# Investigations about co-firing of herbaceous biomass in an Integrated Gasification Combined Cycle


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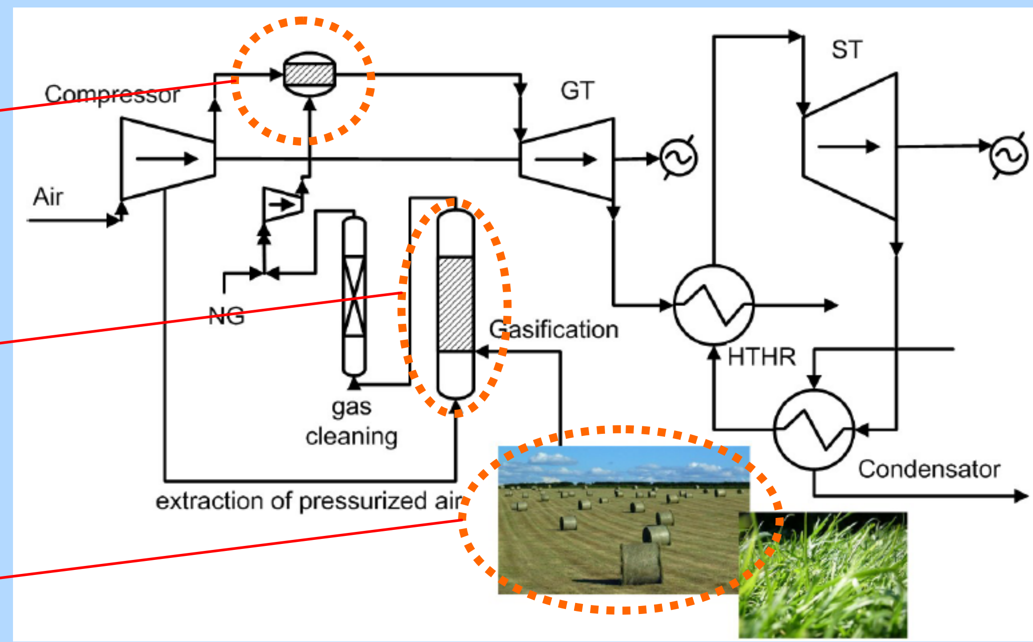
# Approach

- Geographic Information System (GIS) analysis (availability)
- Gasification experiments with grass as fuel (gas quality)
- Combustion experiments with product gas-natural gas mixtures (co-firing characteristics)

combustion characteristics

gas quality

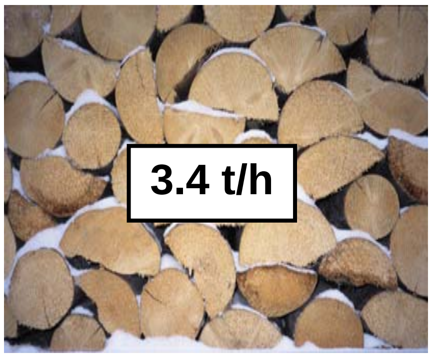
availability



# Motivation

- Swiss Background:
increasing electricity demand and shutdown of old nuclear power plants;
any additional fossil fuel use jeopardizes $CO_2$ emission reduction commitments
- Increased use of biomass for $CO_2$ reduction (as hydropower is fully exploited)
- Limited biomass (wood, straw, grass, hay, …) resources
- Testing grass/hay as additional bio fuel for power production via B-IGCC

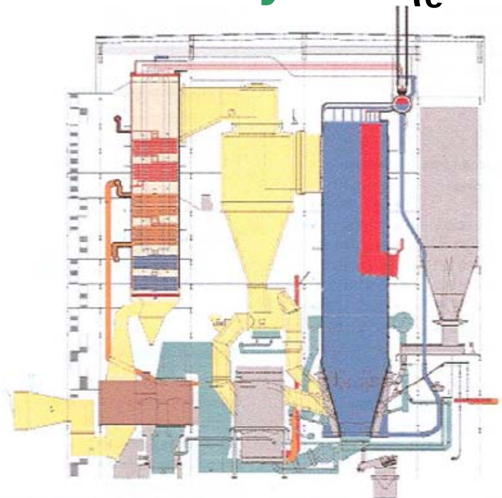
# $CO_2$ MITIGATION VIA CO-FIRING OF BIOMASS



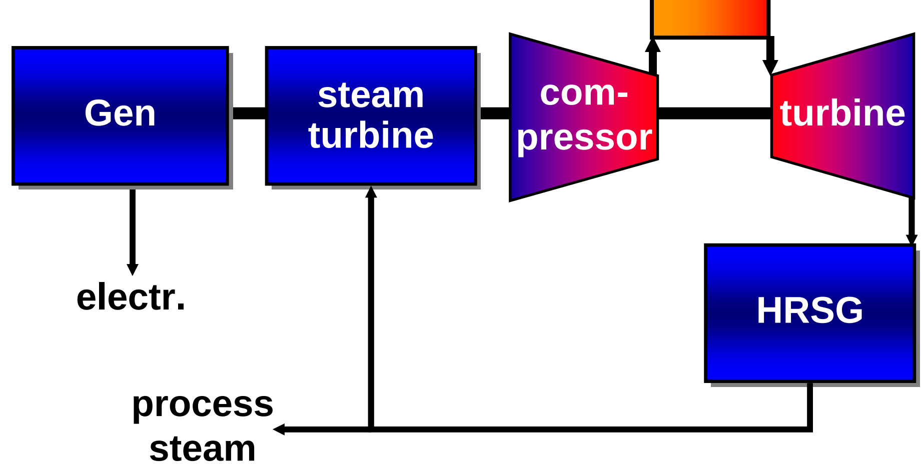

**input for 10 $MW_e$**


Heating value: 30 MJ/kg

**Steam cycle** $\eta_e \approx$ **35%**

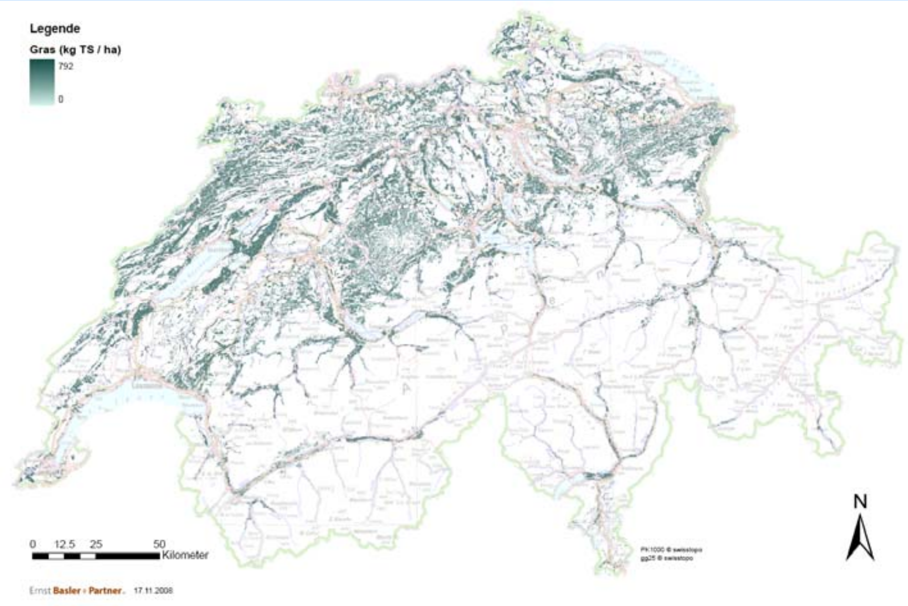


**B-IGCC** $\eta_e \approx$ **49%**

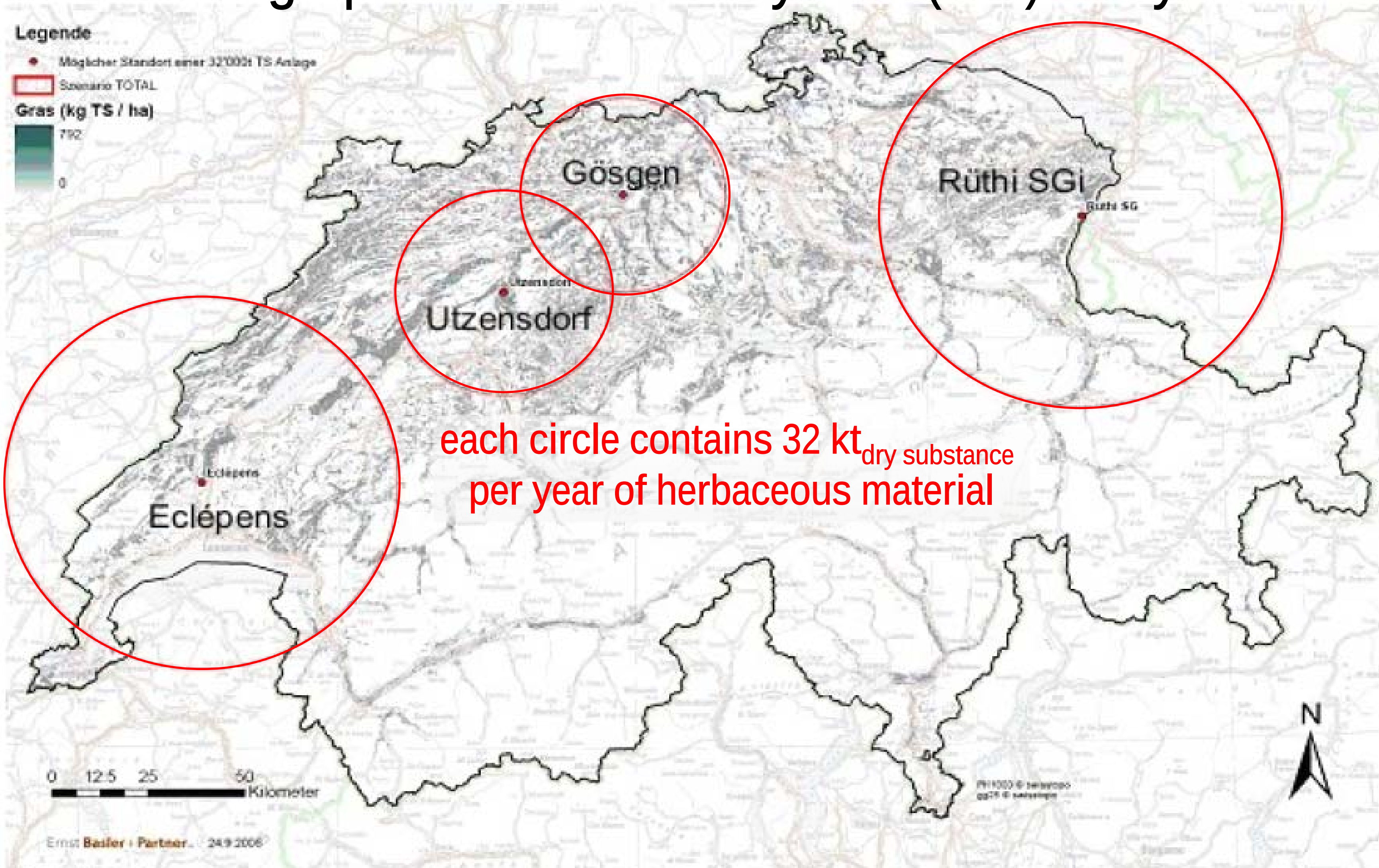


# Geographic Information System (GIS) analysis

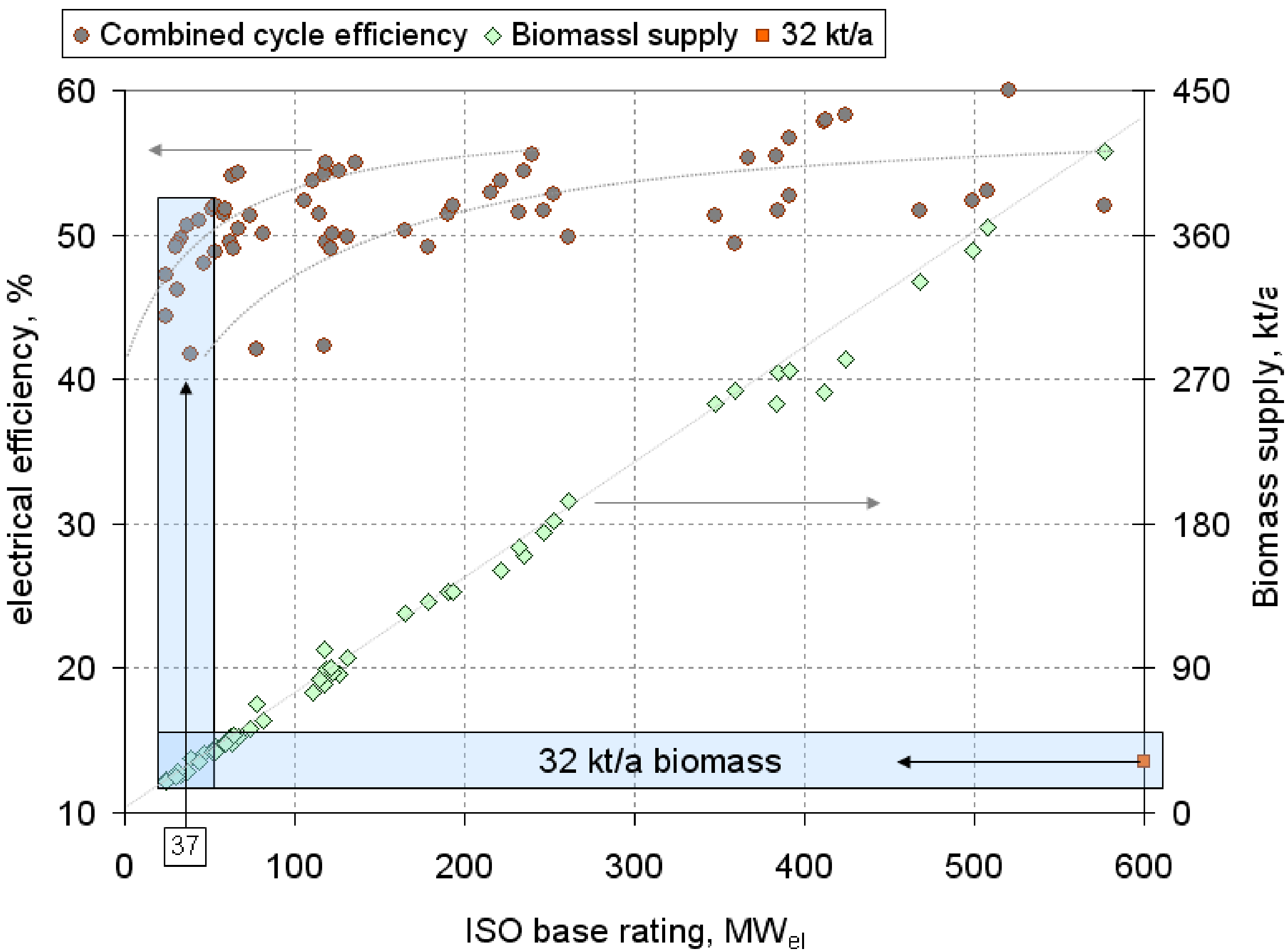
- Basic information material (Swiss „Areal Statistik“): grassy grounds
- Filters imposed: slope, orientation, elevation, precipitation, exposition
- Restrictions applied:
only minor soil quality
(no competition of energy use
vs. food production)
- site selection:
power generation infrastructure
(electricity grid, natural gas pipeline)



# Geographic Information System (GIS) analysis



# $10\%_{LHV}$ co-firing of biomass to natural gas IGCC




6000 operating hours

NG : Biosyngas

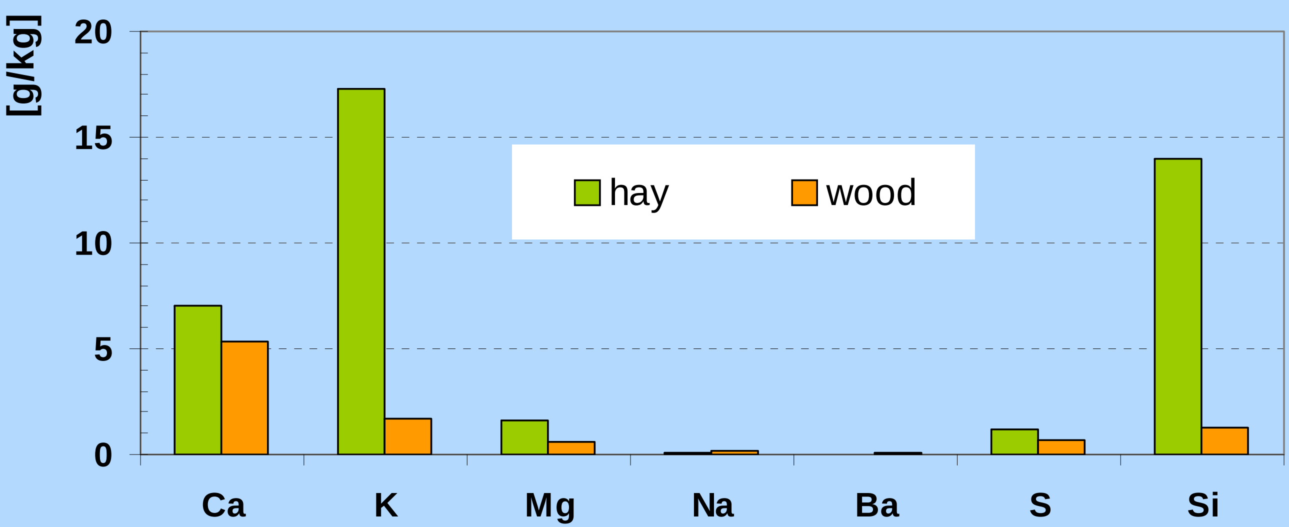
90% : 10% by LHV

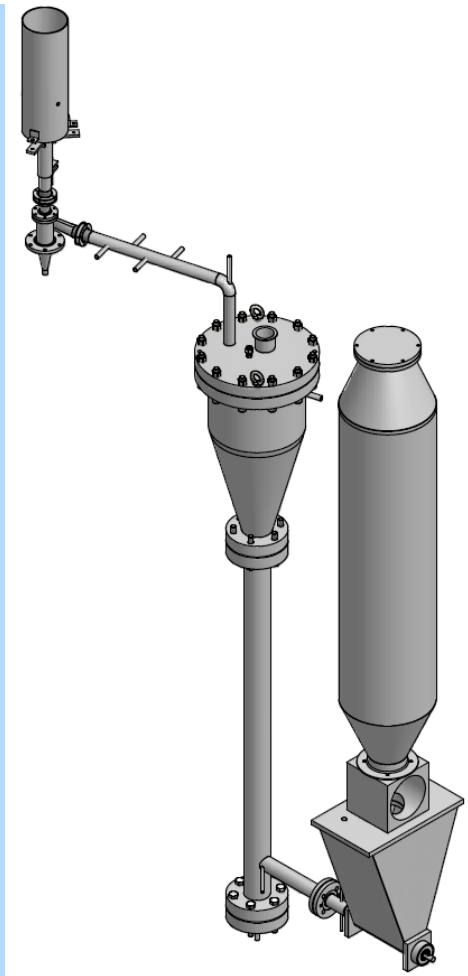
45% : 55% by gas volume

→ LHV mixed gas 21 $MJ/m^3$

→ 37 $MW_{el}$ total

# Gasification of grass: trace species in the fuel

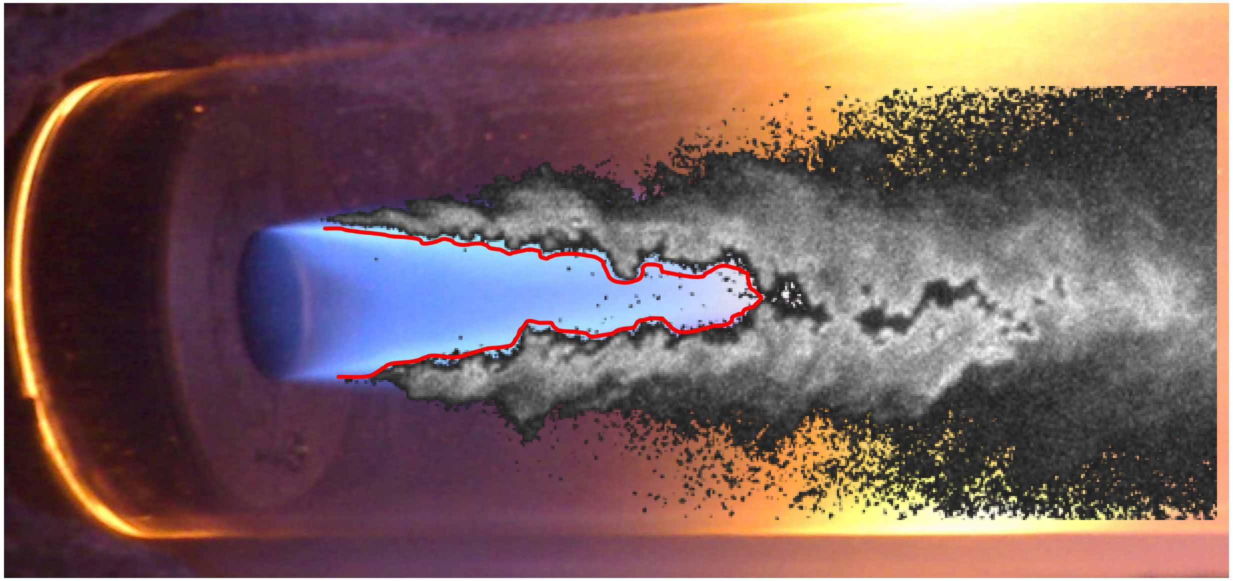
# Fuel quality requirements for gas turbines

| Element | Limit average lit. | Current mixture |
|---|---|---|
| K, Na < $mg/m^3$ | 0.27 | 0.05 |
| V,< $mg/m^3$ | 0.01 | 0.0001 |
| Ca, < $mg/m^3$ | 0.04 | 0.002 |
| Ba, < $mg/m^3$ | NA | 0.006 |
| P, < $mg/m^3$ | NA | 0.006 |
| Cd, < $mg/m^3$ | NA | 0.0001 |


http://ec.europa.eu/

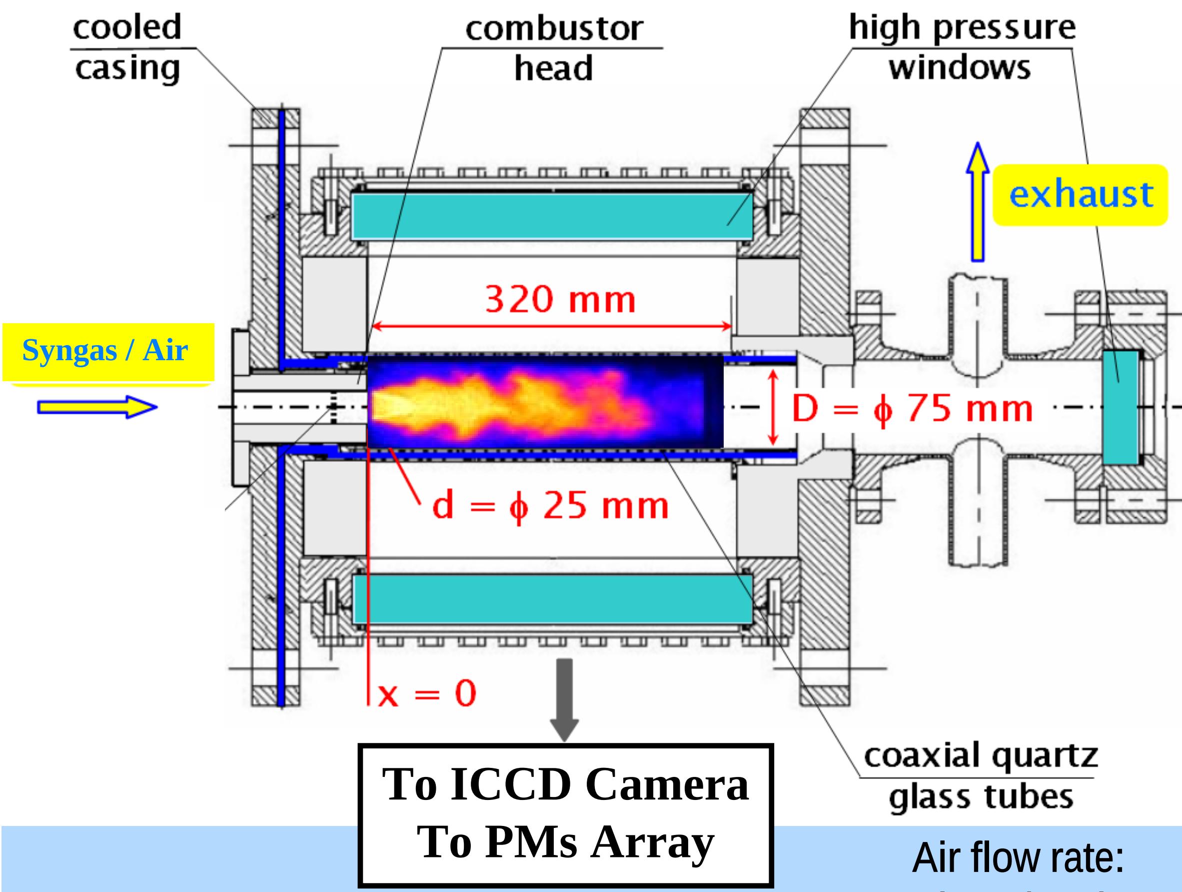
- Co-firing fraction ~ 45% ► dilution by a factor of about 2
- Dilution with combustion air ($\lambda$ > 3 incl. cooling air) ► factor of 35

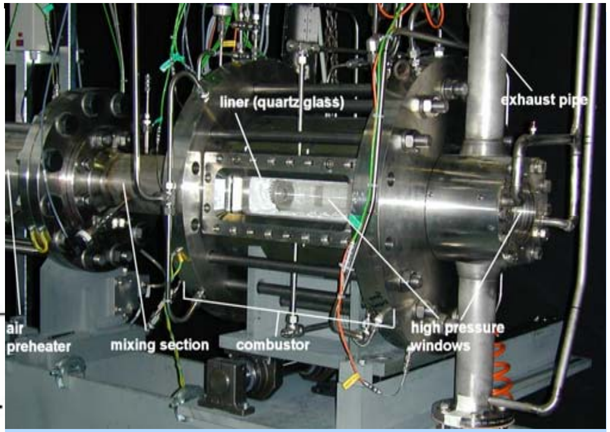
# Flame Front position / Turbulent Flame Speed

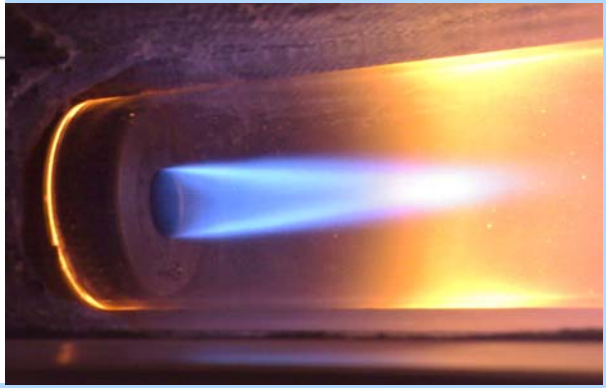


- OH -PLIF
- data processing for flame front surface

# Optically accessible combustion test rig (LIF, chemiluminescence)

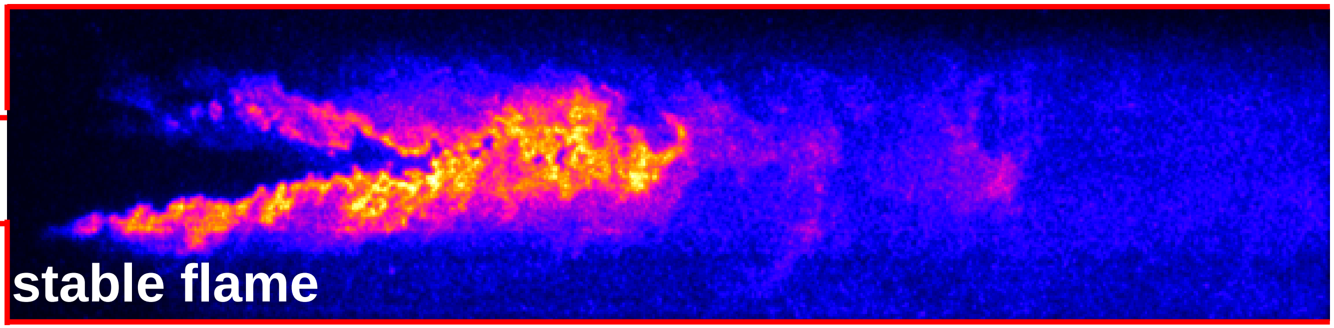


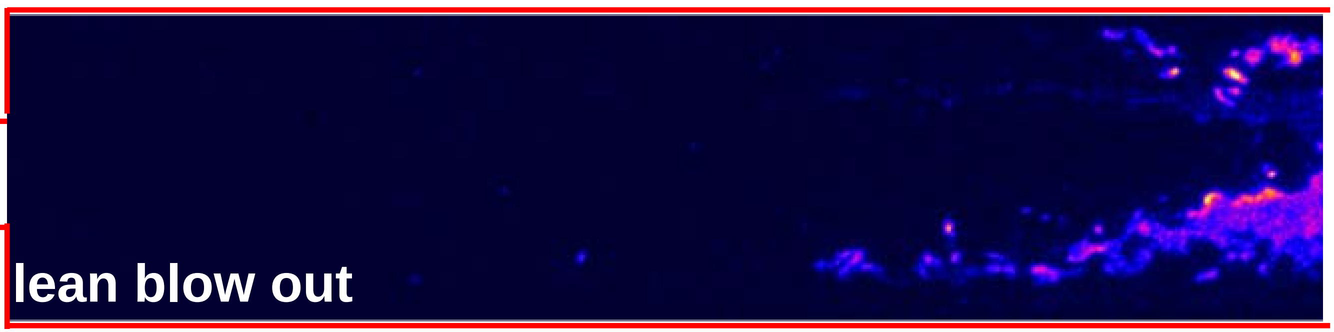



| | |
|---|---|
| Air flow rate: | max. 270 g/s |
| Air preheating temperature: | max. 823 K |
| Pressure: | max. 30 bar |
| Thermal power: | max. 400 kW |

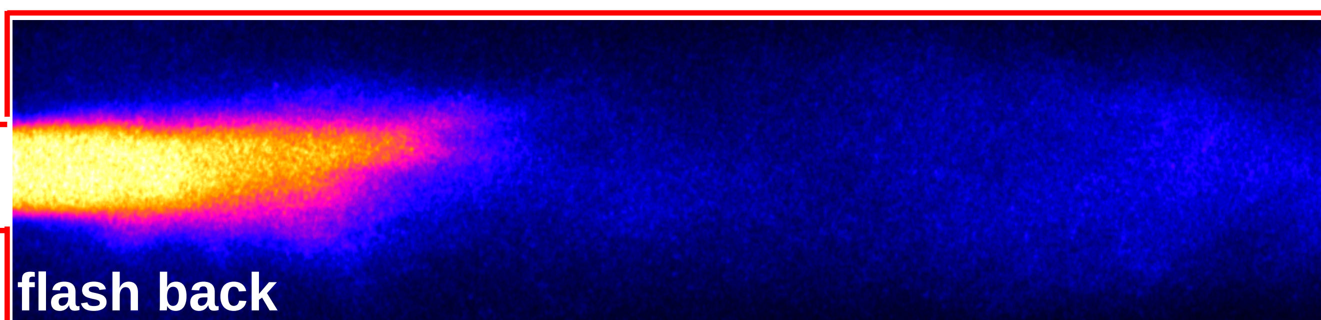
# Varying the equivalence ratio $\phi = \left(\frac{F}{A}\right) \Big/ \left(\frac{F}{A}\right)_{st}$




shear layer stabilized due to sudden expansion geometry



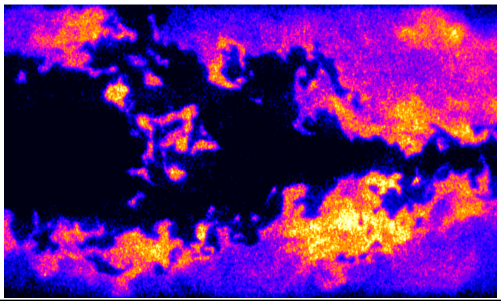

lifted flame




flame speed overtakes flow velocity locally and/or globally

# Post processing

**single shot OH-PLIF**

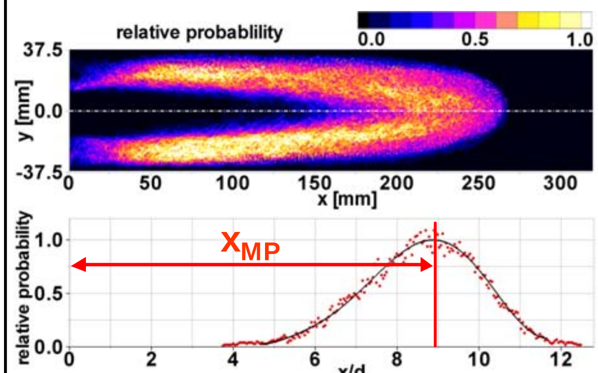


**flame front contour**

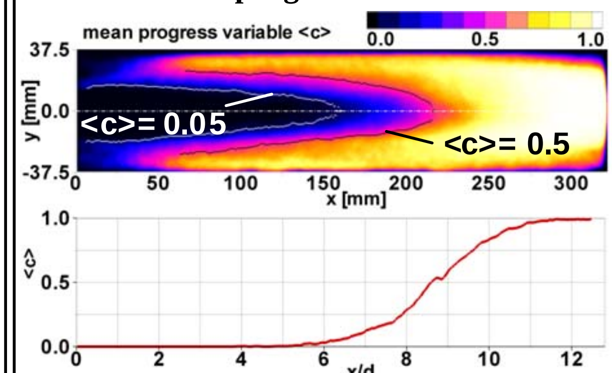
**progress variable**

**binary image**

**flame front statistics**



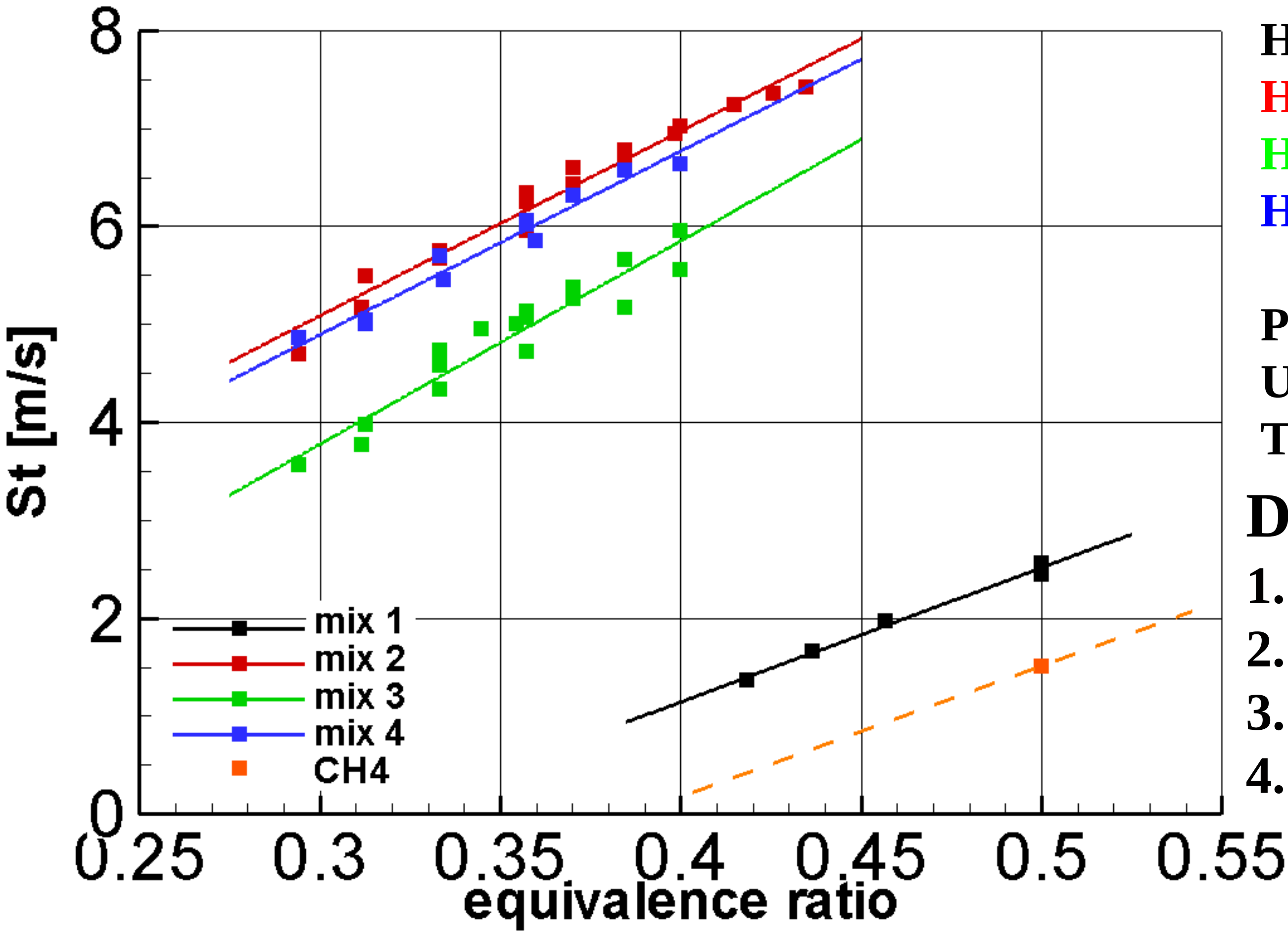

**mean progress variable**




**E., Boschek et al.,**
**FUEL VARIABILITY EFFECTS ON TURBULENT, LEAN PREMIXED FLAMES AT HIGH PRESSURES,**
**GT2007-27496, ASME Turbo Expo 2007**

$$\rho_0 A_0 \; u_0 \quad = \quad \rho_f \; A^{av} \; s_T$$

# $S_T$: mixture and ER dependence



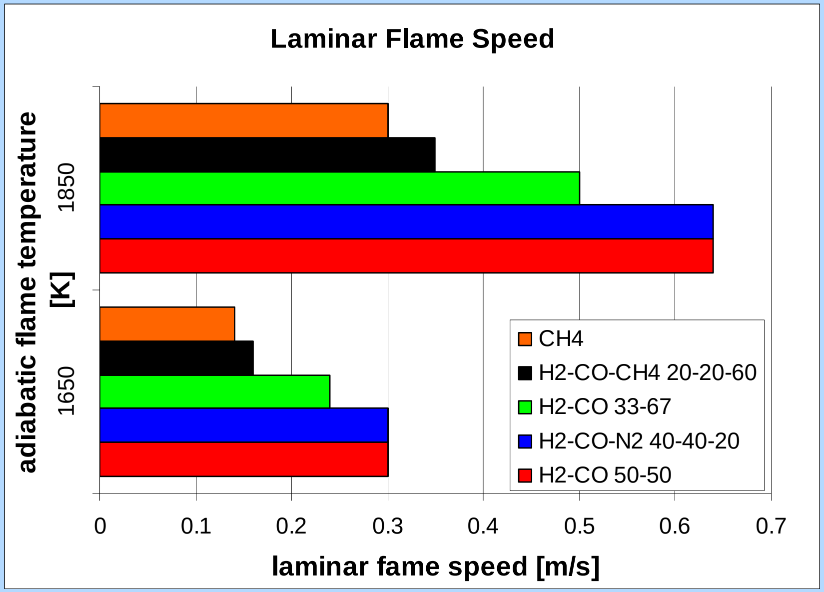

**H2-CO-CH4 20-20-60 - black**
**H2-CO 50-50 - red**
**H2-CO 33-67 - green**
**H2-CO-N2 40-40-20 - blue**

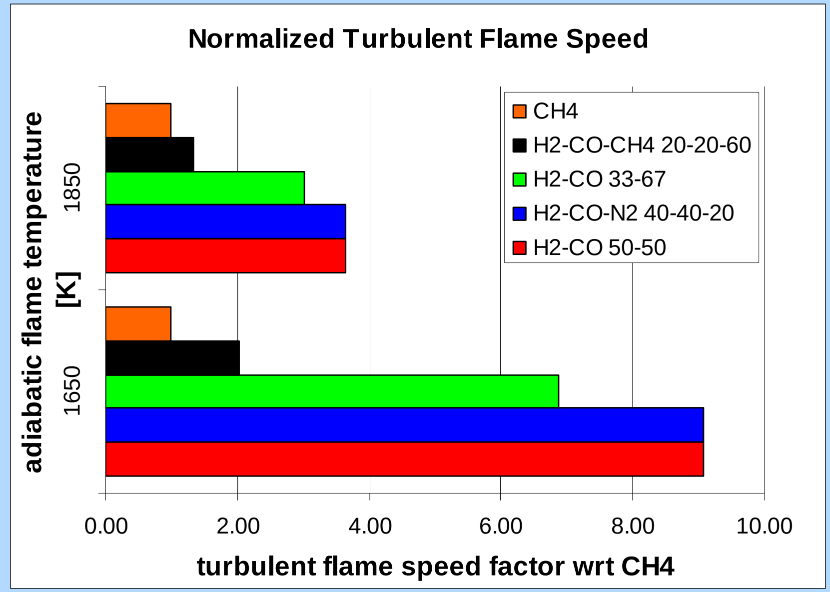
**P = 5 bar**
**$U_{bulk}$ = 40 m/s**
**$T_{ph}$ = 673K**

## Differences depend on:

1. **Flame temperature**
2. **Chemistry**
3. **Turbulence**
4. **Diffusivity (H2 %)**

# Flame Speed



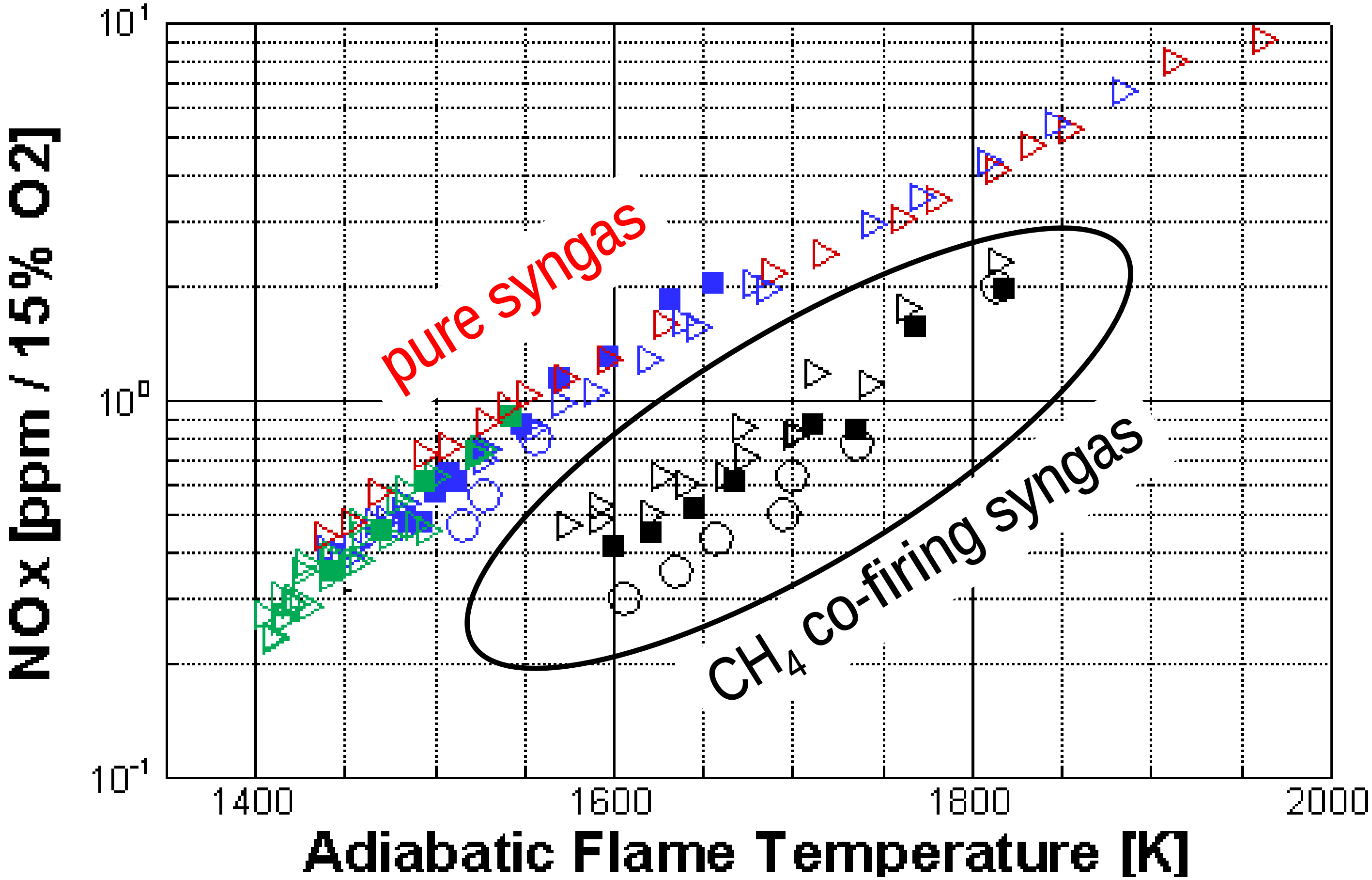




With increasing hydrogen content the fuel consumption rate (laminar burning velocity) is enhanced, similar for both temperatures

The ability to propagate faster is much more pronounced for turbulent flames and varies significantly with temperature (due to the specific physical properties of $H_2$)

- co-firing looks achievable for a GT requiring only minor modifications
- a fully flexible engine represents still a major challenge

# $NO_x$ emissions depend on gas mixture and temperature




Lower NOx for co-firing mixture: Different pathway for $C_xH_y$ oxidation

# Conclusions

- ► Grass is an available fuel for gasification
  - ► Amount in CH is significant but the security of supply is critical as land is privately owned by small farmers
- ► Gasification experiments proved stable operation at certain conditions
  - ► Contaminants in the gas phase are below the limits
  - ► Ammonia content in syngas < ca. 450 ppmv to limit $NO_x$
- ► Combustion with proposed mixtures (co-firing with 10% of LHV) seems possible with only minor adaptation of burner and combustion chamber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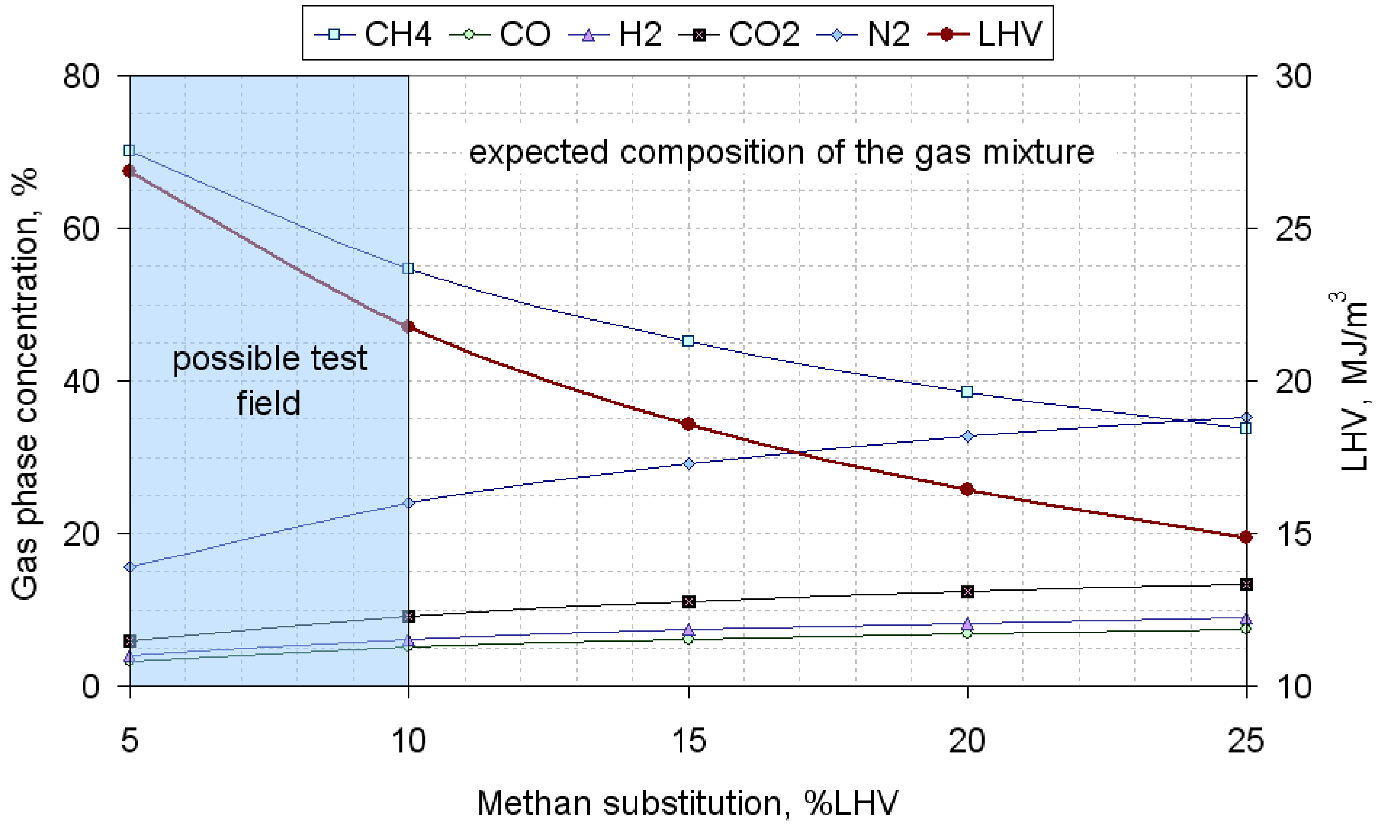
ALSTOM Power Switzerland and Swiss Federal Office of Energy

# Background slides

# Gas mixture composition



# Experimental matrix

green: stable process

yelllow: unstable process

red: not conducted because of risk of slagging

gray: not yet conducted

**dolimite:** tensile strength is too weak for fluidized bed gasification (Mohs hardness 4)

**SiO2:** shows melting behaviour at 750°C because of alkali influence

**Al2O3:** unfavorable carbon conversion

**Olivin:** NaN