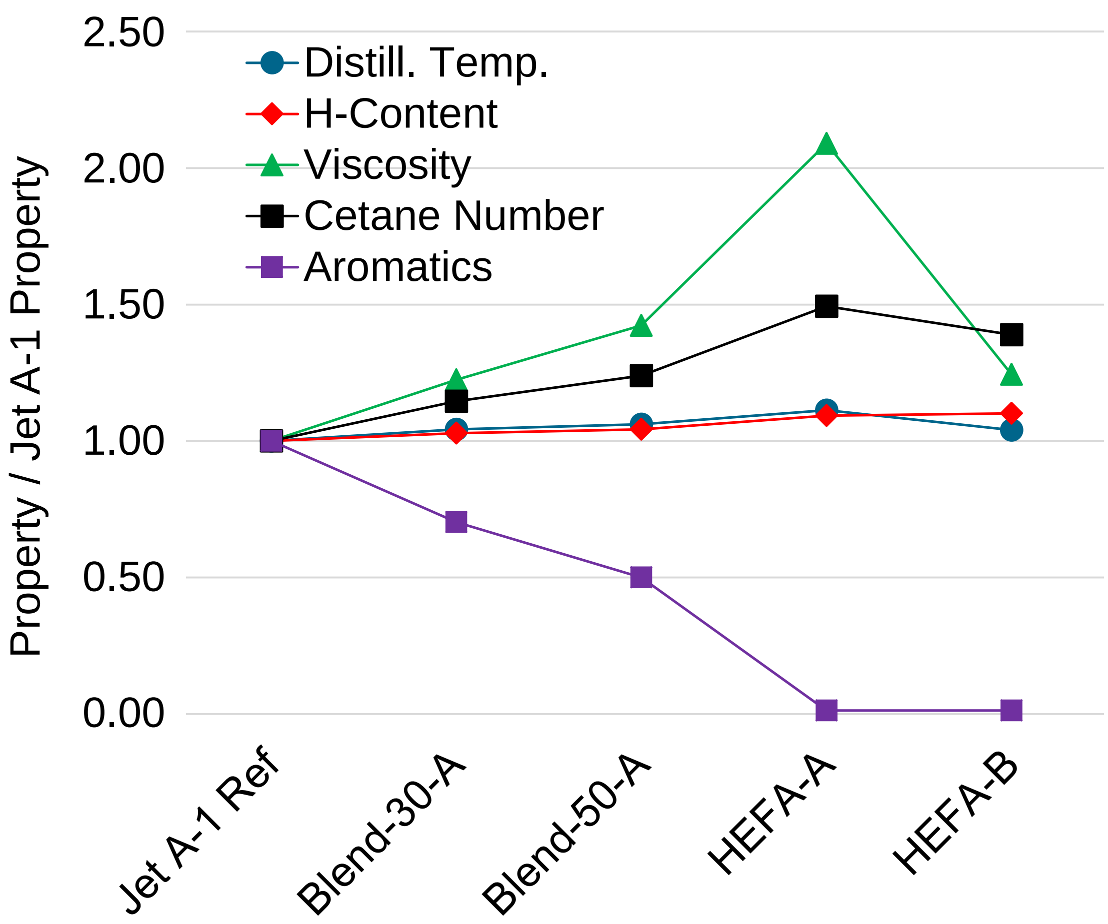
Studies of GT combustors using alternative fuels
Fuel flexibility – from natural gas to hydrogen

- High pressure tests @ HBK-S: - Jet stabilized burner



Studies of GT combustors using alternative fuels
Liquid fuels - Selected Fuel Properties



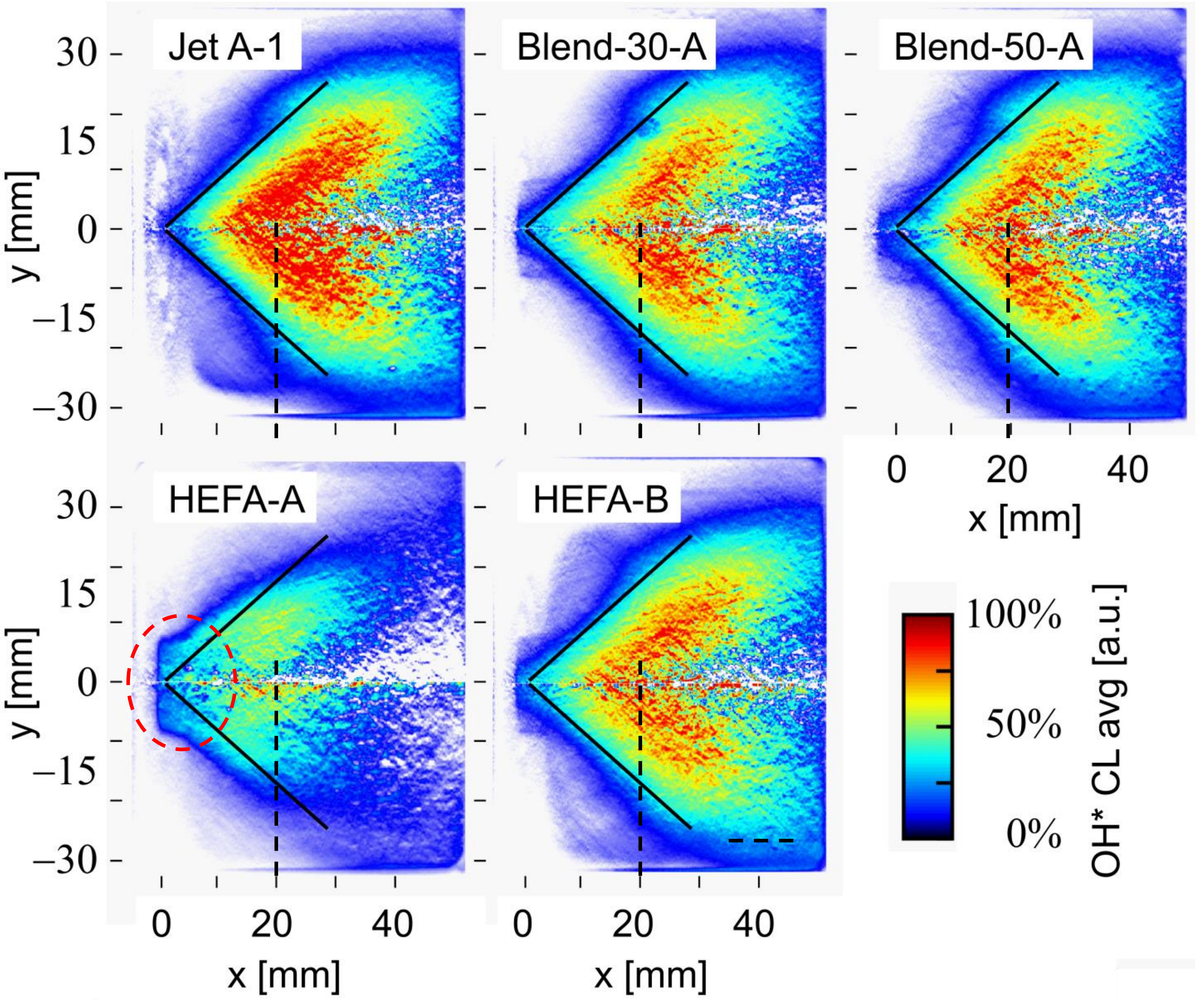


P. Griebel et al., Evaluation of current and future aviation fuels at high-pressure RQL-type combustor conditions, GT2024-128796, ASME Turbo Expo 2024, 25th of June, London, UK

Studies of GT combustors using alternative fuels
Liquid fuels - Heat Release Zone

- Primary heat release zone not strongly affected by fuel type
- With increasing HEFA content, modestly advanced reaction onset
- Can be attributed to:
  - Higher fuel loading in the central region
  - Higher Cetane number 44 to 66

P = 10 bar, T_a = 673 K, Φ_{pz} = 0.71



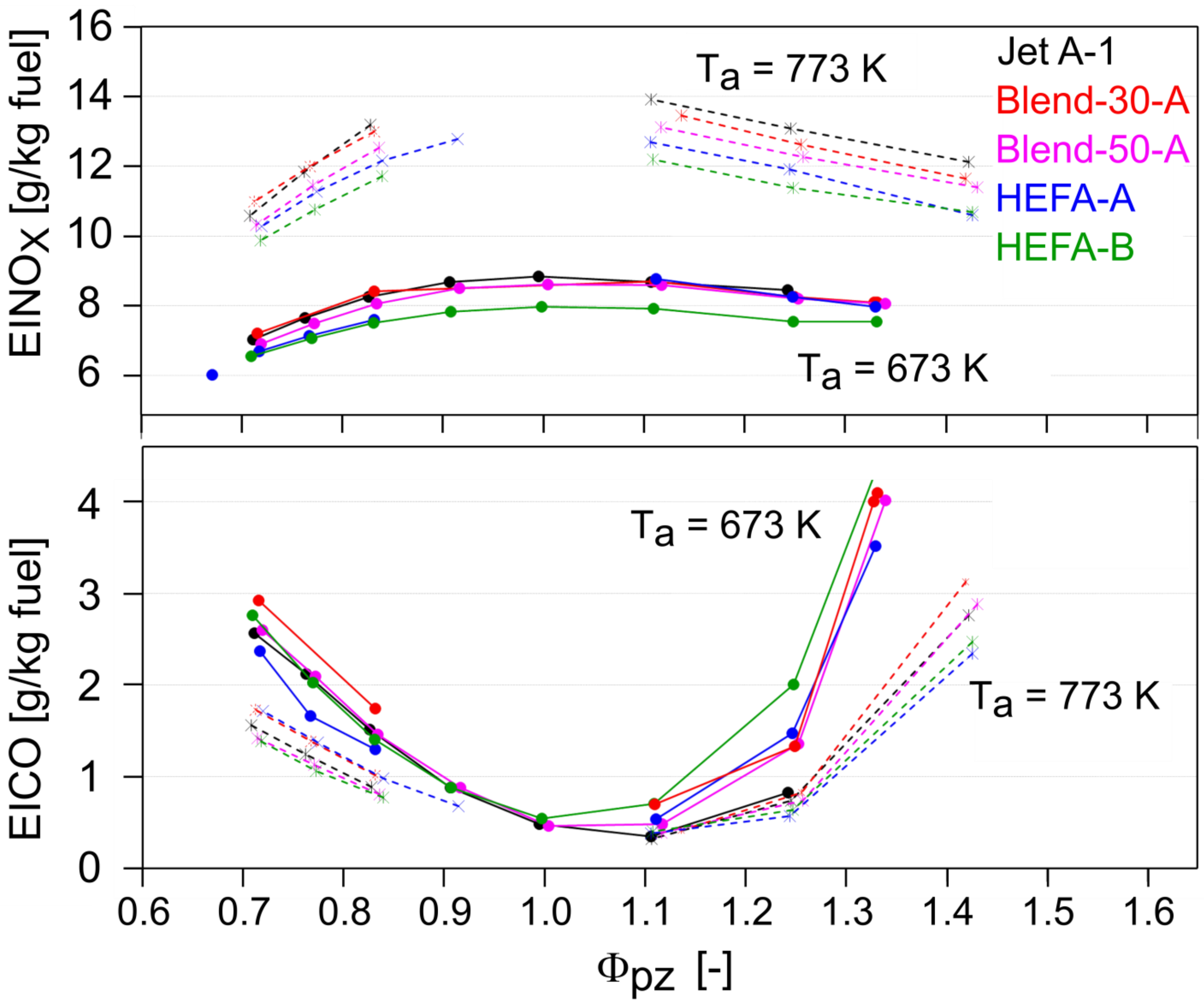
P. Griebel et al., Evaluation of current and future aviation fuels at hi[gh] pressure RQL-type combustor conditions, GT2024-128796, ASME Turbo Expo 2024, 25th of June, London, UK

Studies of GT combustors using alternative fuels

Emission Index

- Higher T_a yields lower CO emissions due to enhanced burn-out
- Higher T_a yields higher NO_X due to thermal formation pathway
- Gaseous emissions (NO_X & CO) only modestly fuel dependent
- NO_X emission reduce modestly with increasing HEFA blending

P = 10 bar, T_a = 673 and 773 K



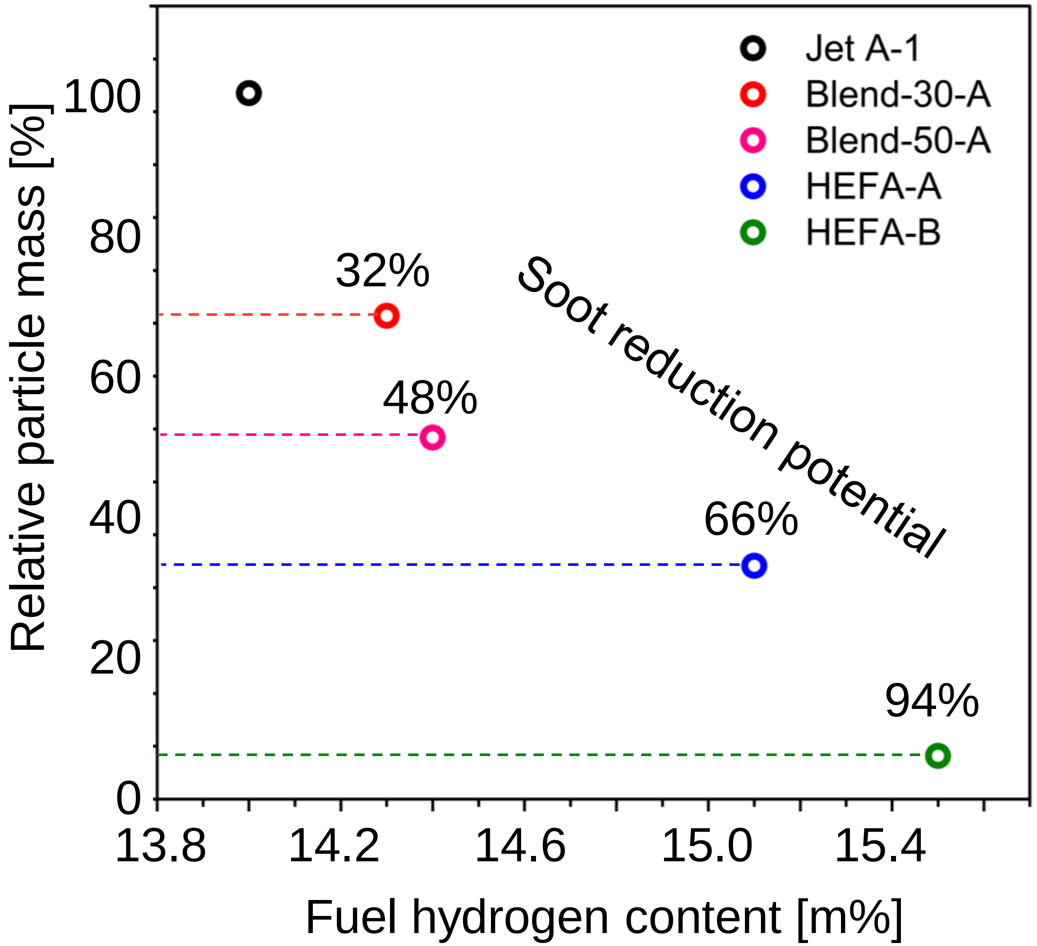
P. Griebel et al., Evaluation of current and future aviation fuels at high-pressure RQL-type combustor conditions, GT2024-128796, ASME Turbo Expo 2024, 25th of June, London, UK

Studies of GT combustors using alternative fuels

Soot Emissions Index

P = 7.5 bar, T_a = 673 K, Φ_{pz} = 1.66

- Emission index for particle mass decreases with increasing hydrogen / lower aromatic fuel
- “Green” HEFA offers distinct CO_2 and non-CO_2 emission saving potential

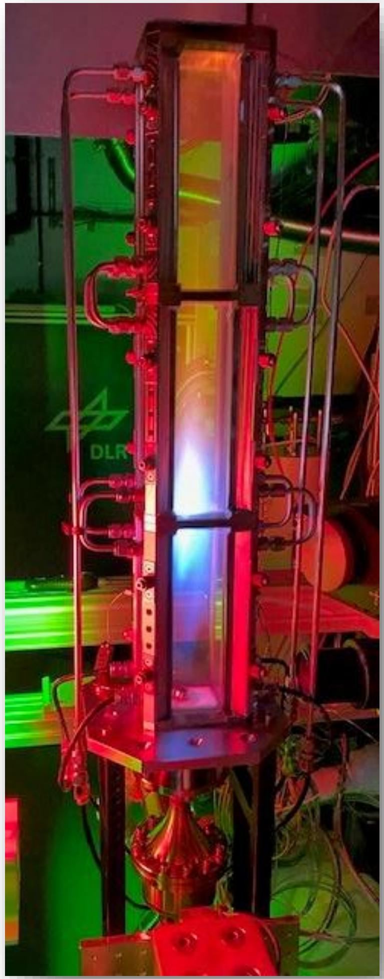


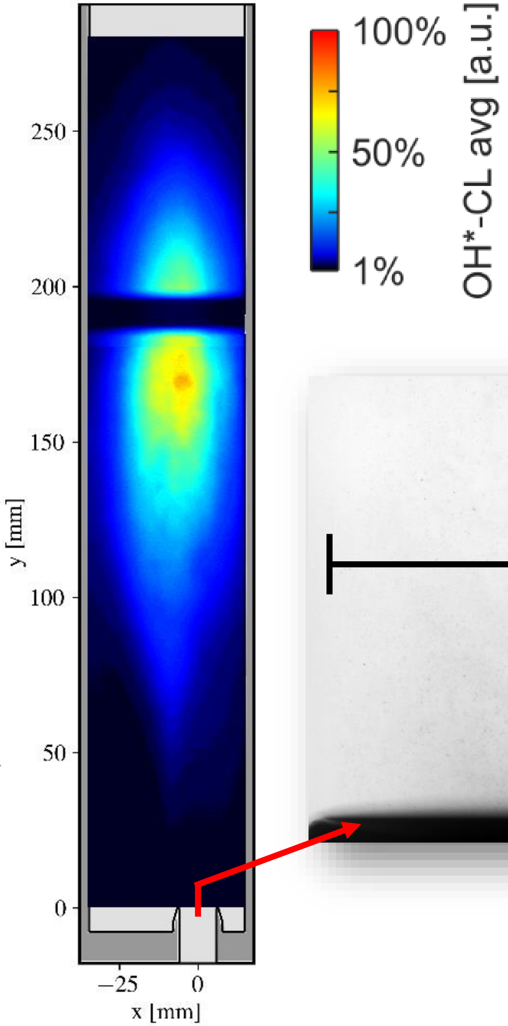
P. Griebel et al., Evaluation of current and future aviation fuels at high-pressure RQL-type combustor conditions, GT2024-128796, ASME Turbo Expo 2024, 25th of June, London, UK

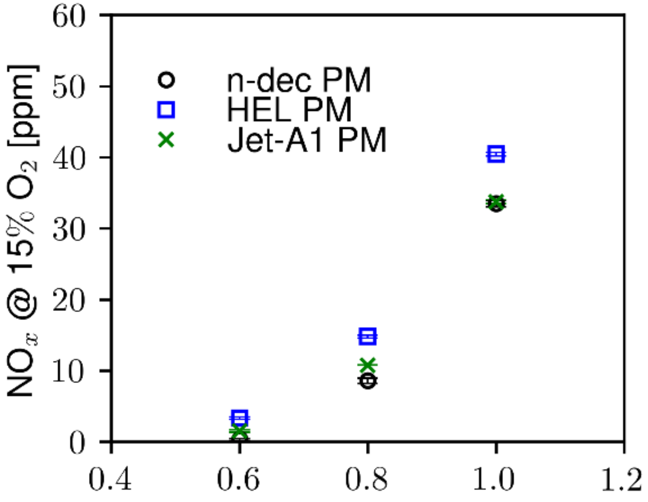
Studies of GT combustors using alternative fuels

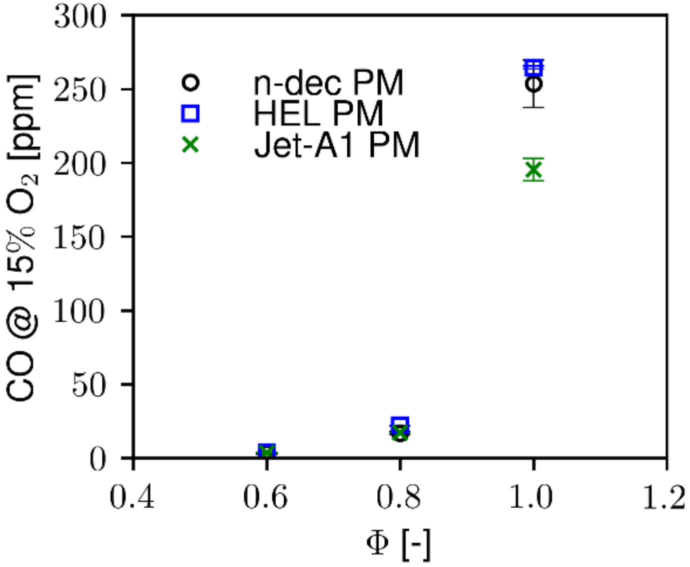
Liquid fuels - DLR Airblast Injektor

→ Lean, premixed and pre-vaporised combustion



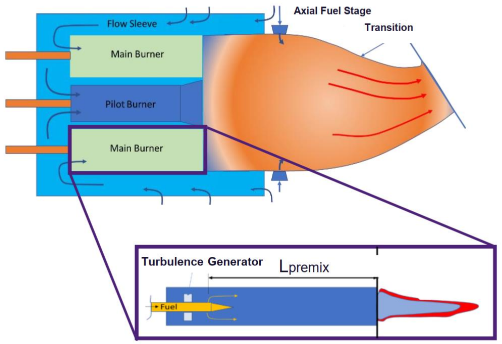


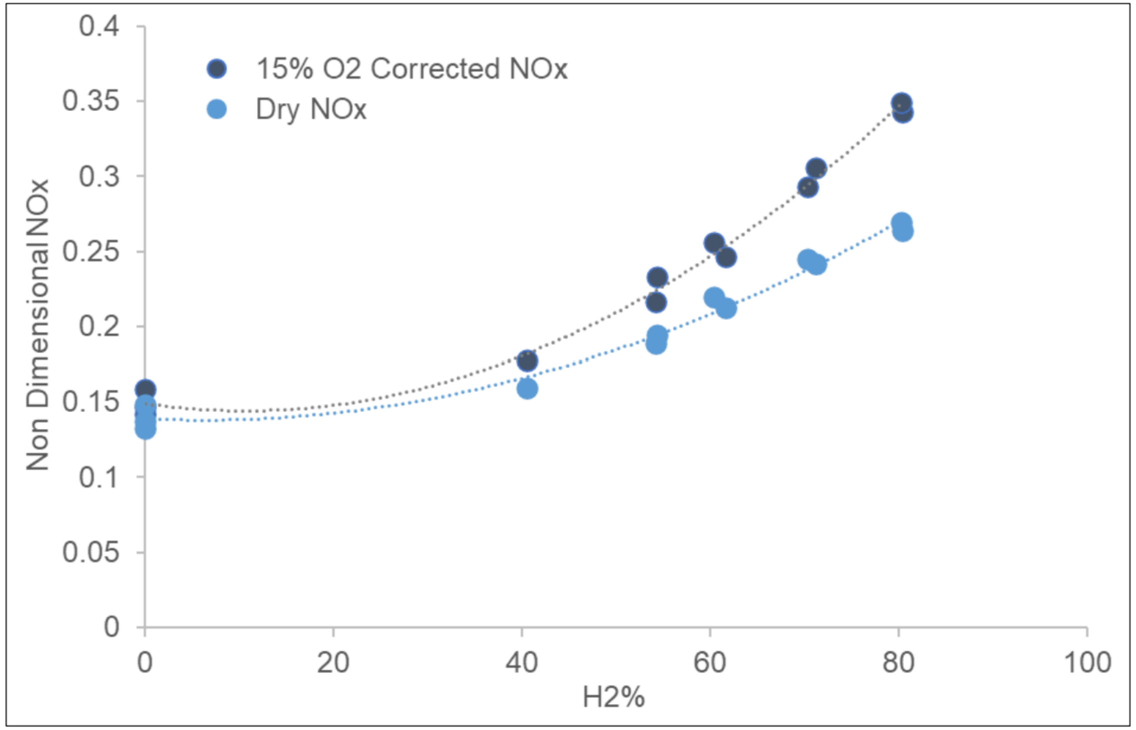




Examples of GTs using alternative fuels

Siemens – Hyflexpower Project – SGT-400

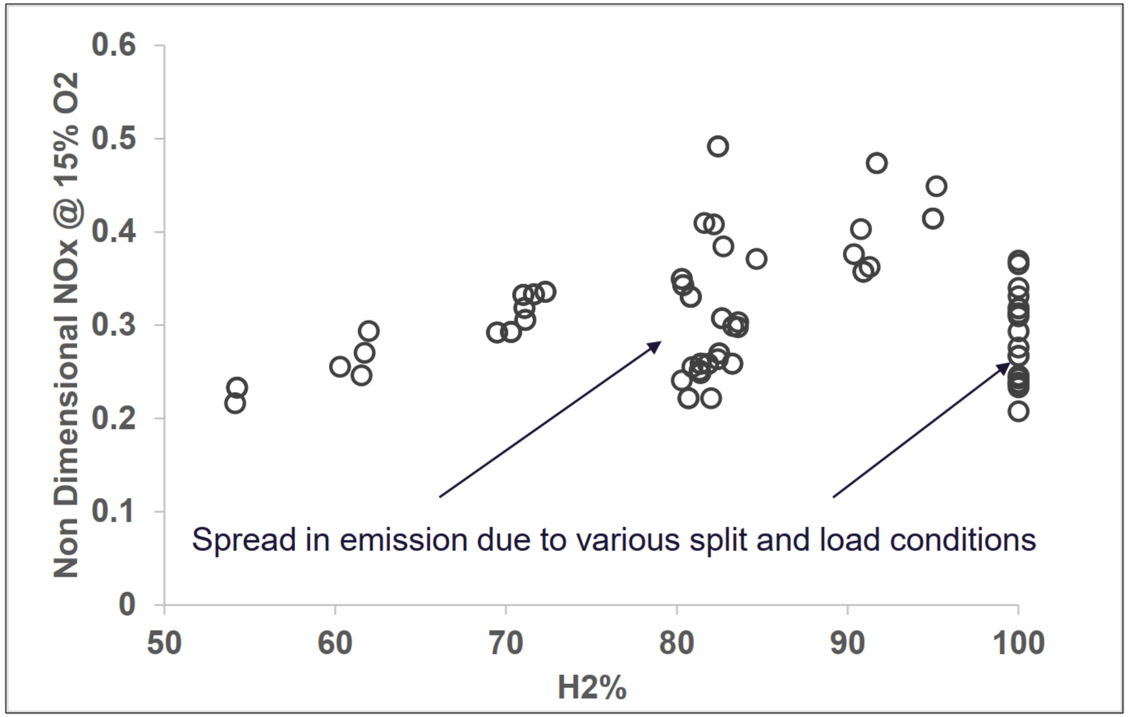




NO_x emissions @ constant

- Load / TET
- Fuel split

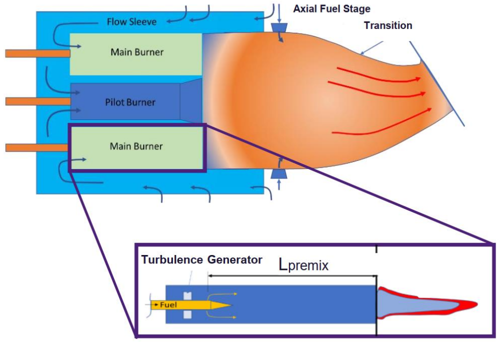
NO_x emissions @ multiple load and fuel splits

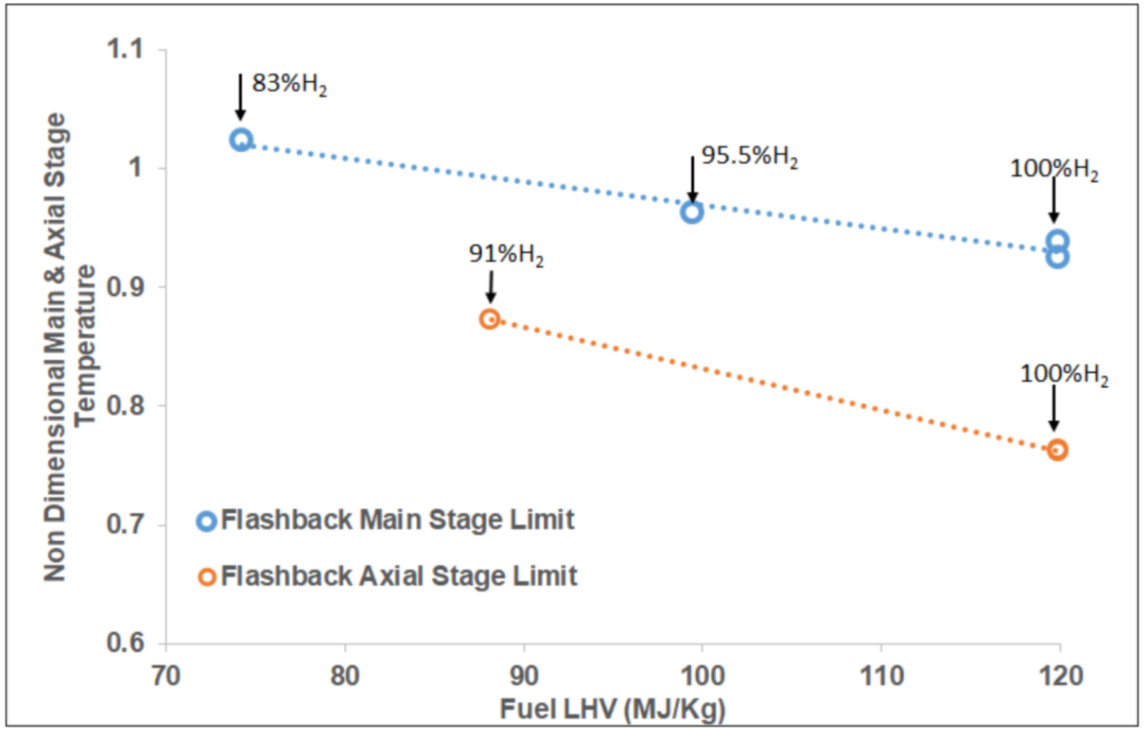


N. Parsania et. al., HYFLEXPOWER PROJECT: DEMONSTRATION OF AN INDUSTRIAL POWER-TO-H2-TO POWER ADVANCED PLANT CONCEPT WITH UP TO 100% H2 IN AN SGT-400 GAS TURBINE, Proceedings of ASME Turbo Expo 2024, June 24-28, 2024, London, UK, GT2024-124016

Examples of GTs using alternative fuels

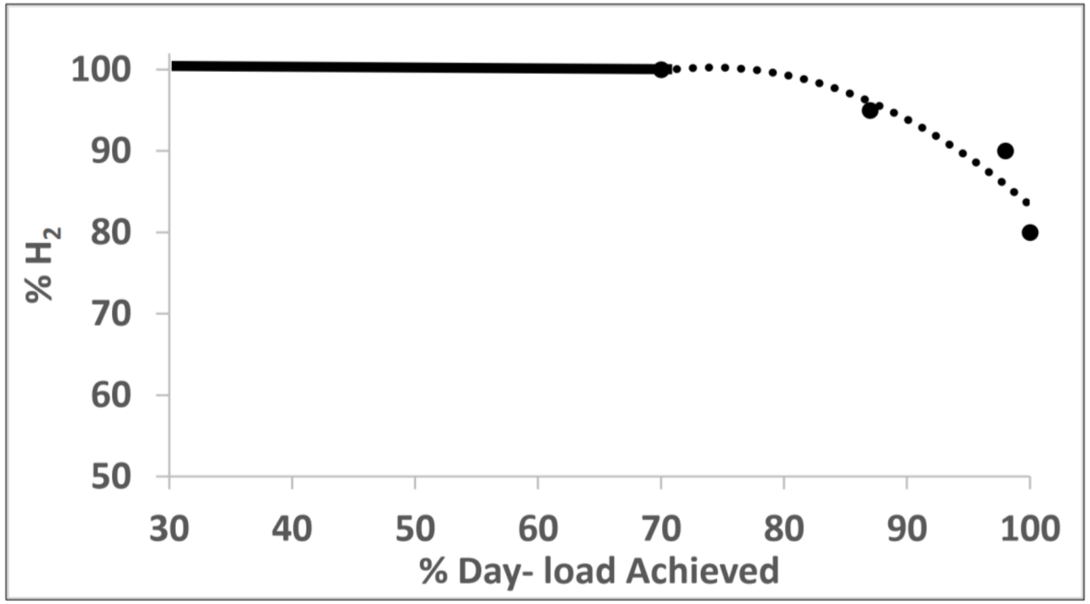
Siemens – Hyflexpower Project using H_2 – SGT-





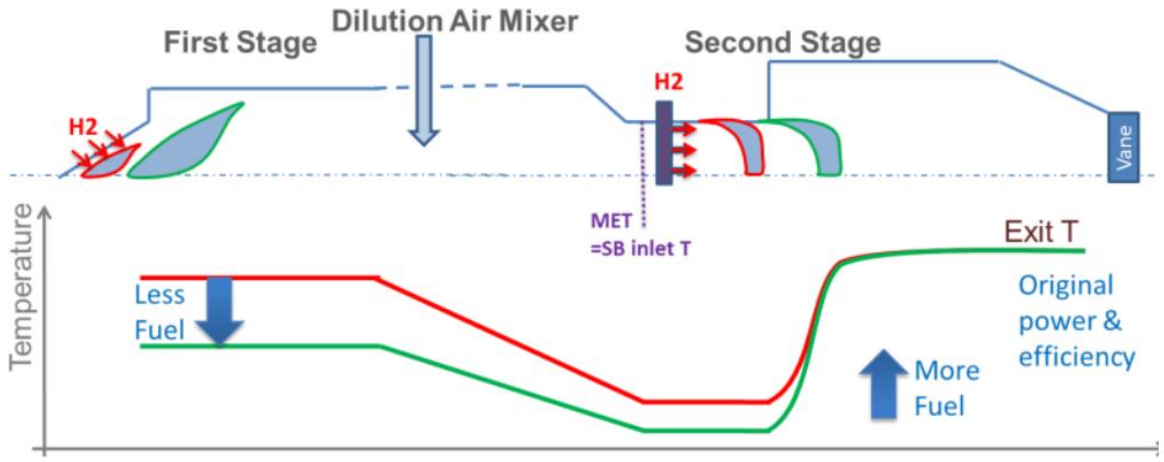
Flashback limits of main and axial stage depend on stage temperature

Operational limits maintaining flashback limits with safety tolerance



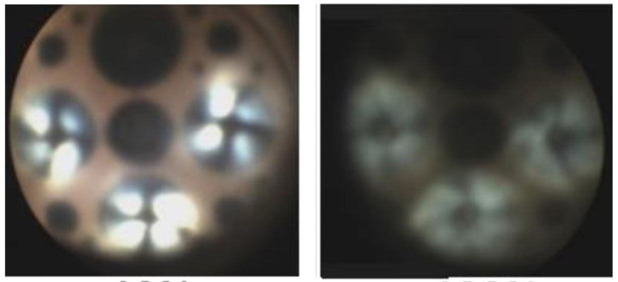
N. Parsania et. al., HYFLEXPOWER PROJECT: DEMONSTRATION OF AN INDUSTRIAL POWER-TO-H2-TO POWER ADVANCED PLANT CONCEPT WITH UP TO 100% H2 IN AN SGT-400 GAS TURBINE, Proceedings of ASME Turbo Expo 2024, June 24-28, 2024, London, UK, GT2024-124016

Examples of GTs using alternative fuels
Ansaldo – Load and fuel flexibility using H_2 - GT36

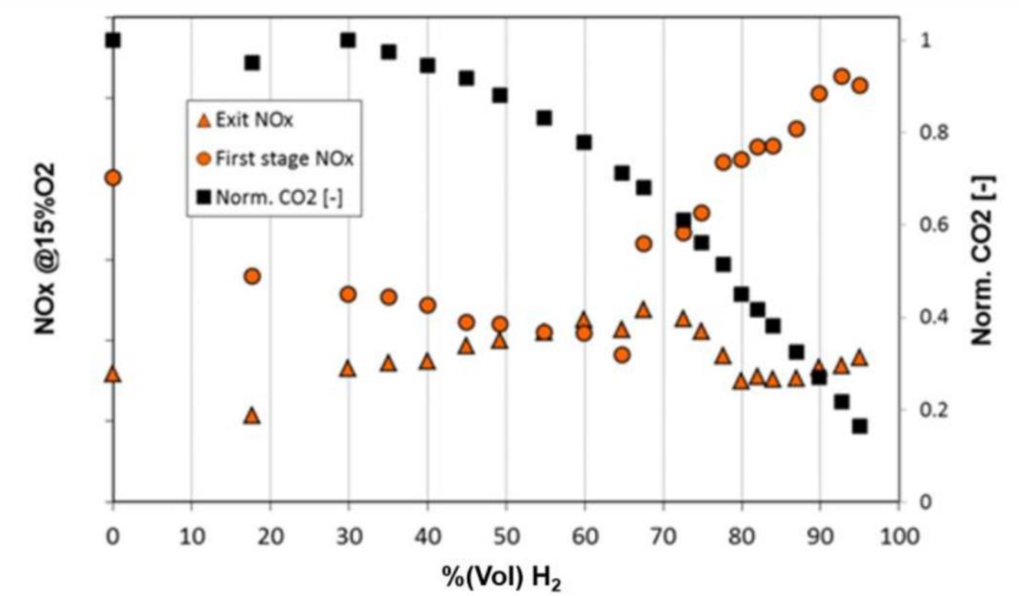


Mixing Exit temperature (MET) = controllable parameter for

- fuel flexibility
- optimum load CO & NO_x performance



10% 100%



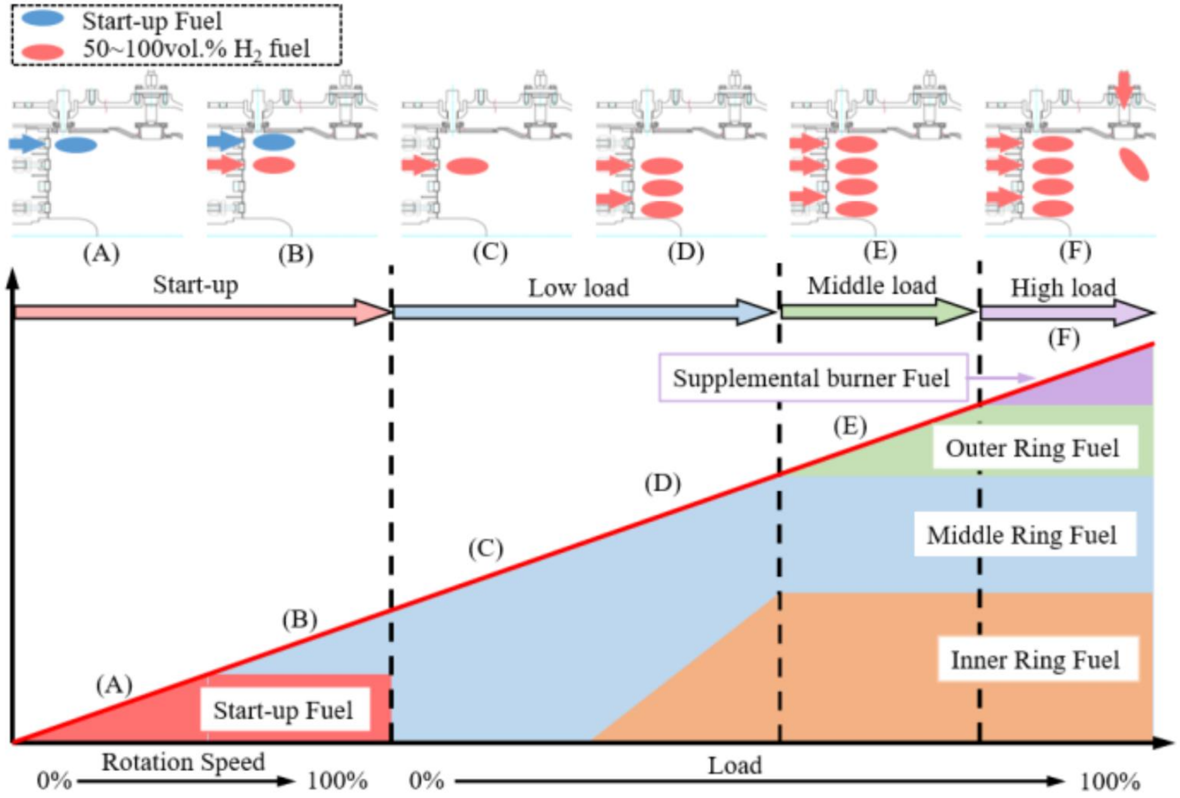
High-pressure full load single can validation

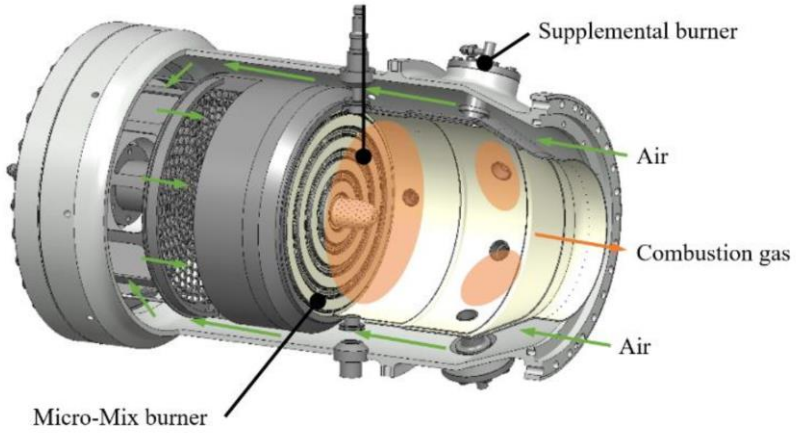
D. Pennell et. Al., GT36 FIRST STAGE DEVELOPMENT ENABLING LOAD AND FUEL (H2) FLEXIBILITY WITH LOW EMISSIONS, Proceedings of ASME Turbo Expo 2023, June 26-30, 2023, Boston, Massachusetts, USA, GT2023-103568

Examples of GTs using alternative fuels

Kawasaki – Load and fuel flexibility using H_2 – M1A-17

- Fuel flexibility by fuel staging of inner, middle and outer micromix ring and supplement burner → Ignition and load ramping procedure using NG as start up fuel

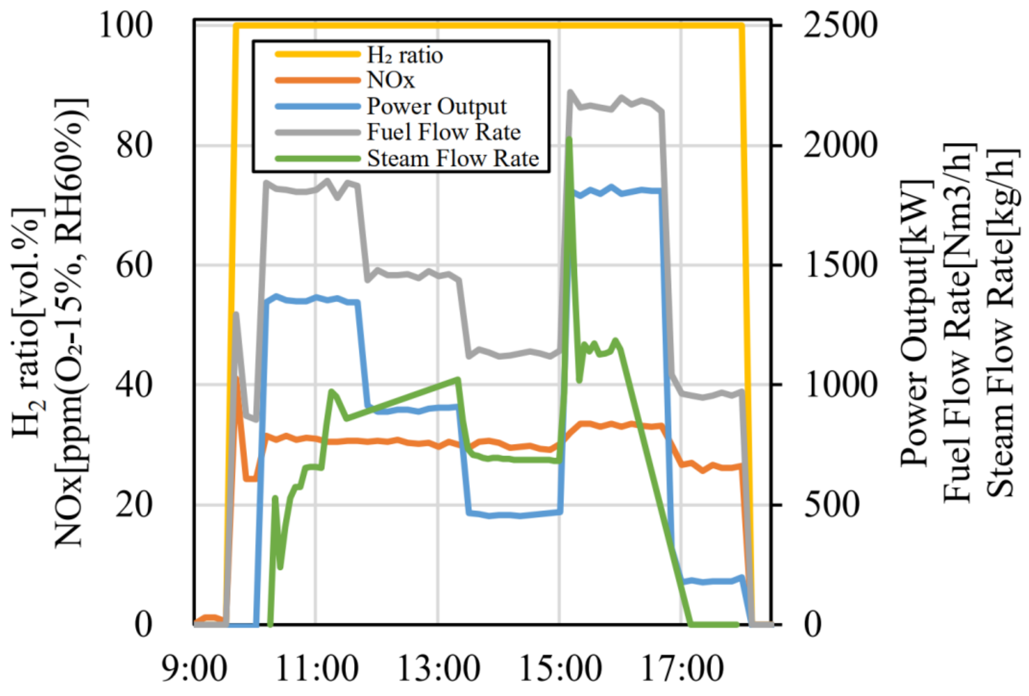




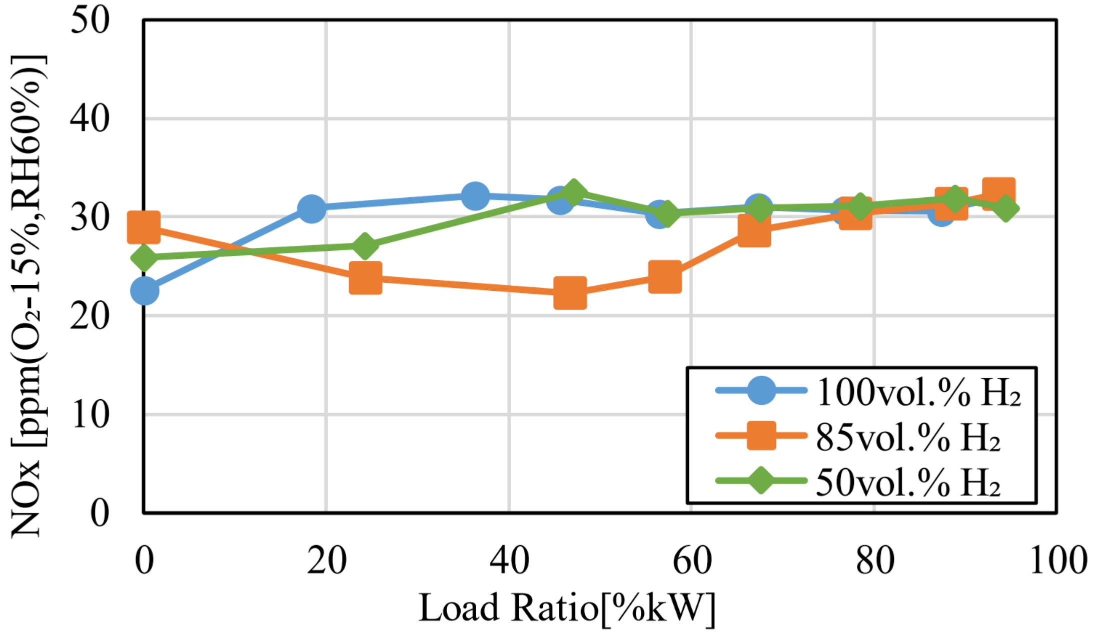
S. Aoki et. al., DEVELOPMENT OF HYDROGEN AND MICROMIX COMBUSTOR FOR SMALL AND MEDIUM SIZE GAS TURBINE OF KAWASAKI, Proceedings of ASME Turbo Expo 2024, June 24-28, 2024, London, UK, GT2024-121073

Examples of GTs using alternative fuels

Kawasaki – Load and fuel flexibility using H_2 – M1A-17



Operational proceedings of demonstration test for 100 Vol.% H_2

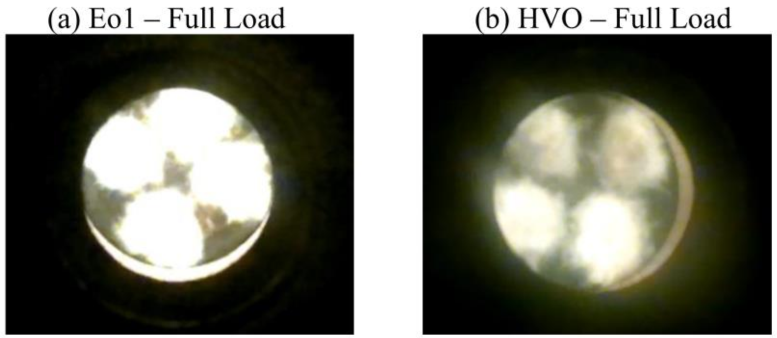


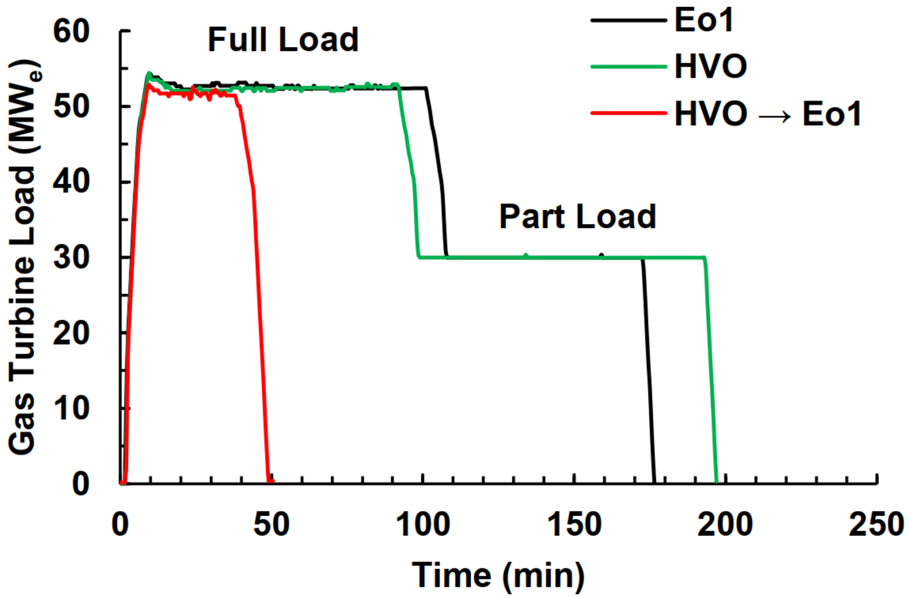
NO_x-emissions for H_2 fuel blends and natural gas

S. Aoki et. al., DEVELOPMENT OF HYDROGEN AND MICROMIX COMBUSTOR FOR SMALL AND MEDIUM SIZE GAS TURBINE OF KAWASAKI, Proceedings of ASME Turbo Expo 2024, June 24-28, 2024, London, UK, GT2024-121073

Examples of GTs using alternative fuels
Uniper – Hydrotreated Vegetable Oil – Siemens V93.0

- Peaker unit with silo combustors (diffusion flames) and water injection
- HVO suitable drop-in fuel





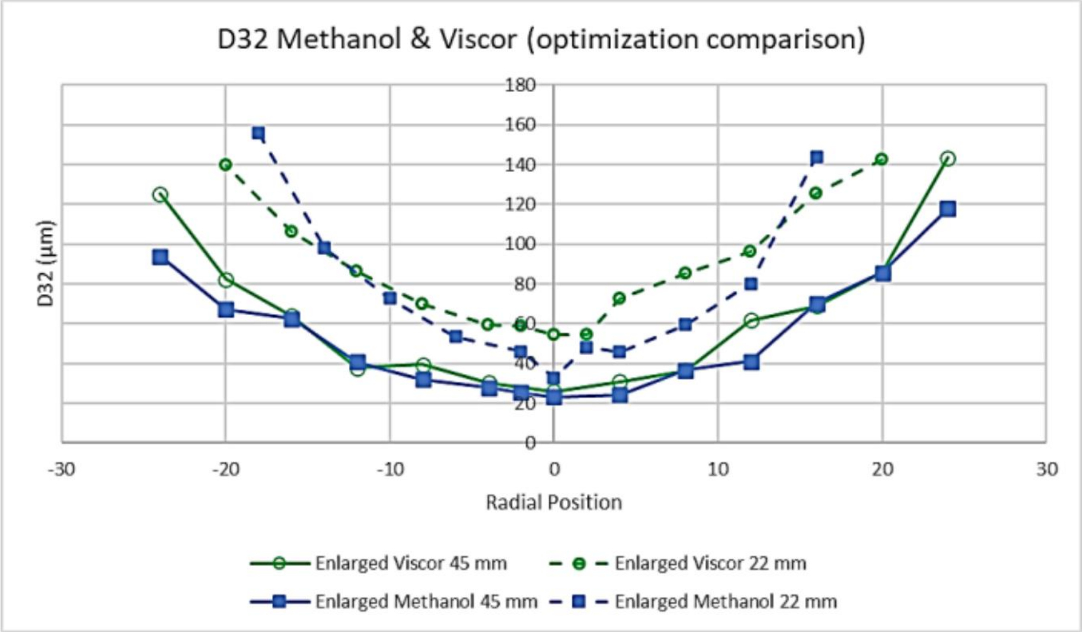
Parameter (X, mg/Nm³)	HVO (X_{HVO} / X_{Eo1})
Dust	0.81
NO_x	1.02
CO	0.83
SO_2	0.02
O_2	1.01
CO_2	0.96

HVO emissions at full load conditions (normalized by fuel oil)

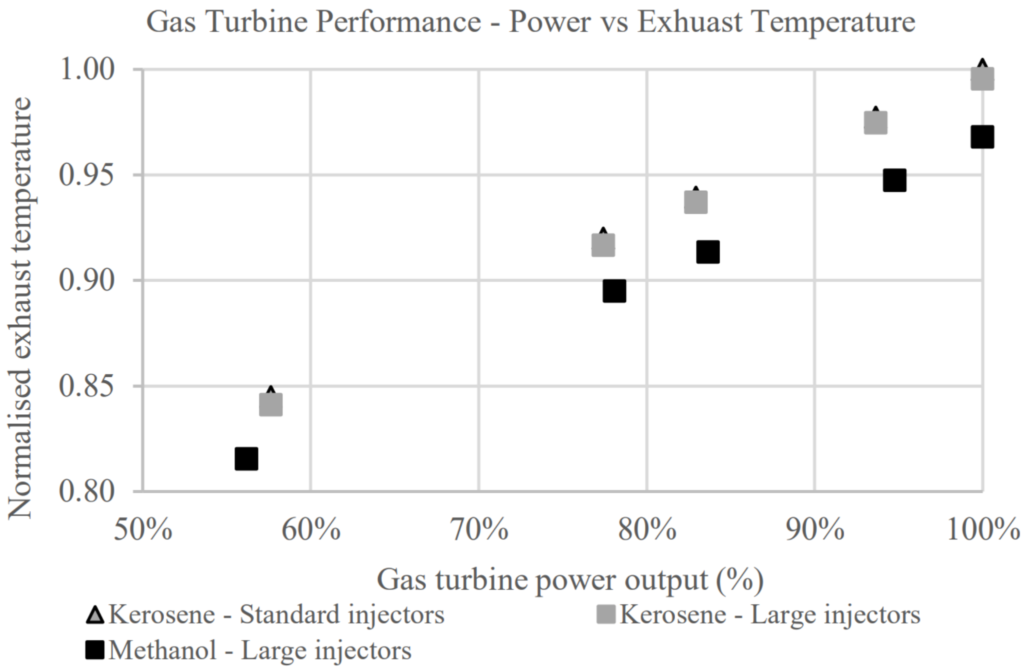
J. Runyon et. Al., PERFORMANCE, EMISSIONS, AND DECARBONIZATION OF AN INDUSTRIAL GAS TURBINE OPERATED WITH HYDROTREATED VEGETABLE OIL, Proceedings of ASME Turbo Expo 2023, June 26-30, 2023, Boston, Massachusetts, USA, GT2023-101972

Examples of GTs using alternative fuels
Siemens – Bio-Methanol – SGT-A20

- Doubling of the flow capacity of the standard dual fuel injectors required



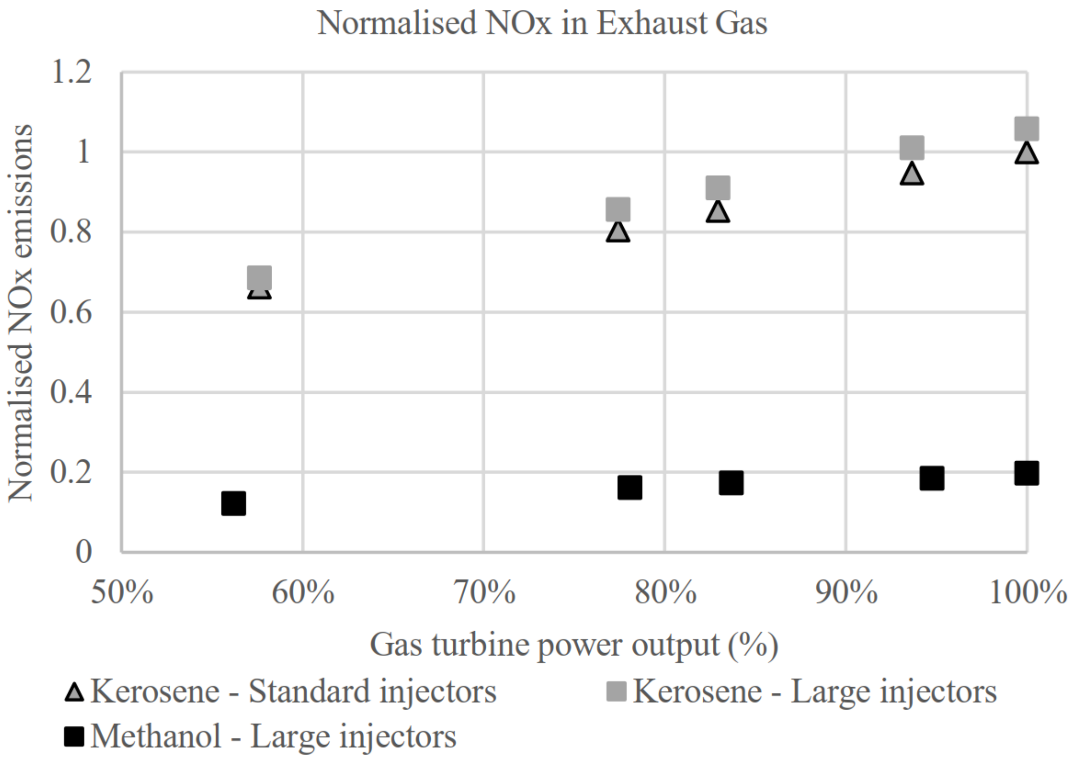
Sauter mean droplet diameter for increased flow capacity injectors for methanol and viscor (calibration fluid) with 22 / 45 mm distance from injector

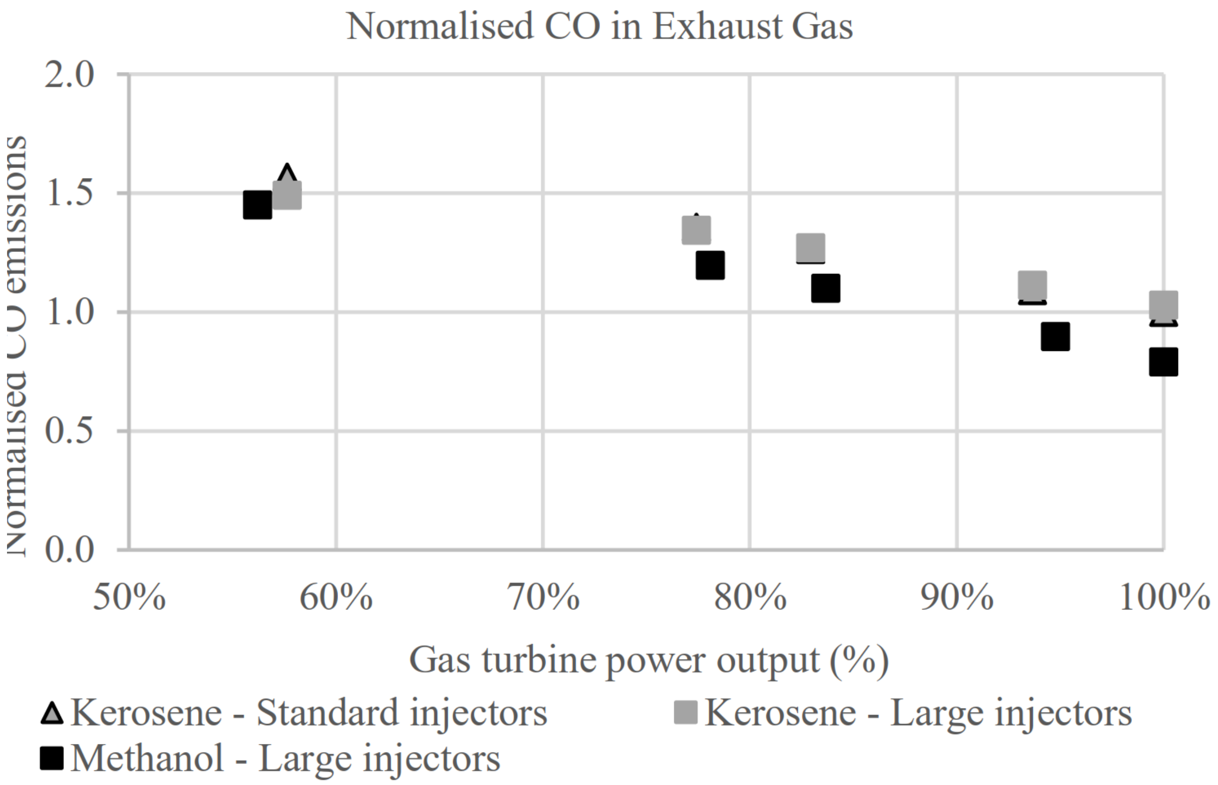


→ Methanol could provide a performance improvement by an increase in power and thermal efficiency

T. Clifford et. al., GREEN METHANOL DEMONSTRATED AS AN ALTERNATIVE FUEL TO DECARBONISE GAS TURBINES, Proceedings of ASME Turbo Expo 2024, June 24-28, 2024, London, UK, GT2024-122266

Examples of GTs using alternative fuels
Siemens – Methanol – SGT-A20





- Lower NO_x emissions due to lower flame temperatures
- Lower soot emissions

T. Clifford et. al., GREEN METHANOL DEMONSTRATED AS AN ALTERNATIVE FUEL TO DECARBONISE GAS TURBINES, Proceedings of ASME Turbo Expo 2024, June 24-28, 2024, London, UK, GT2024-122266

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