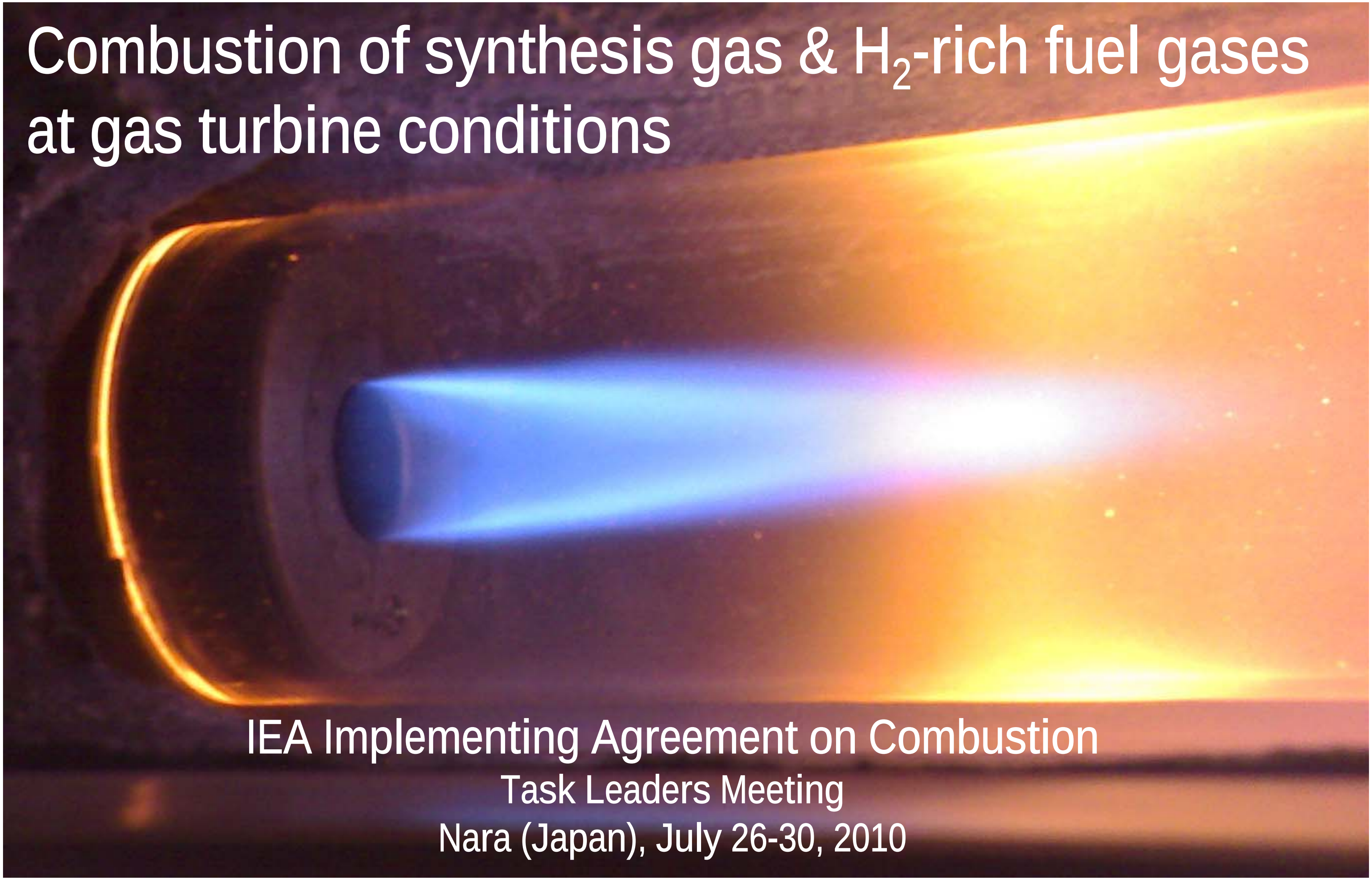
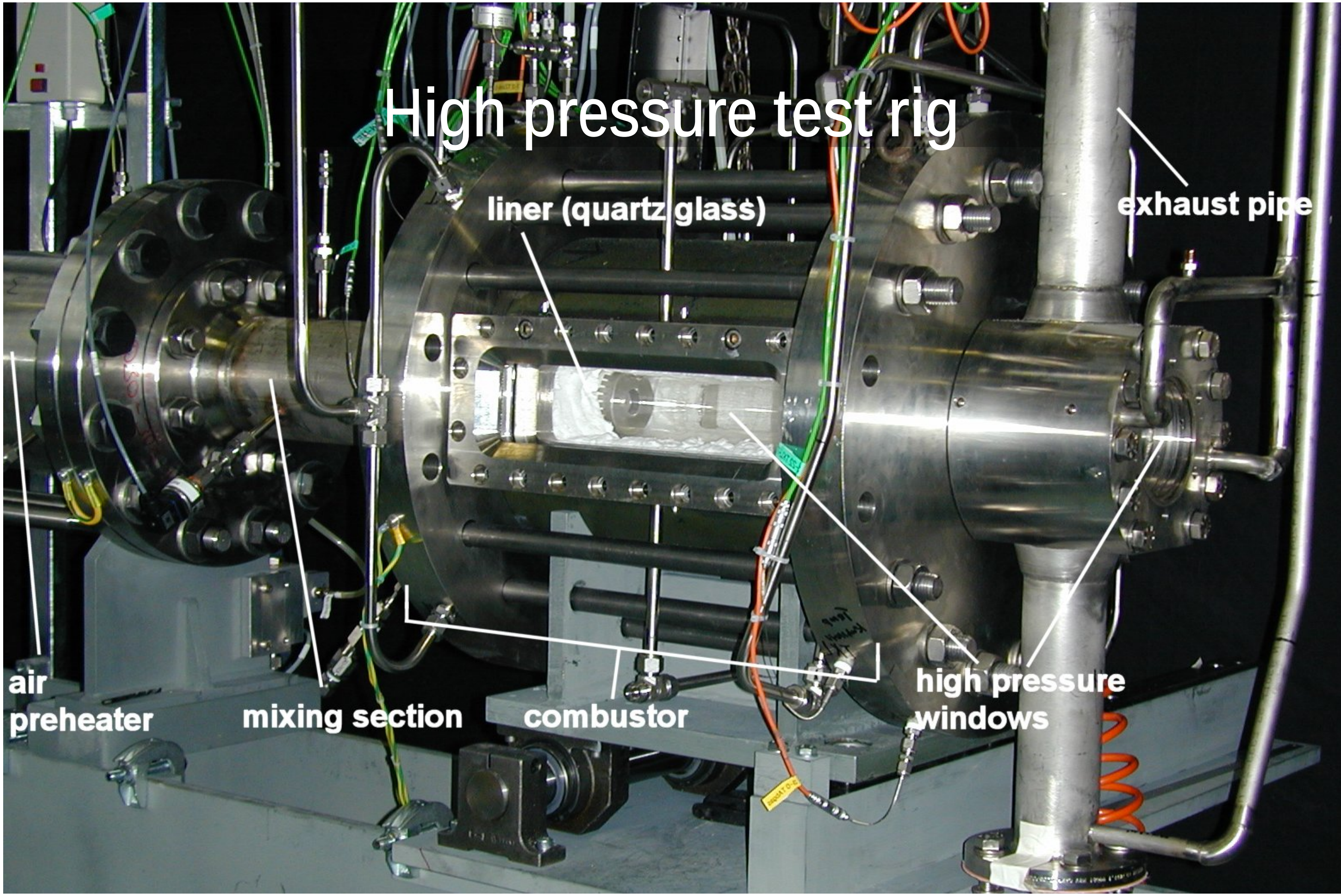


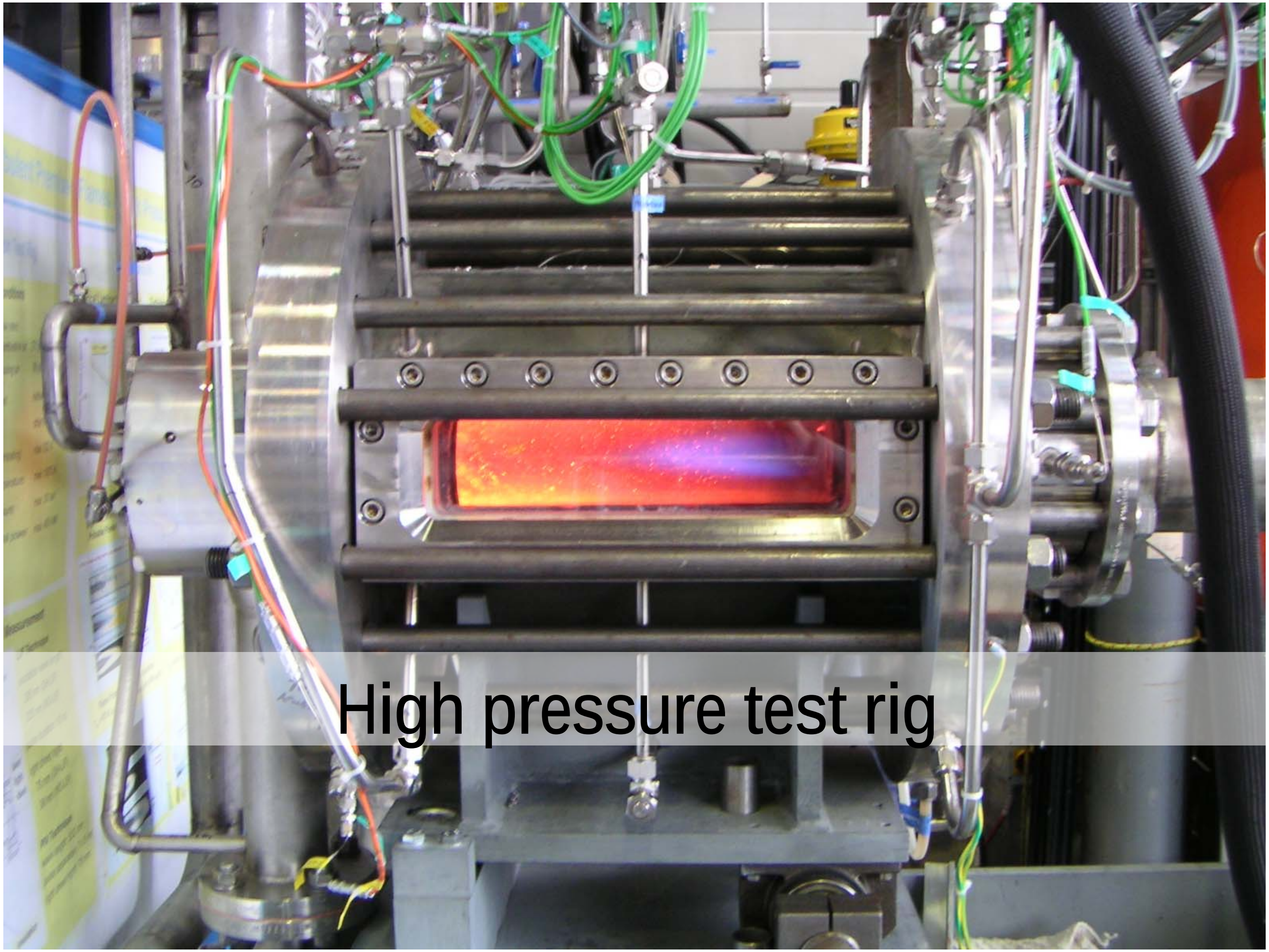
Combustion of synthesis gas & H_2-rich fuel gases at gas turbine conditions

IEA Implementing Agreement on Combustion

Task Leaders Meeting

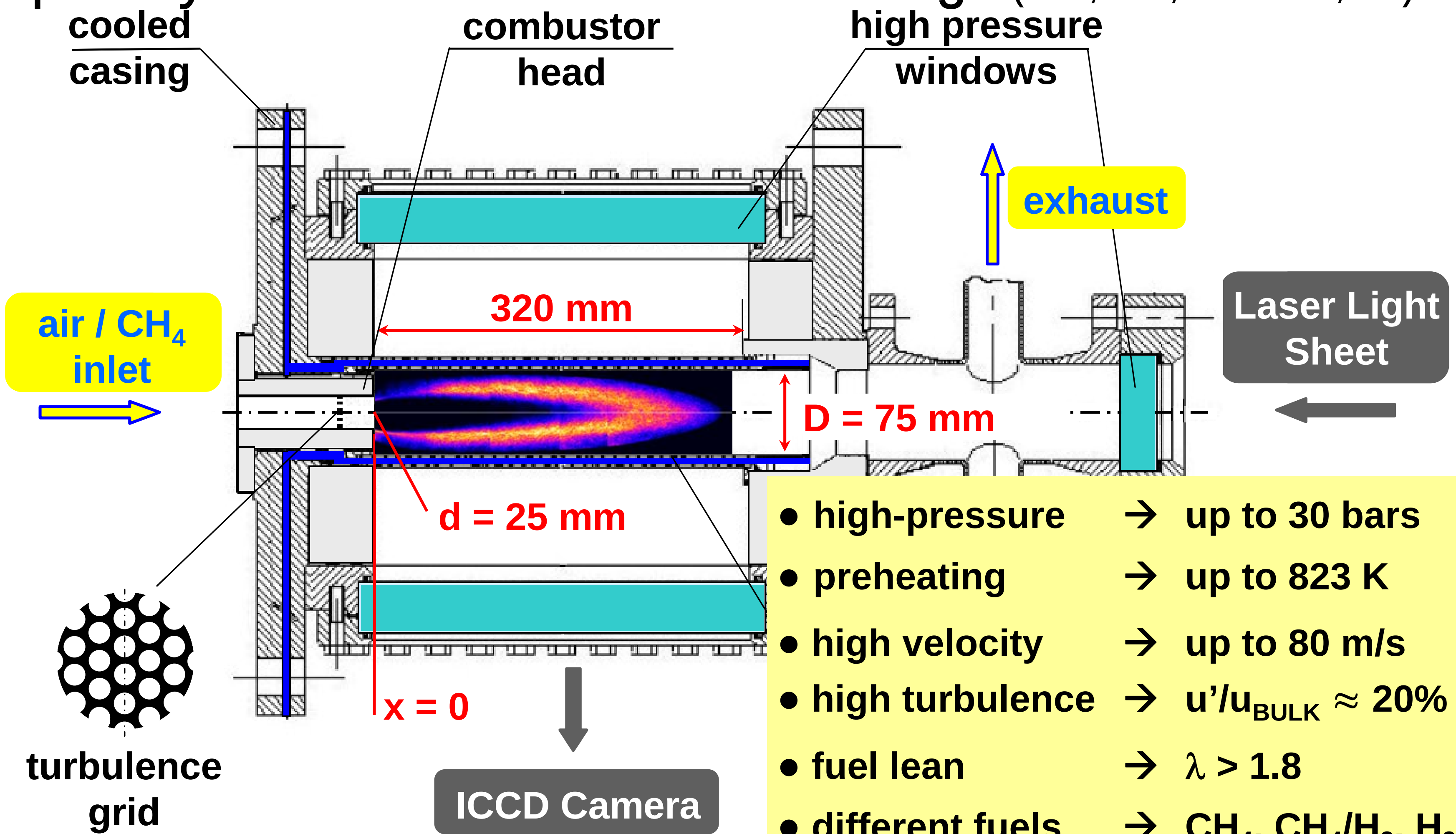
Nara (Japan), July 26-30, 2010


High pressure test rig
liner (quartz glass)
exhaust pipe
air
preheater
mixing section
combustor
high pressure
windows



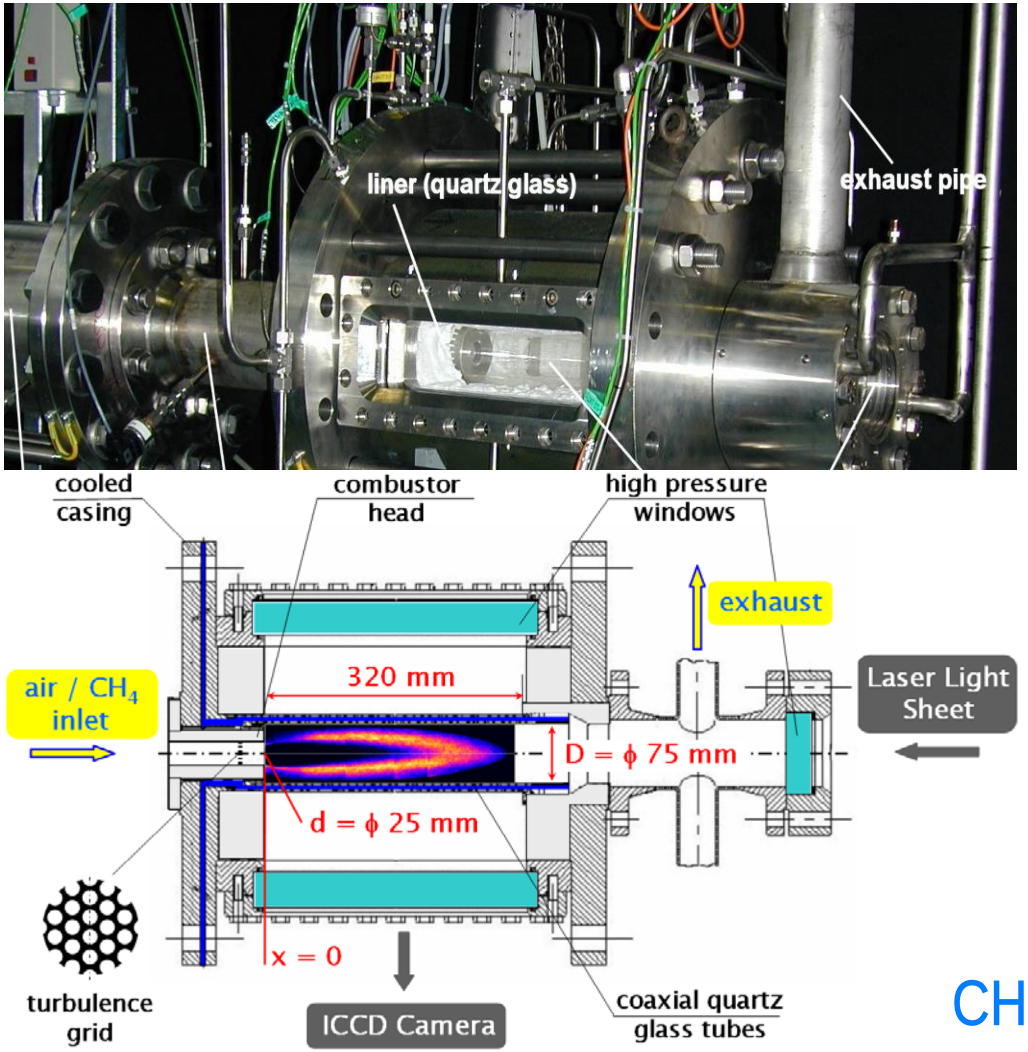
High pressure test rig

Optically accessible combustion test rig (LIF, CL, Raman, ...)



- high-pressure → up to 30 bars
- preheating → up to 823 K
- high velocity → up to 80 m/s
- high turbulence → $u'/u_{BULK} \approx 20\%$
- fuel lean → $\lambda > 1.8$
- different fuels → CH_4, CH_4/H_2, H_2, CH_4/C_2^+, CO/H_2

Turbulent Lean Premix Combustion



Objectives

lean premixed combustion technology for gas turbines

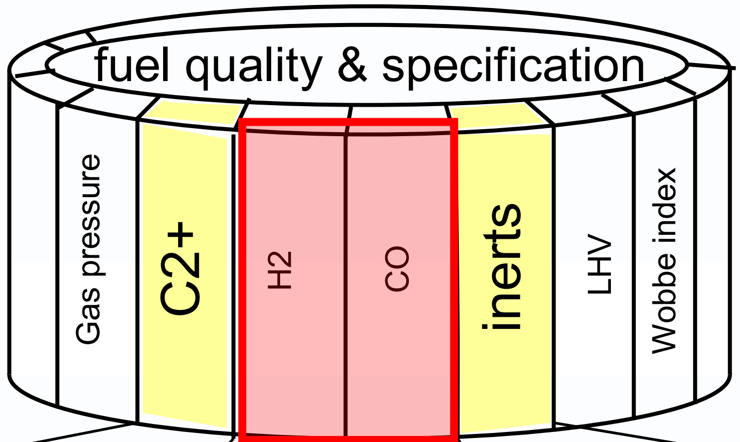
- **enhancing flame stability**
  (extension of lean blow-out limit;
  prevent flashback;
  reduce flame front fluctuations)
- **lower NO_x emissions**
  (improved fuel/air mixing)

flame characteristics of lean premixed flames

- **influence of turbulence**
- **broad fuel spectrum**

CH_4, CH_4/H_2, CH_4/C_3H_8 , CO/H_2 , H_2

Combustion Impact of Gas Composition



High Hydrocarbons "C2+"

- Ethane C_2H_6
- Propane C_3H_8
- Butane C_4H_{10}
- C5, C6, ..

"Inerts"

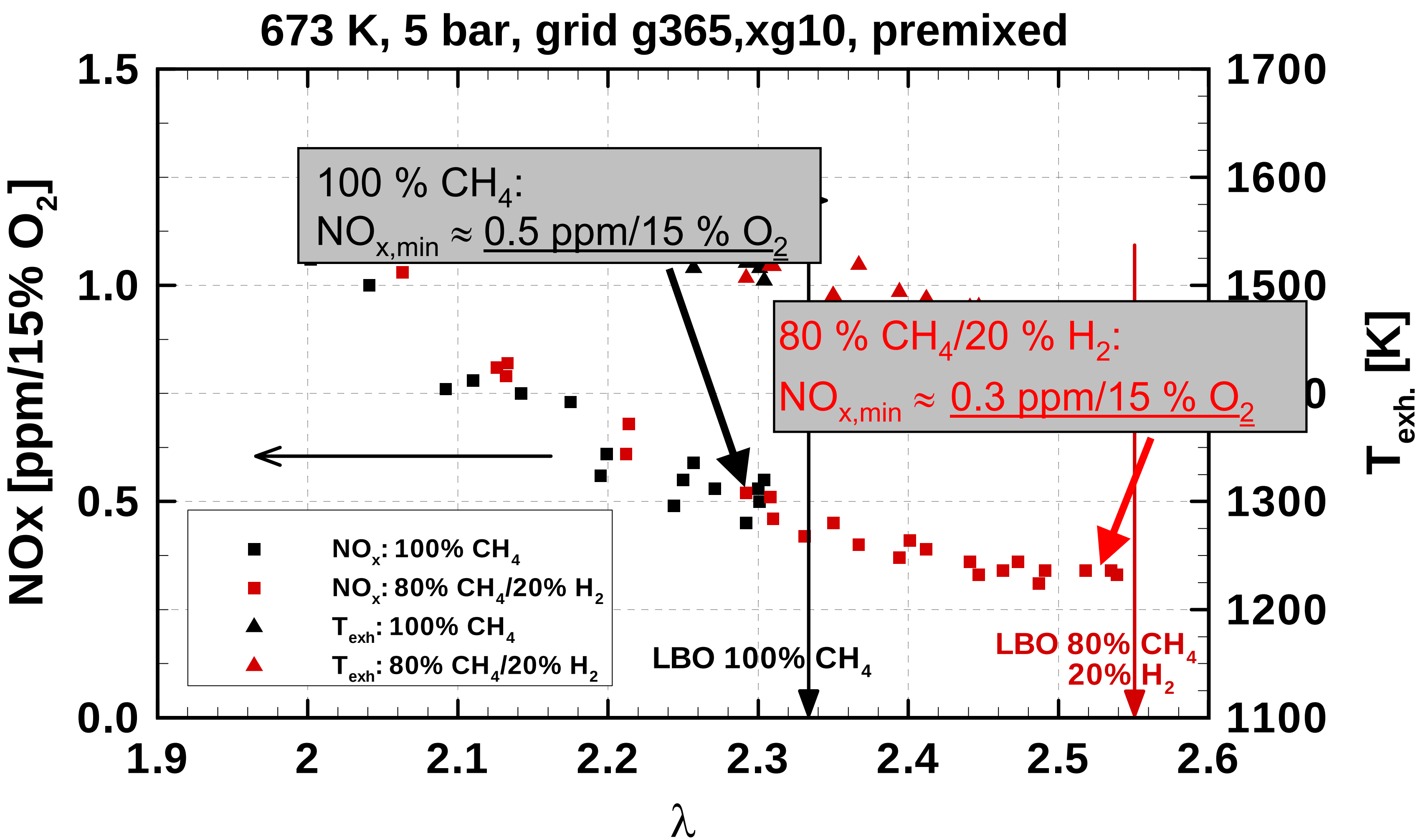
- Nitrogen N_2
- Carbon Dioxide CO_2

- Reactivity
  - flashback
  - ignition
  - flammability limits
  - emissions

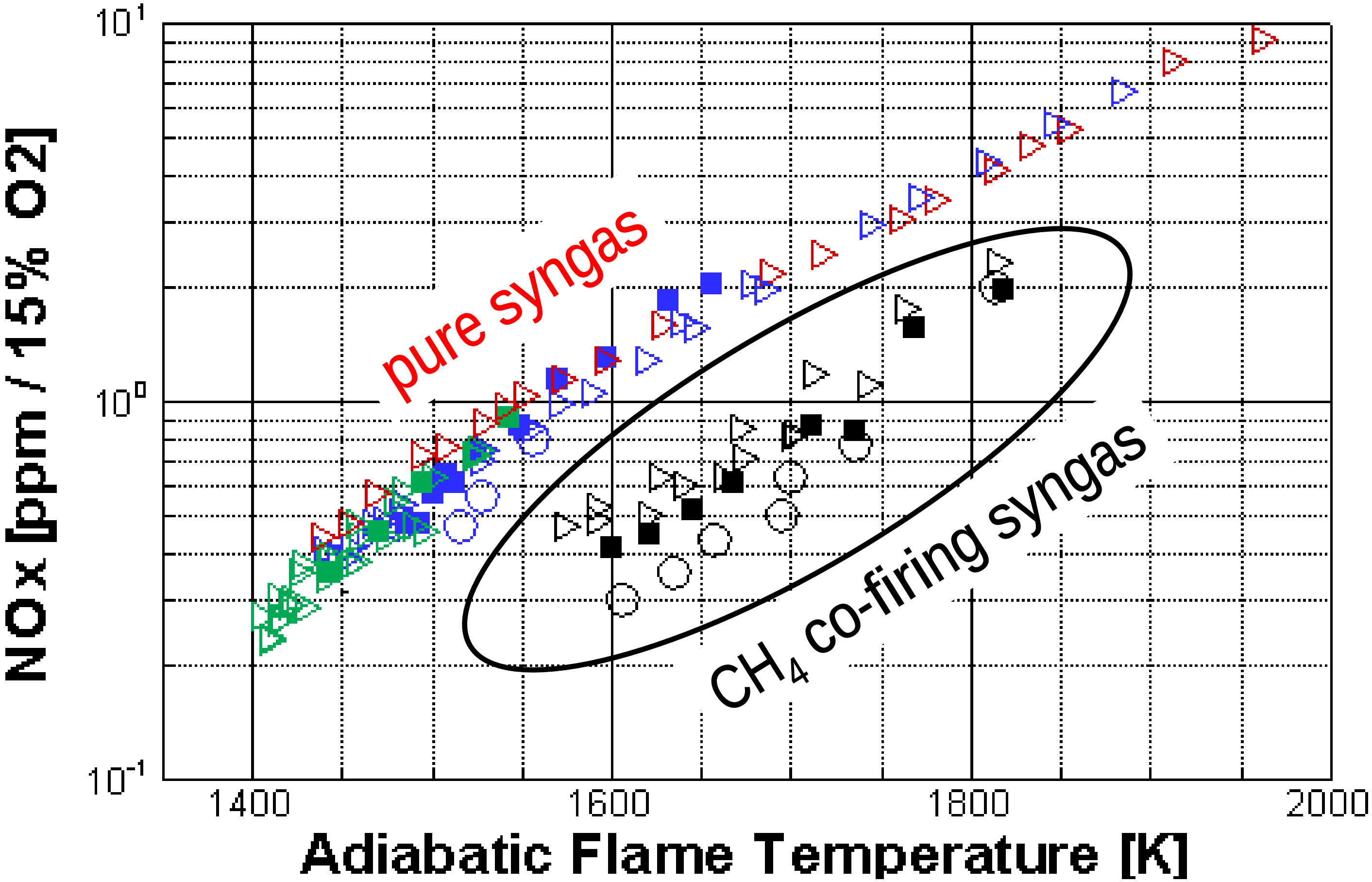
- Volumetric air/fuel ratio
  - injector design
  - fuel-air mixing
  - combustion stability

Source: original slide from ALSTOM (modified)

NO_x emissions



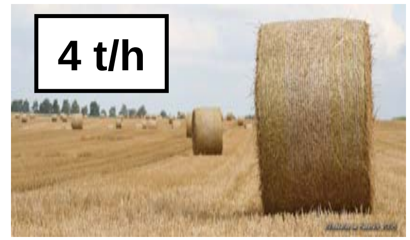
NO_x emission depend on gas mixture and temperature



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

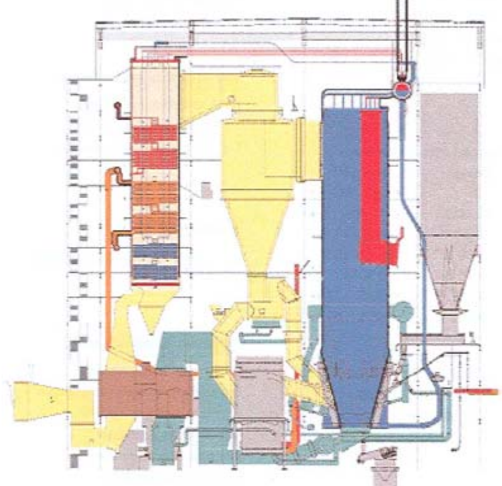
CO_2 MITIGATION VIA CO-FIRING OF BIOMASS

input for 10 MW_e

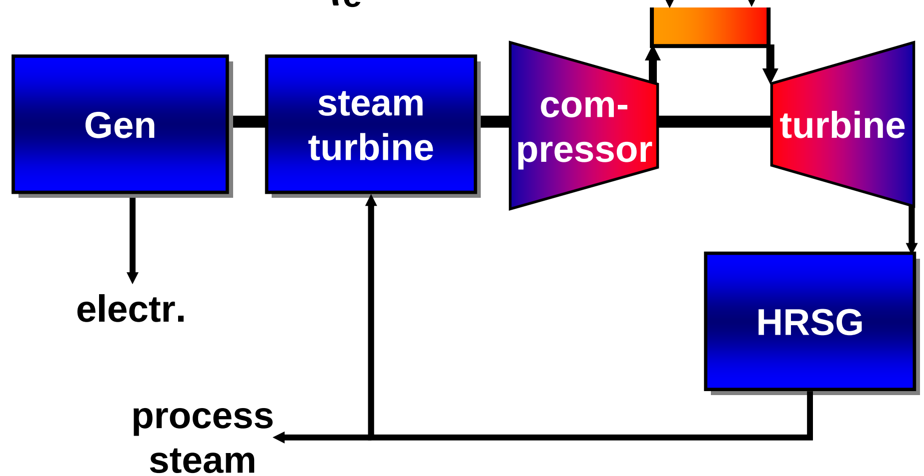


Heating value: 18 MJ/kg

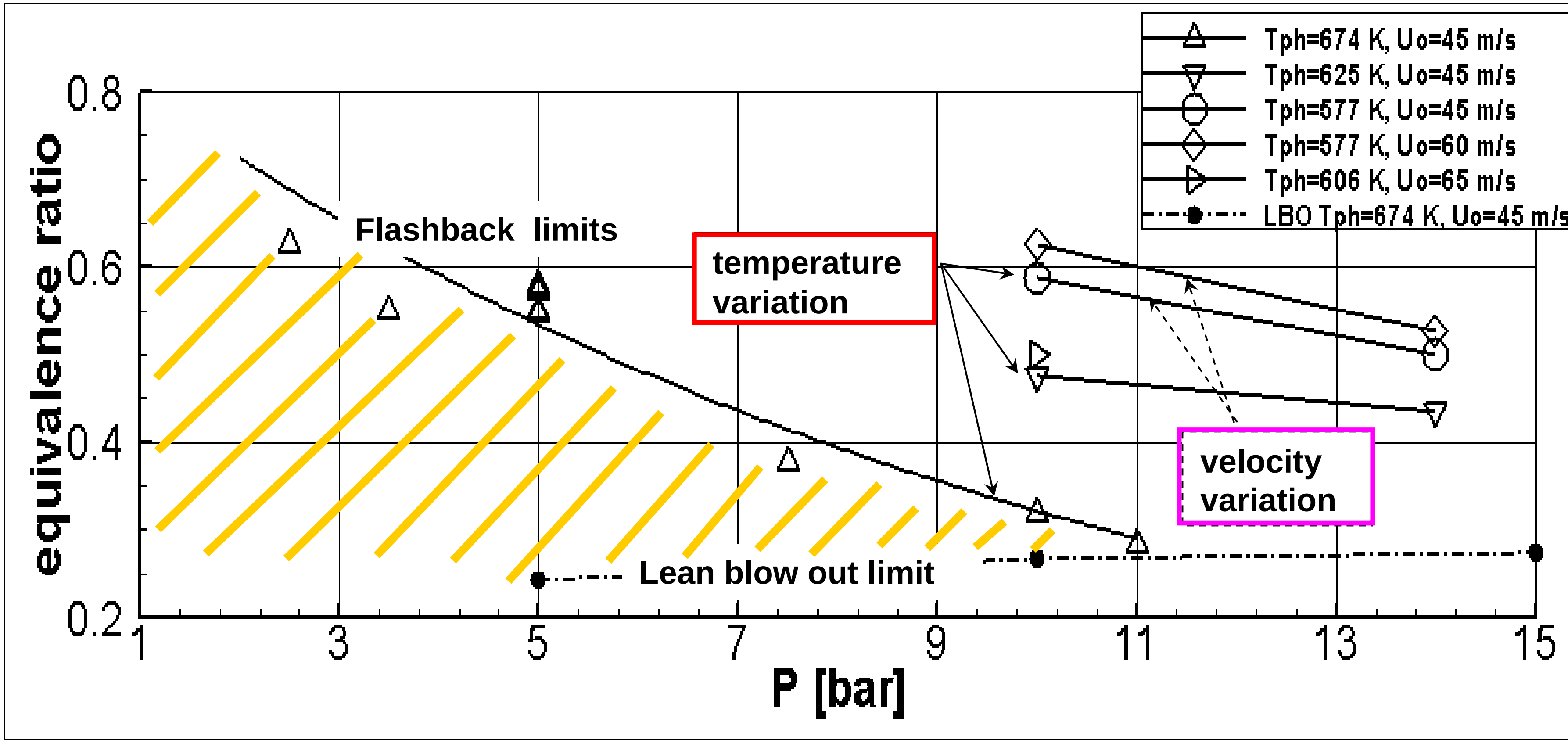
Steam cycle $\eta_e \approx$ **35%**



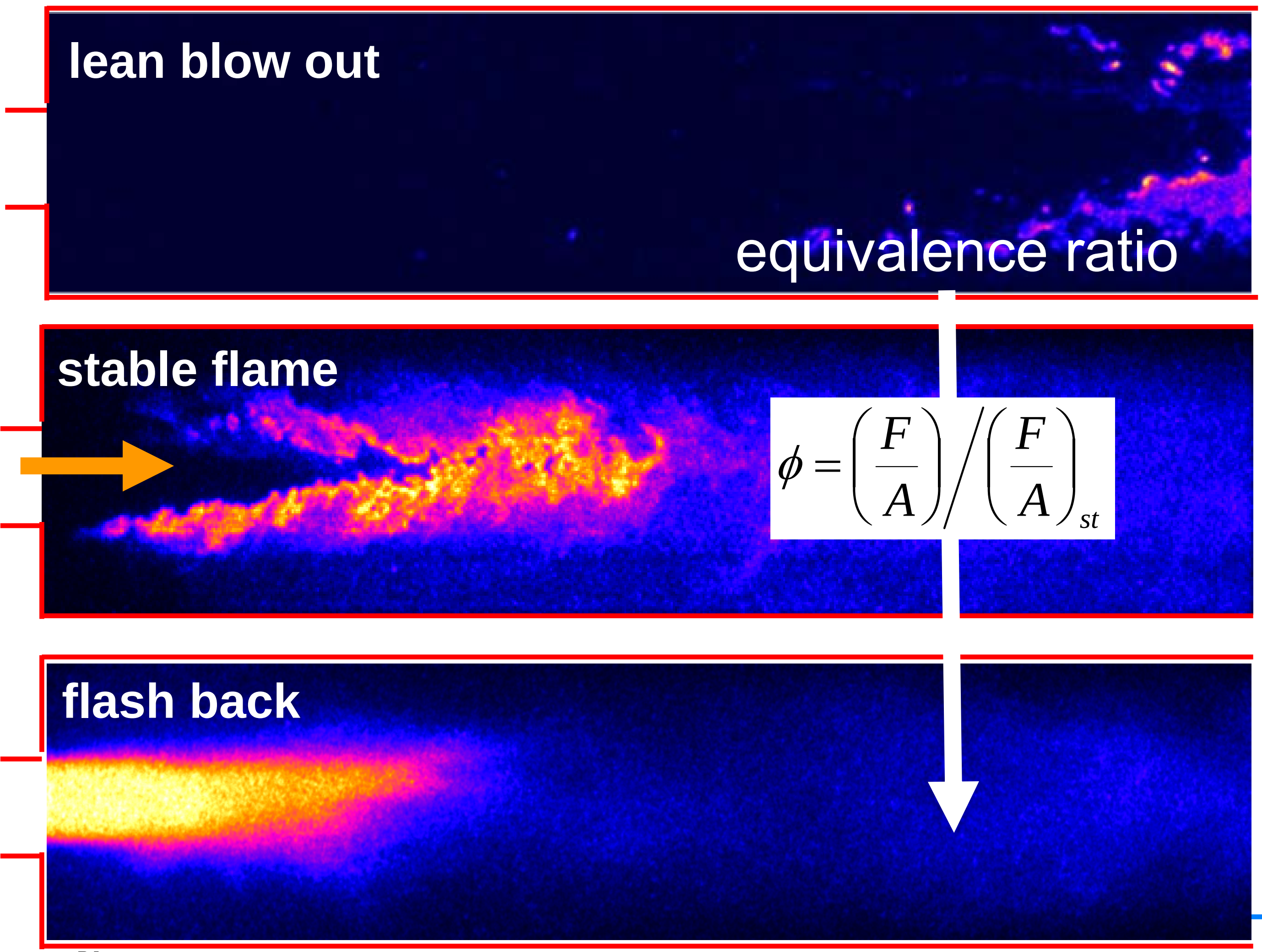
B-IGCC $\eta_e \approx$ **49%**



Operational window (syngas: 50% H_2 / 50% CO)



Operational window (syngas: 50% H_2 / 50% CO)



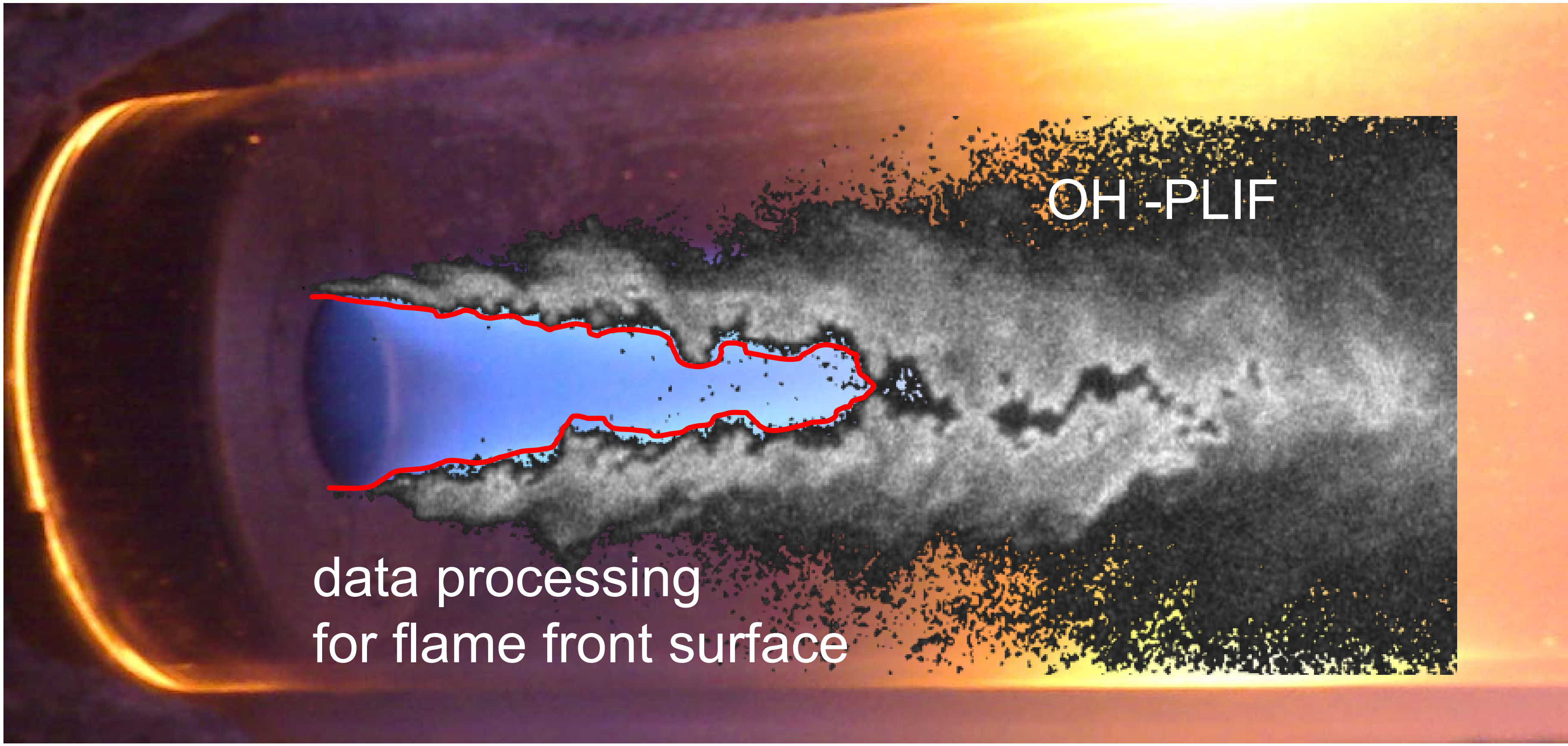
$$\phi = \left(\frac{F}{A}\right) \Big/ \left(\frac{F}{A}\right)_{st}$$

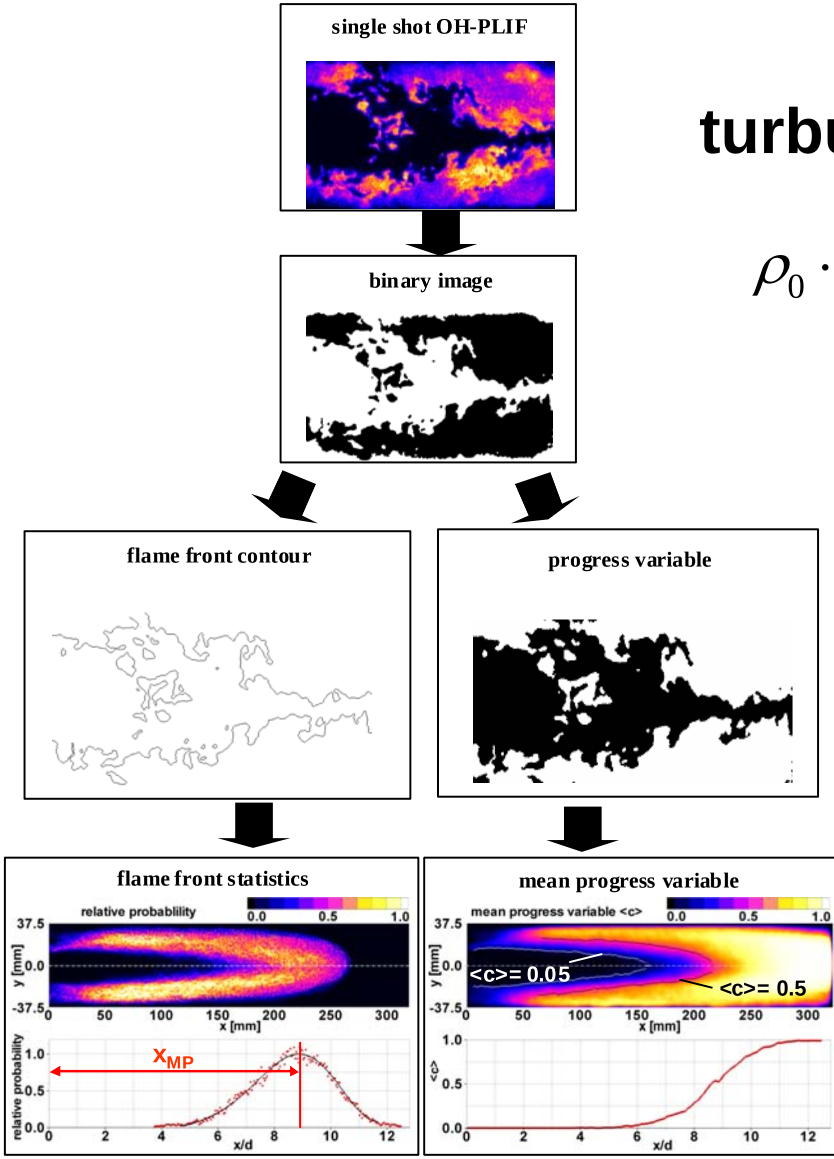
lifted flame

flame stabilized close to sudden expansion

flame speed overtakes flow velocity locally and/or globally

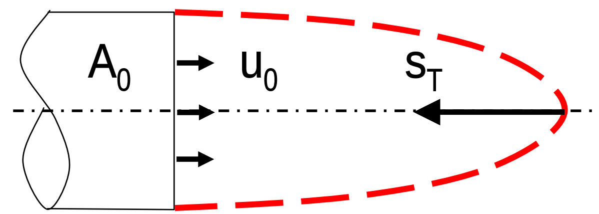
Flame Front Detection & Characterization



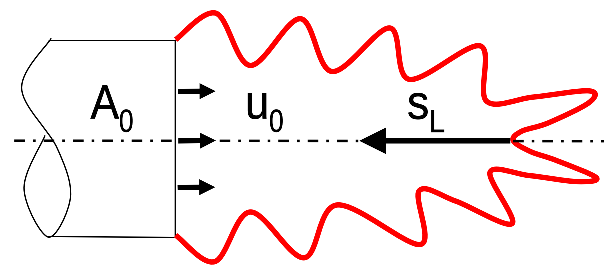


How to determine turbulent flame speed (S_T) data

$$\rho_0 \cdot A_0 \cdot U_0 = \rho_0 \cdot A_f^{av} \cdot S_T = \rho_0 \cdot A_f^{inst} \cdot S_L$$

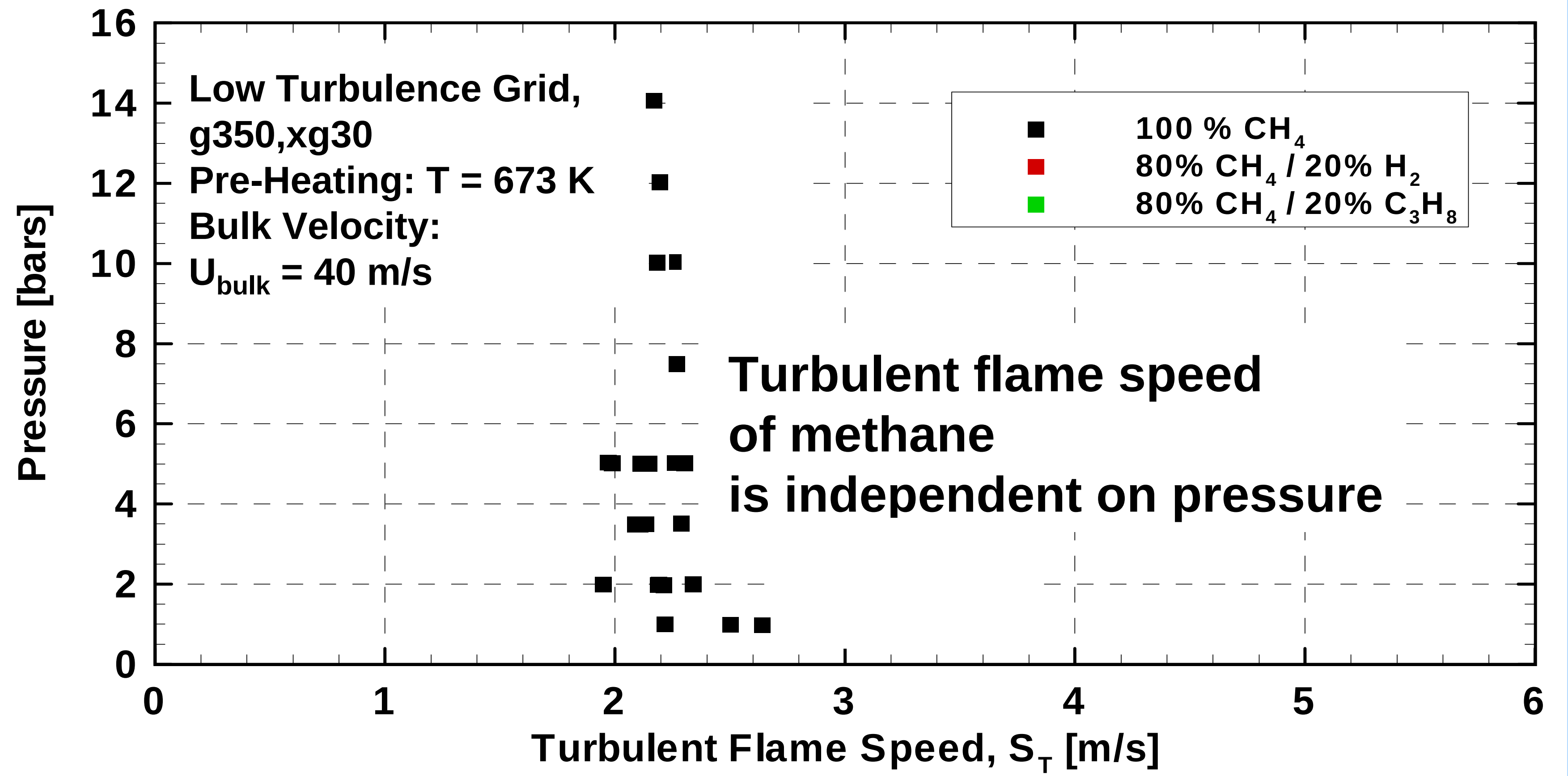


$$s_T = u_0 \frac{A_0}{A_f^{av}}$$



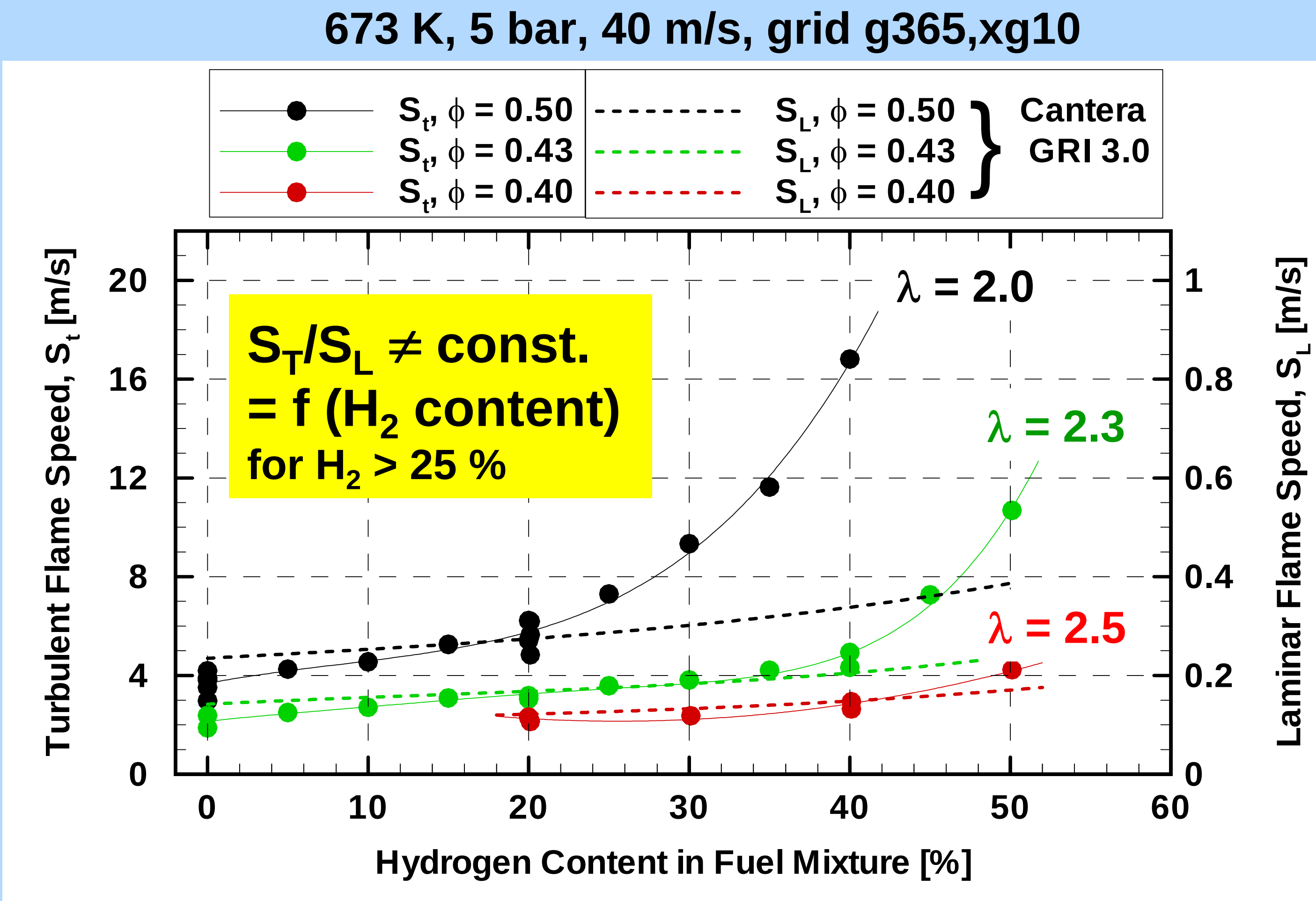
$$\frac{s_T}{s_L} = \frac{A_f^{inst}}{A_f^{av}}$$

Turbulent Flame Speed



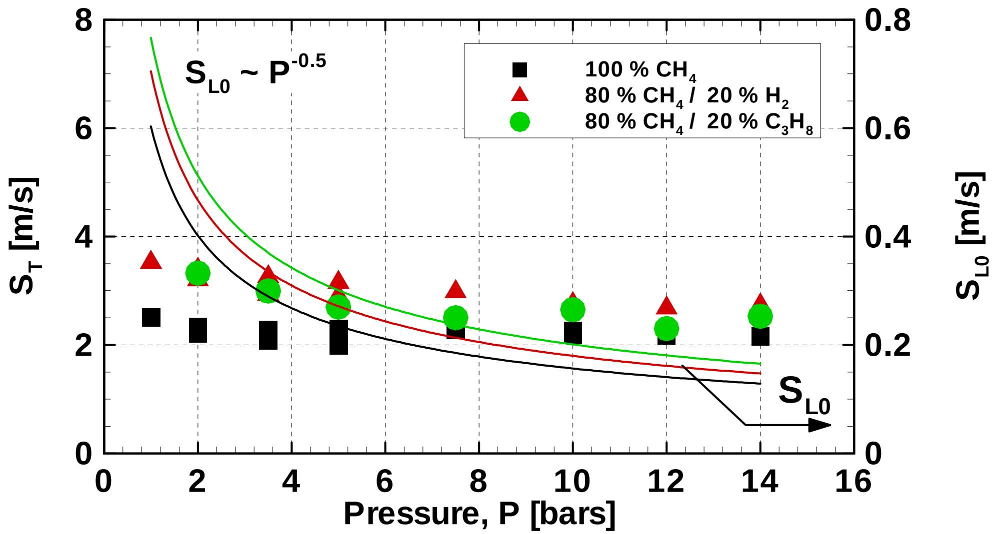
Turbulent flame speed of methane mixtures (with C_3H_8, H_2) is dependent on pressure (even though the effect is very small above 10 bar)

Turbulent Flame Speed



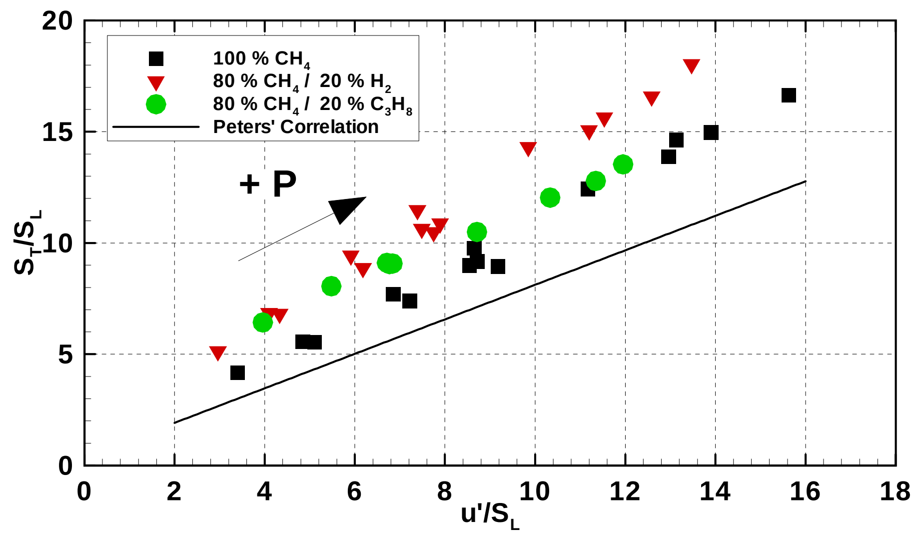
Up to approx. 25 % Vol. H_2: chemical kinetics dominate (S_T/S_L const.)
H_2 > 25 % Vol.: additional effects (preferrential diffusion, stretch)

Turbulent Flame Speed: Influence of Pressure

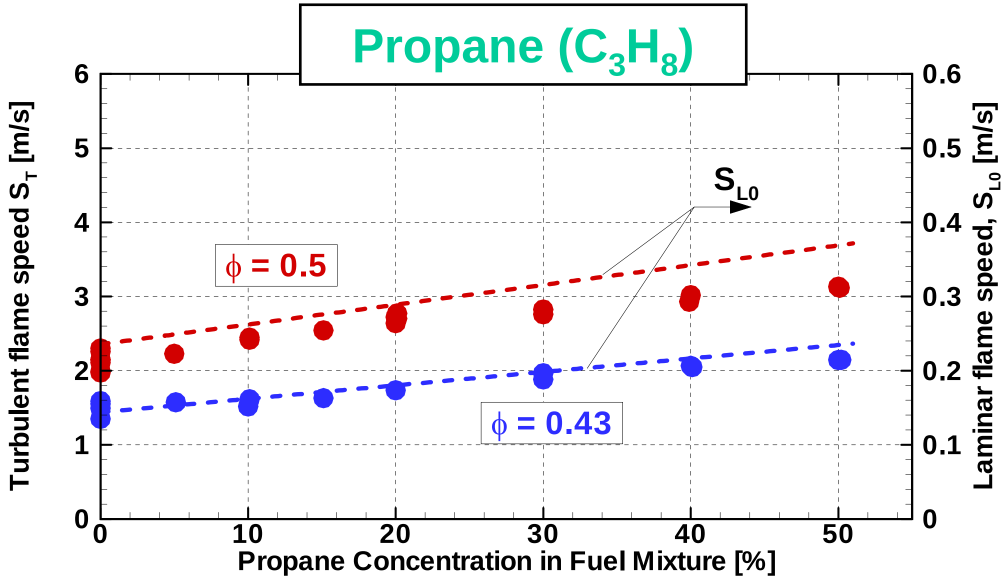


- Laminar flame speed is heavily dependent on pressure
- Turbulent flame speed is nearly independent of pressure for the three mixtures
- The increase in Re_T by increasing the pressure decreases the size of the smallest turbulent eddies

The resulting increase in turbulent flame surface counteracts the decrease of laminar flame speed

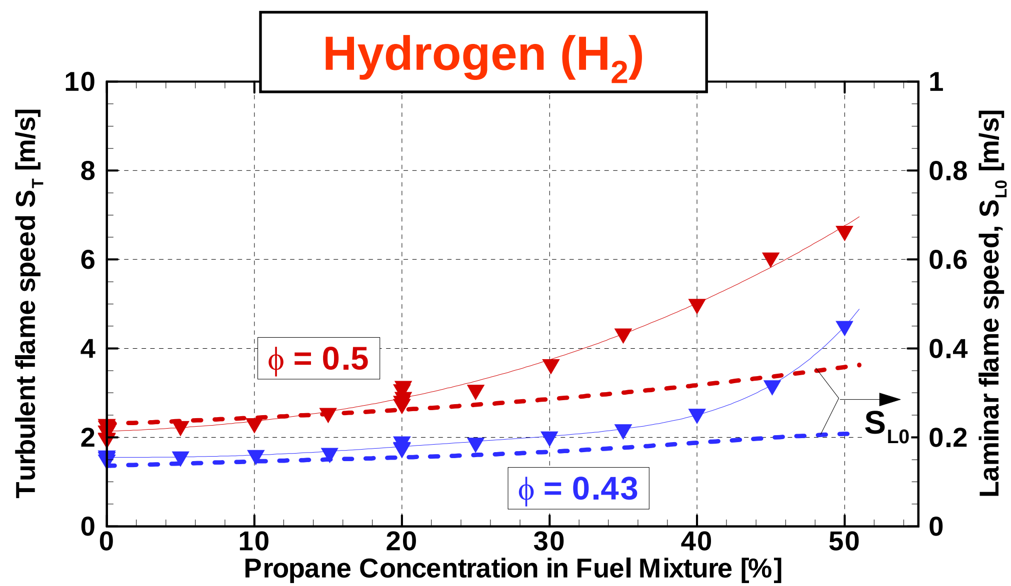


Turbulent Flame Speeds: Influence of Fuel Blend



- Effect of C_3H_8 addition:
  1. Trend is consistent for both ϕ
  2. Turbulent flame speed trend seems to be dominated by chemistry
  3. Constant $S_T/S_L \approx 10$ in the measured range (100 % CH_4 – 50 % C_3H_8)

- Effect of H_2 addition:
  1. S_T deviates greatly from S_L trend, especially at higher hydrogen content. i.e. more than just chemical effect
  2. Effect is less pronounced for leaner mixtures.



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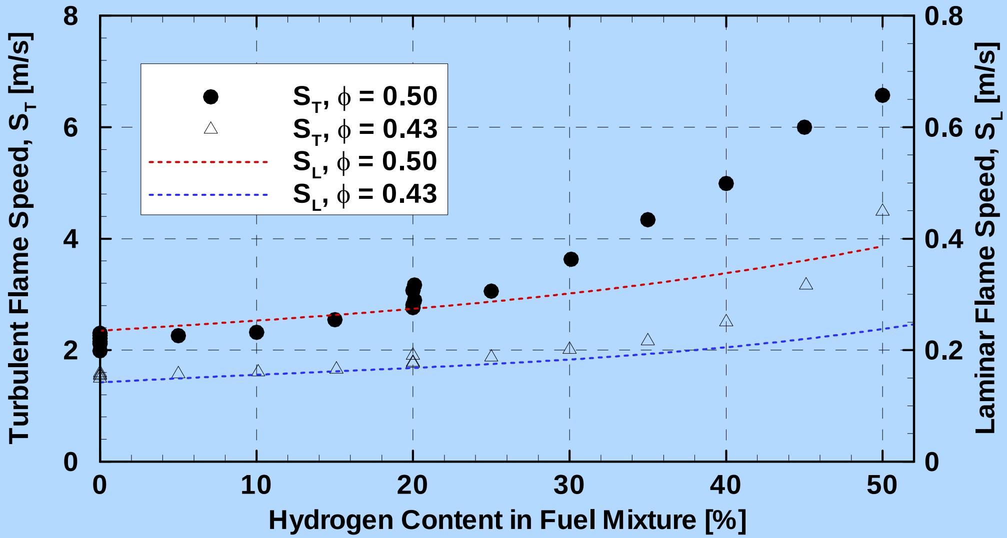
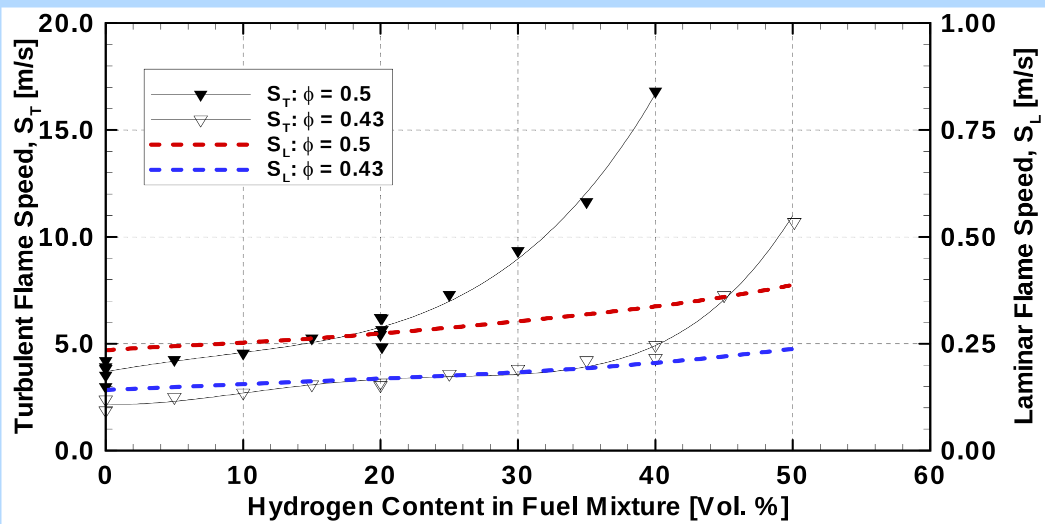
Turbulent Flame Speed



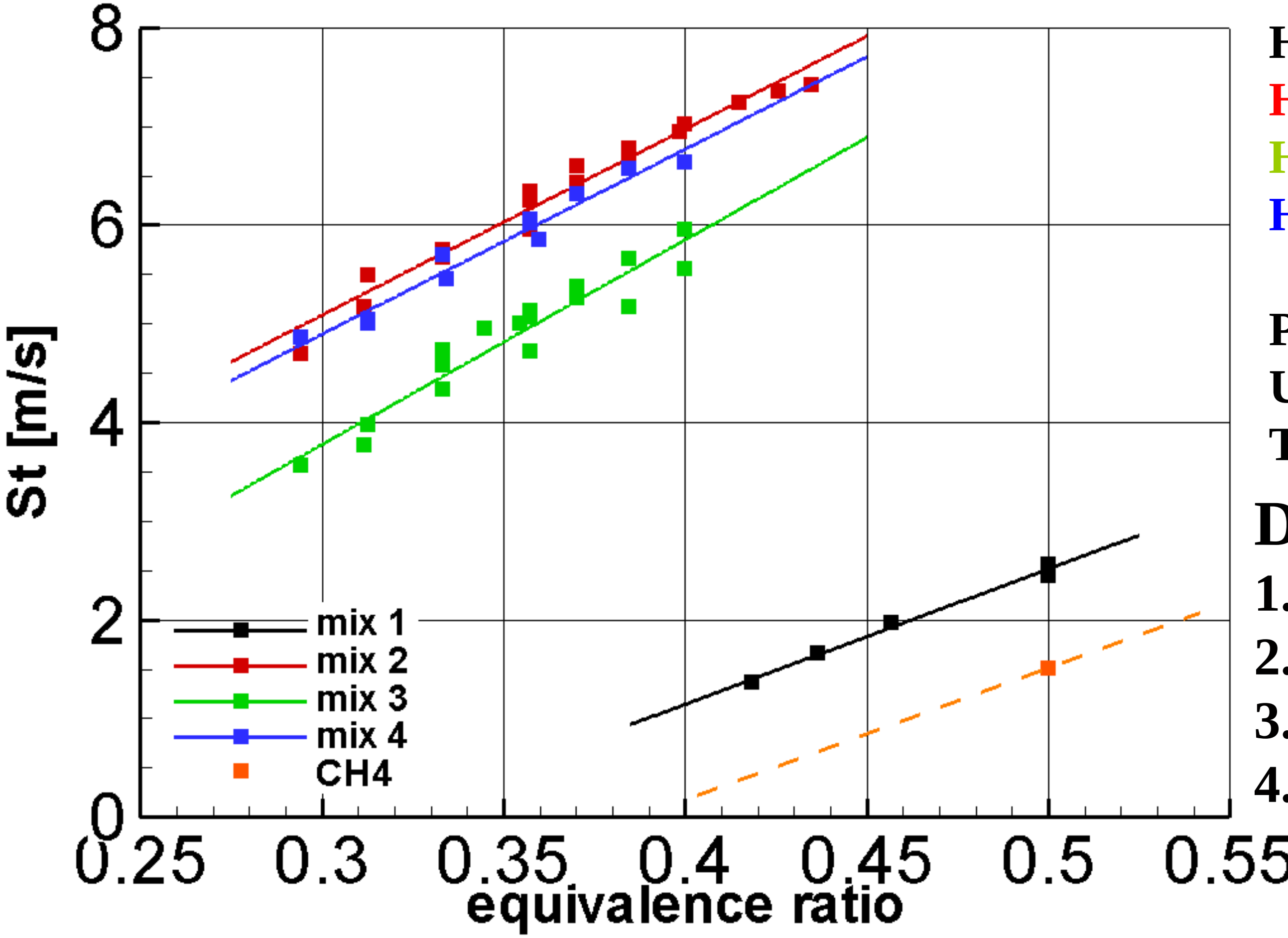
Low Turbulence **Grid,**
g350,xg30
Pre-Heating: T = 673 K
Bulk Velocity: U_{bulk} = 40 m/s
Pressure = 5 bar

$S_T/S_L \neq$ const.
= f (H_2 content)
for H_2 > 25 %



High Turbulence **Grid,**
g365,xg10
Pre-Heating: T = 673 K
Bulk Velocity: U_{bulk} = 40 m/s
Pressure = 5 bar

Turbulent flame speed S_t - dependency on fuel composition and stoichiometry



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

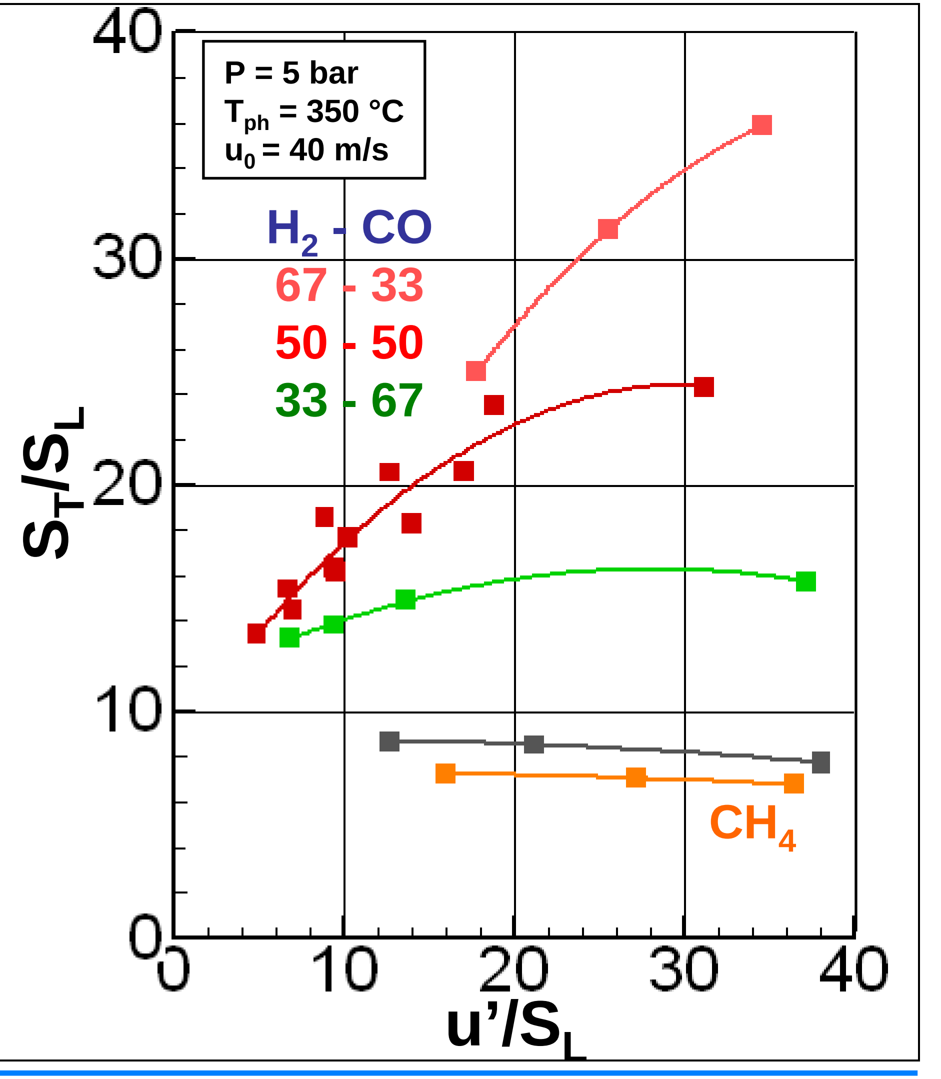
Differences depend on:

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

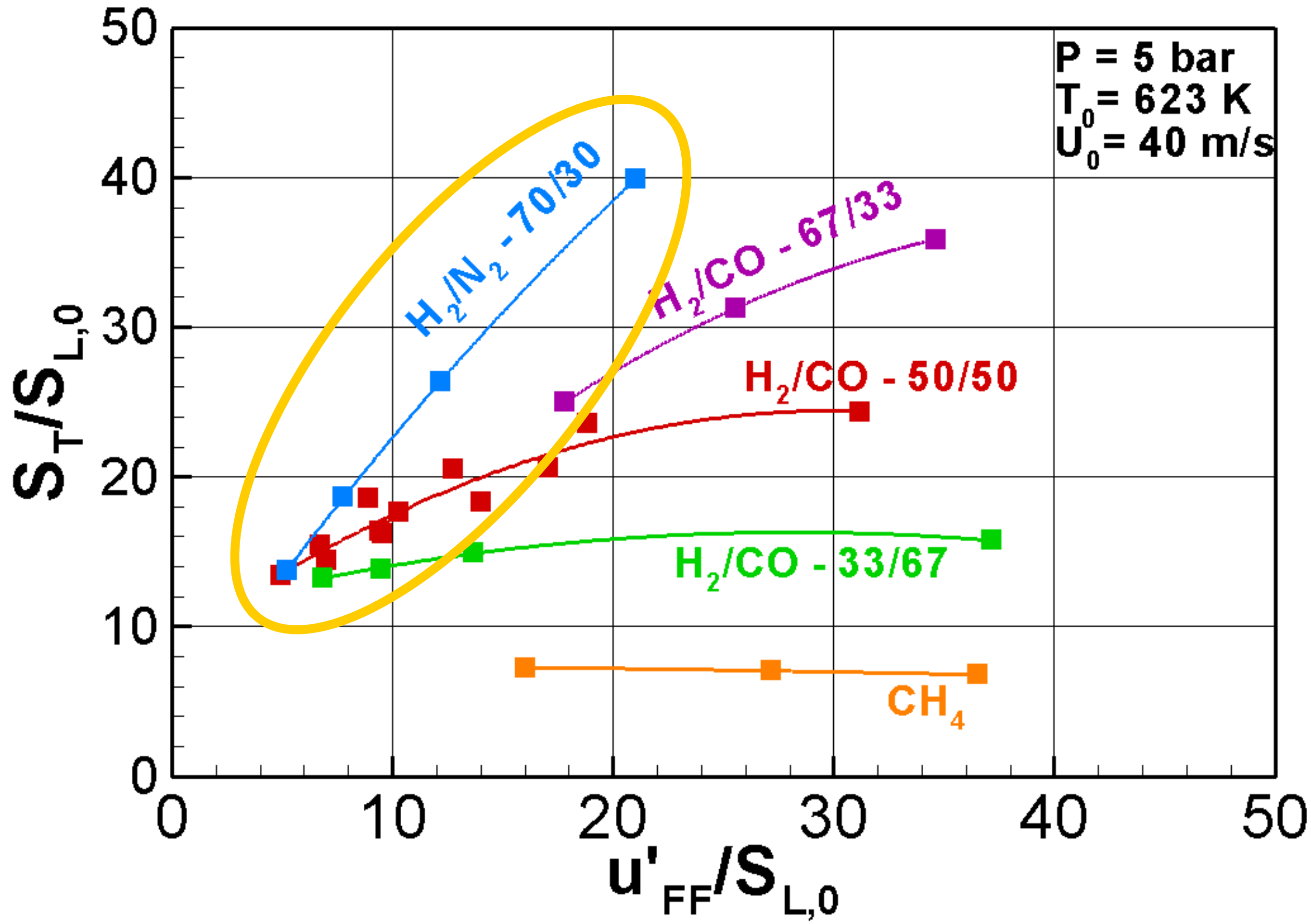
Normalized Turbulent Flame Speed

- co-firing NG and air-blown SG (@ 60% - 40%) leads to an increase of S_T/S_L of 15%

- firing pure SG increases dramatically the ratio S_T/S_L depending on the H_2 content

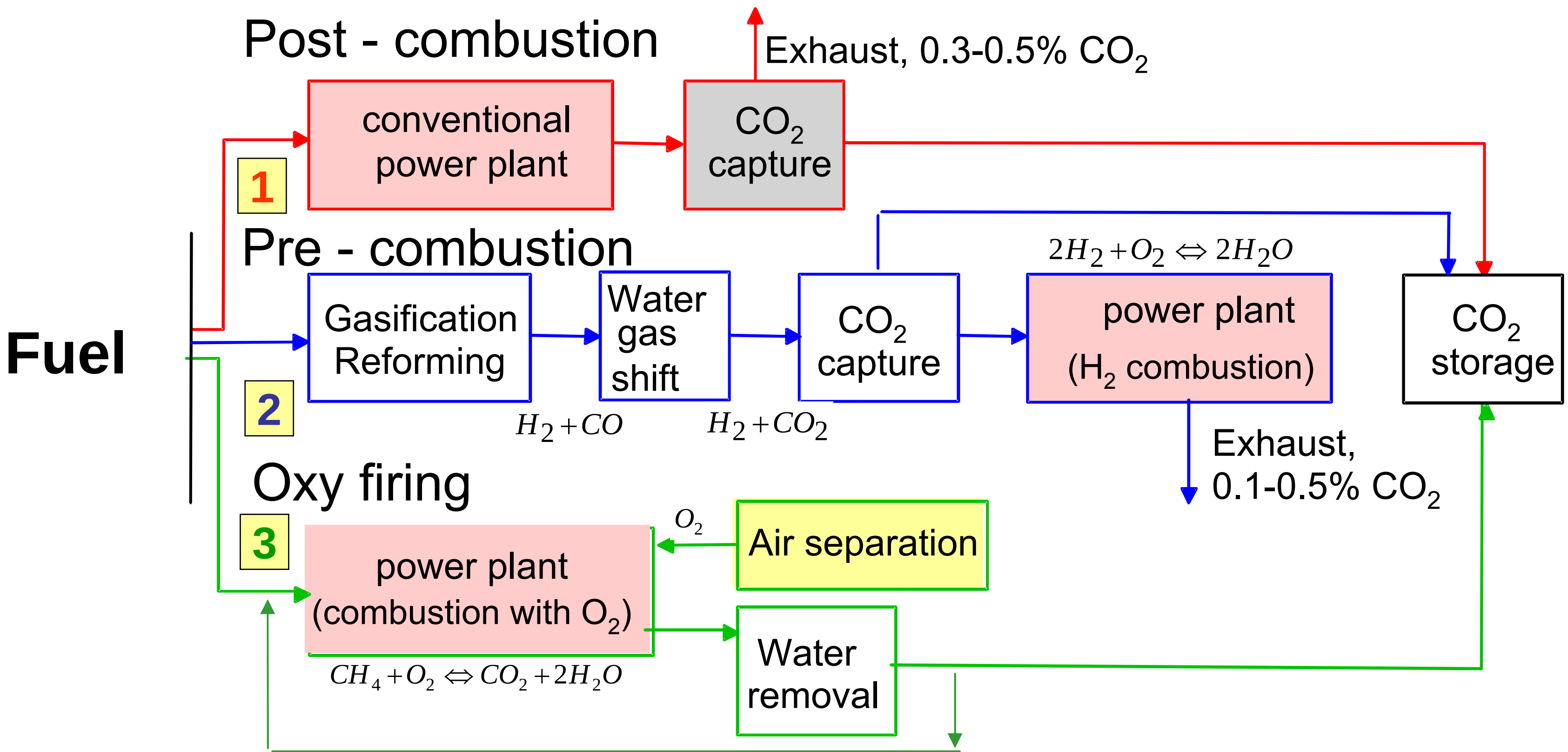


Normalized Turbulent Flame Speed

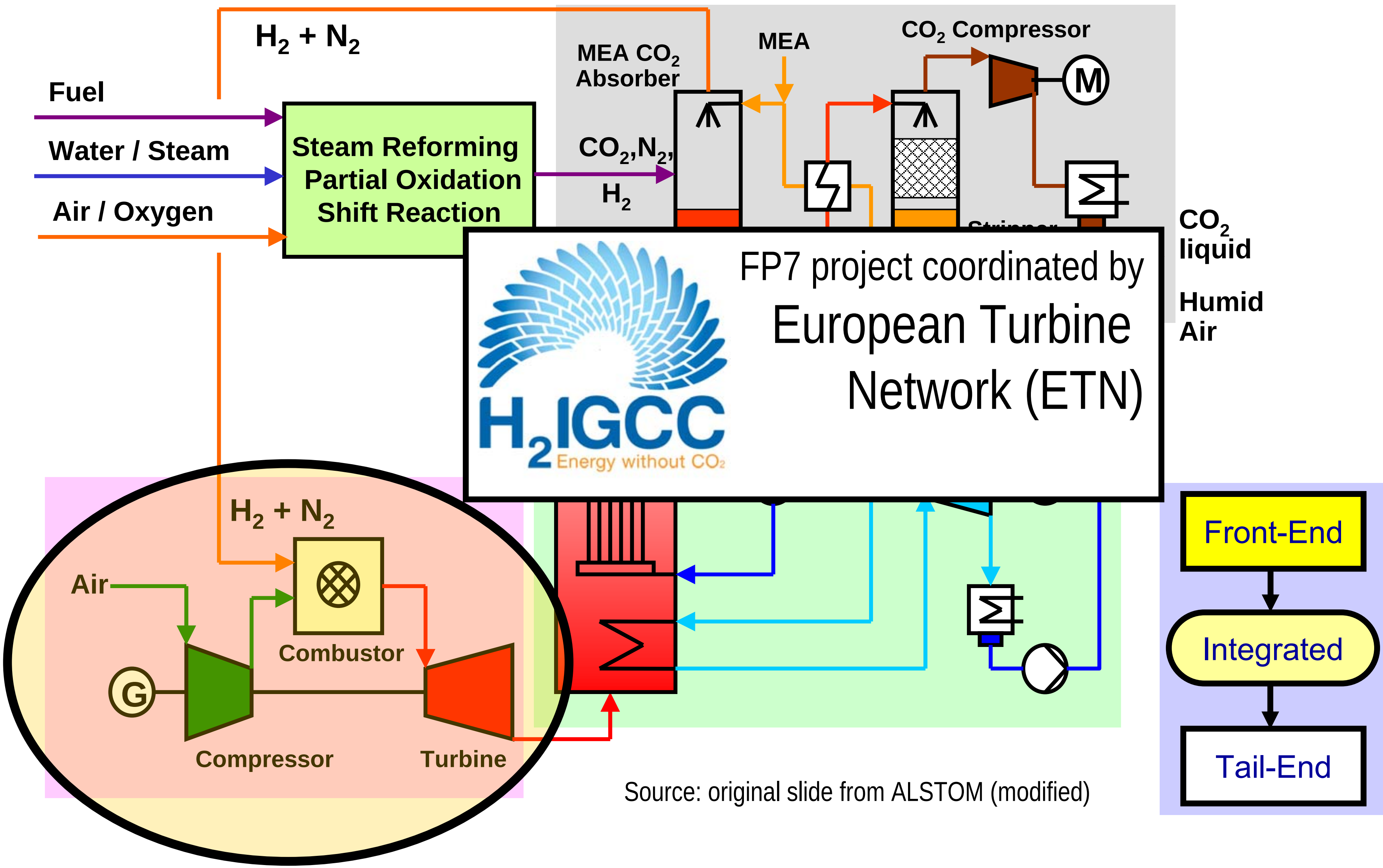


Gasturbine based

Technology options for CO_2-free power generation



Fuel Decarbonization / H_2 combustion



Source: original slide from ALSTOM (modified)

H2IGCC Energy without CO_2

Low Emission Gas Turbine Technology for Hydrogen-rich Syngas

H_2-IGCC Energy without CO_2

Project Details

- Collaborative Project under the EU's Seventh Framework Programme (FP7): Advanced Gas Turbines for Solid Fuel Gasification Processes
- Co-funded by the European Commission, Directorate-General for Energy
- Title: Low Emission Gas Turbine Technology for Hydrogen-rich Syngas
- Acronym: H2-IGCC
- Website: www.h2-igcc.eu
- Duration: 4 years (2009-2013)
- Budget: 17.8 M Euro (11.3 M Euro EU funding)

H_2-IGCC Vision

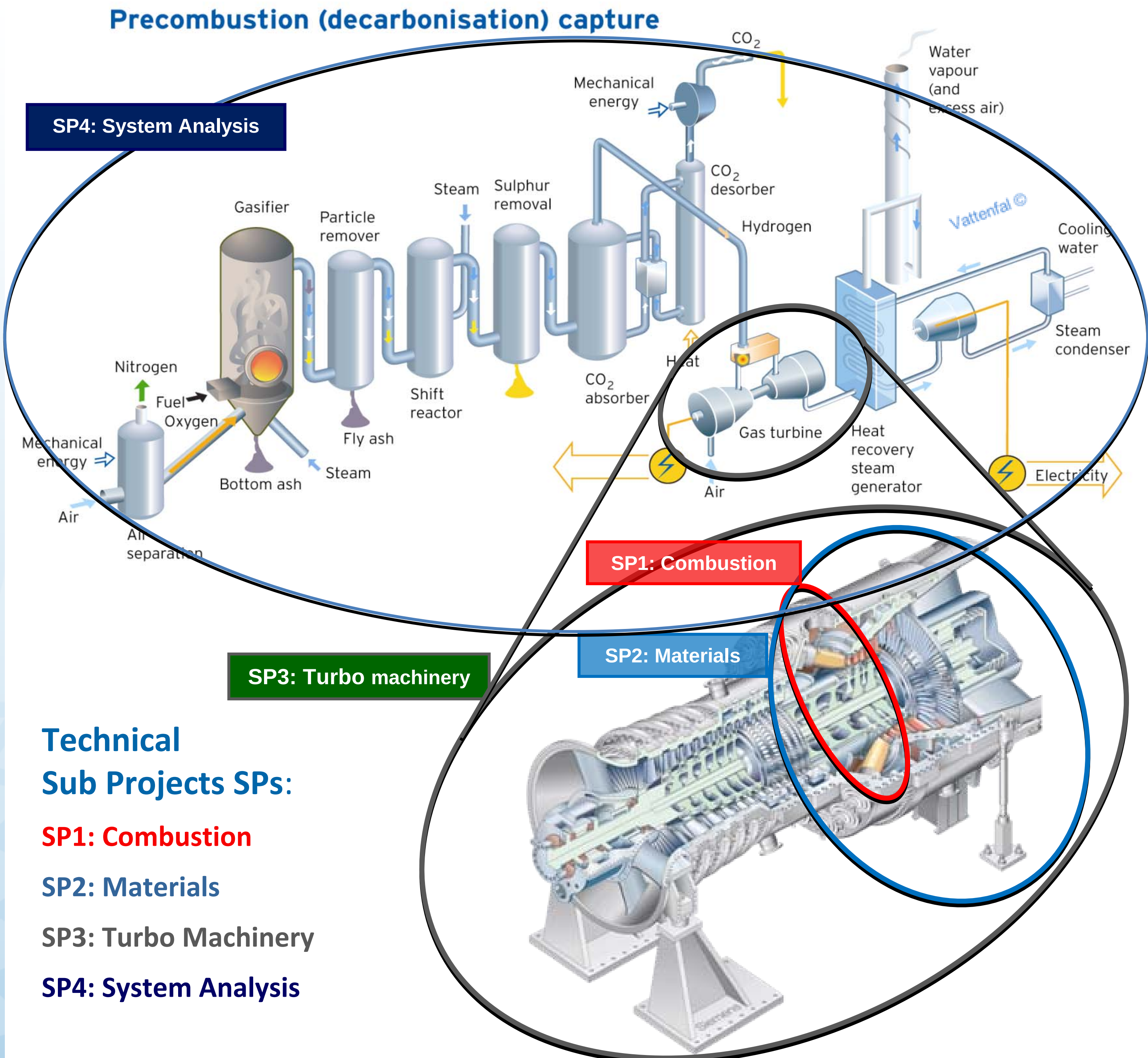
To pave the way for commercial deployment of efficient, clean, flexible and reliable IGCC-CCS plants by 2020

H2-IGCC project
Co-funded by the European Union
2009-2013

IGCC-CCS
Full Scale
Demonstrations
from 2014

Commercially
Available
IGCC-CCS
Technology
by 2020

Energy without CO_2



Technical Sub Projects SPs:

SP1: Combustion

SP2: Materials

SP3: Turbo Machinery

SP4: System Analysis

www.h2-igcc.eu

SubProject Partners (11):

Lead

Ansaldo Energia

Utilities

Enel
E.ON Engineering
Electricite De France

OEM's

Ansaldo Energia
Siemens

Research institutes/Universities

DLR

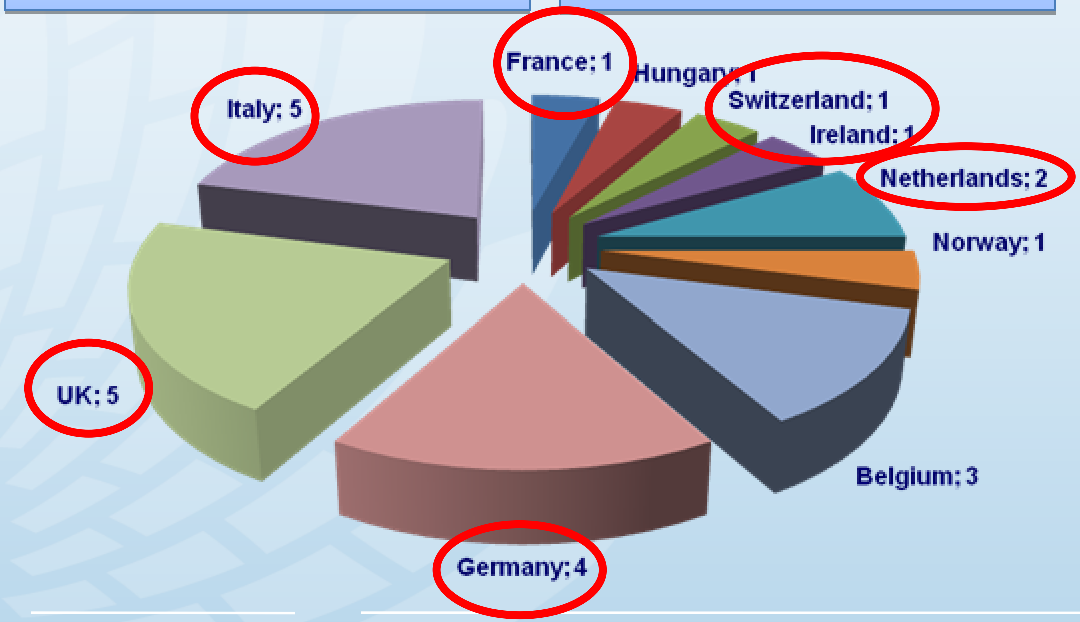
Paul Scherrer Institute

Cardiff University

National Univ. of Ireland Galway

Technical Univ. of Eindhoven

University of Genova



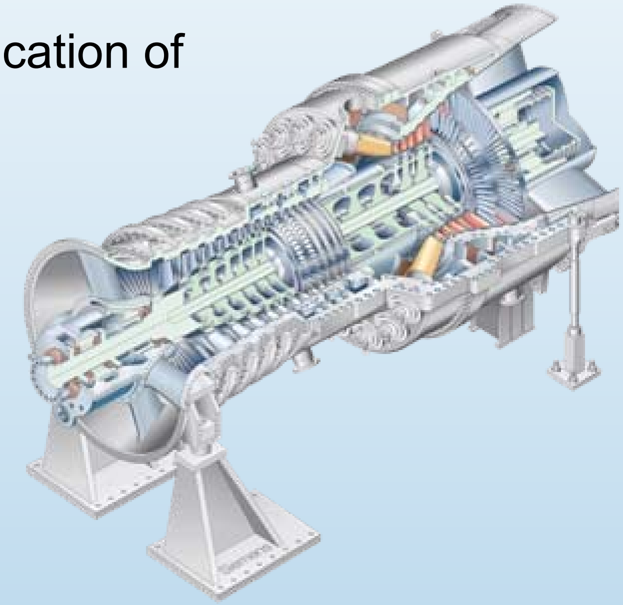
Overall Objective

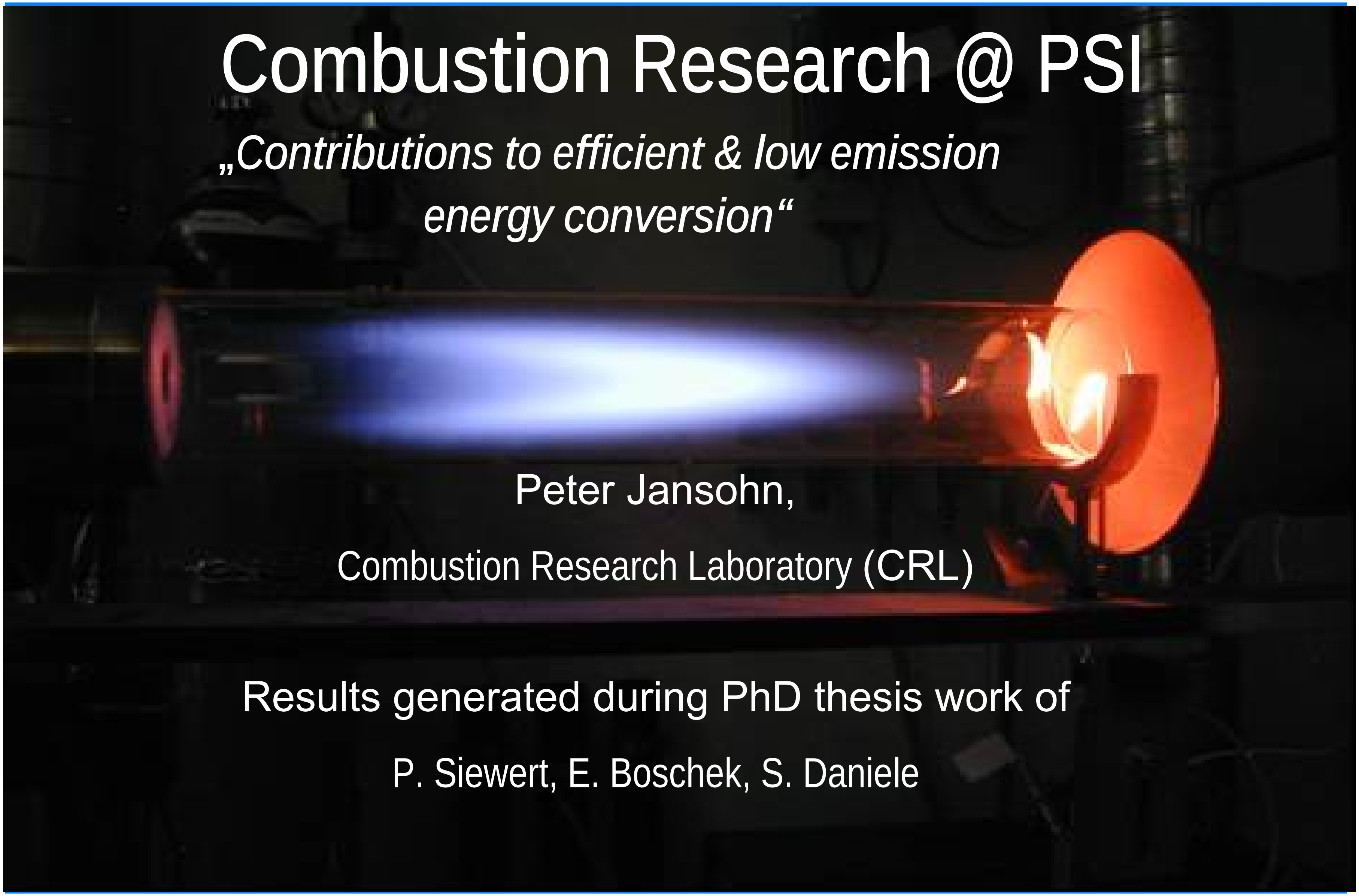
Safe and low emission combustion technology
for undiluted, hydrogen-rich syngas

- Demonstrate the safe use of undiluted, hydrogen rich syngas
  in **lean premixed** combustion mode
  at competitive **low emission levels**
- Demonstrate the safe and competitive use
  of undiluted, hydrogen rich syngas through the application of
  innovative combustion concepts

Parameter of success

- Demonstrate the use of **undiluted, hydrogen rich syngas** derived from a **pre-combustion CO_2 capture** process in typical **F - class combustion systems** with minimal modifications in order to conserve the **ability to burn a variety of fuels**





Combustion Research @ PSI

„Contributions to efficient & low emission energy conversion“

Peter Jansohn,

Combustion Research Laboratory (CRL)

Results generated during PhD thesis work of

P. Siewert, E. Boschek, S. Daniele

General Energy – Combustion Research Laboratory

Wir schaffen Wissen – heute für morgen