Wir schaffen Wissen – heute für morgen

Increased risk for flashback in case of dynamic operation of gas turbines

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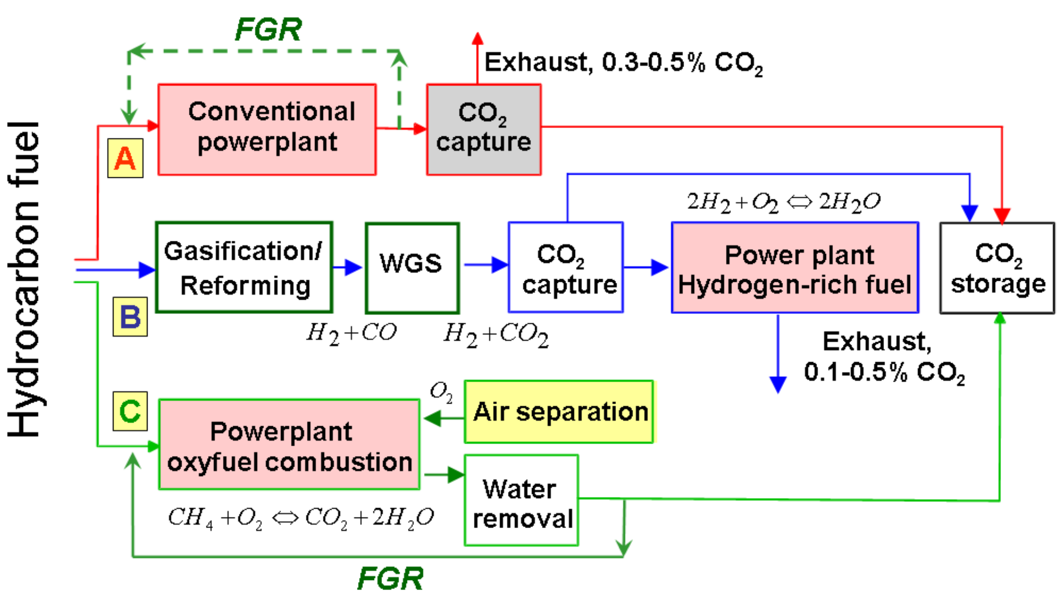
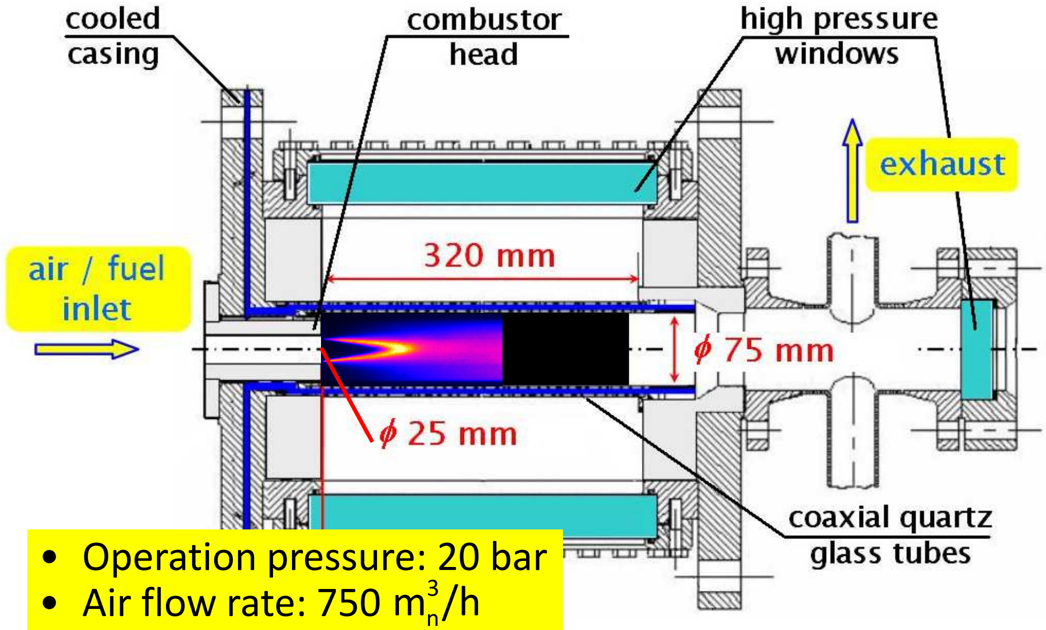
Introduction

Pre-combustion CO_2 capture → H_2-rich fuel mixtures

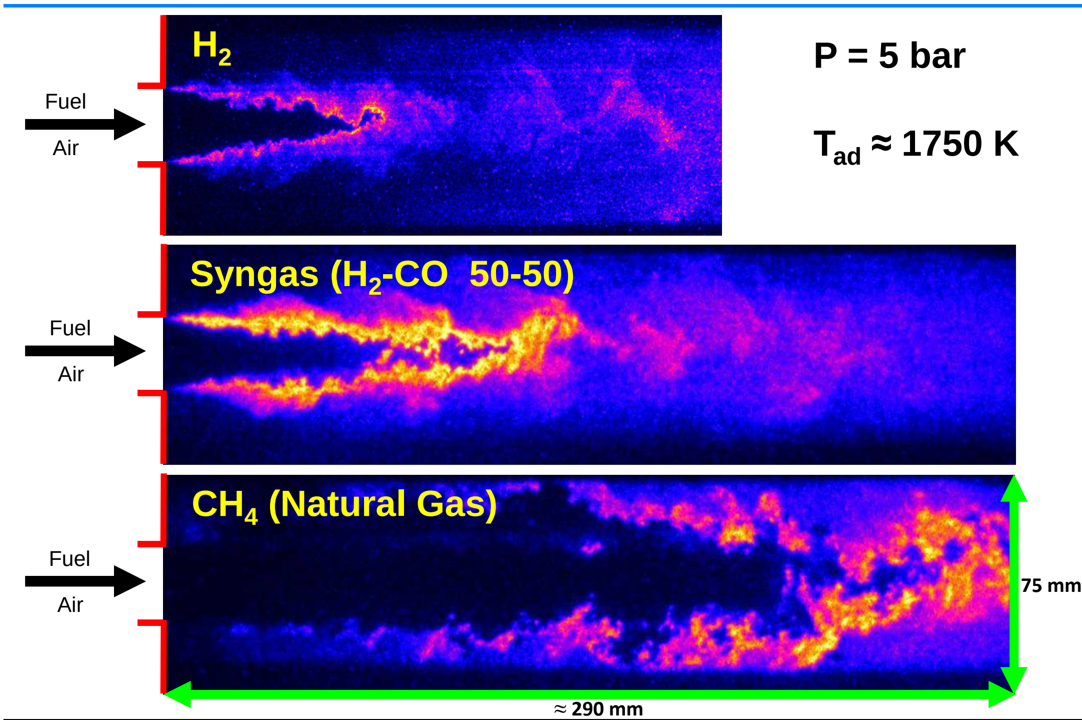


Experiments



- Operation pressure: 20 bar
- Air flow rate: 750 m_n^3/h
- Max. Preheat: 823 K

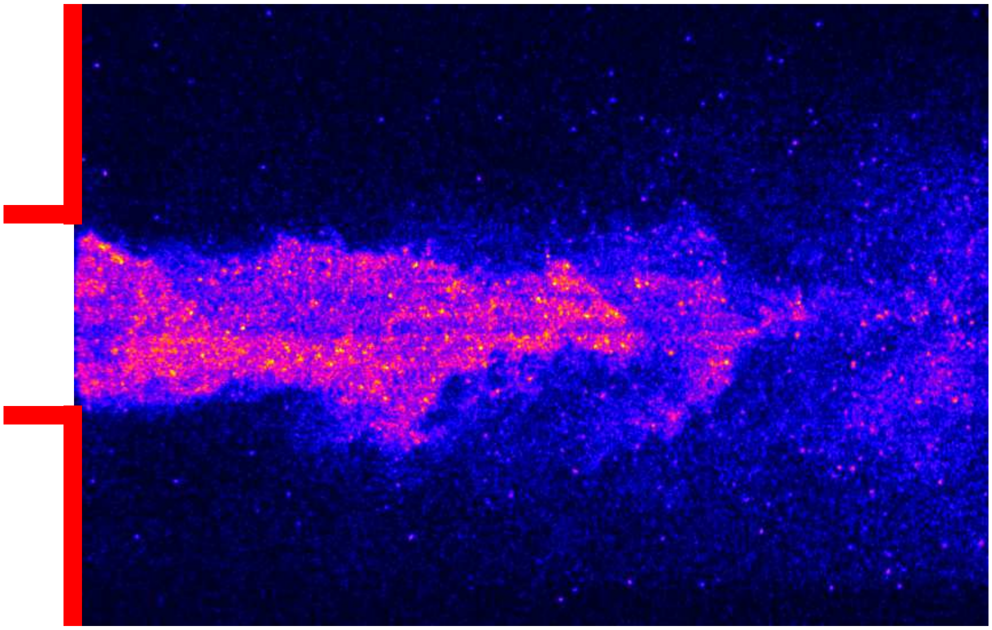
Profiles of Flame Front: H_2, Syngas, and CH_4



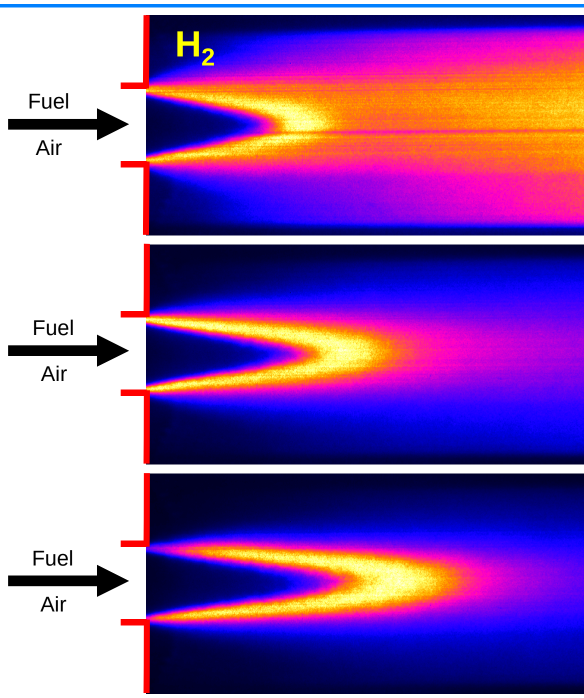
P = 5 bar

T_{ad} ≈ 1750 K

Flashback



When the Flame Gets Shorter…Flashback?



$\Phi = 0.50$

$\Phi = 0.39$

$\Phi = 0.32$

P = 2.5 bar

T_0 = 623 K

u_0 = 40 m/s

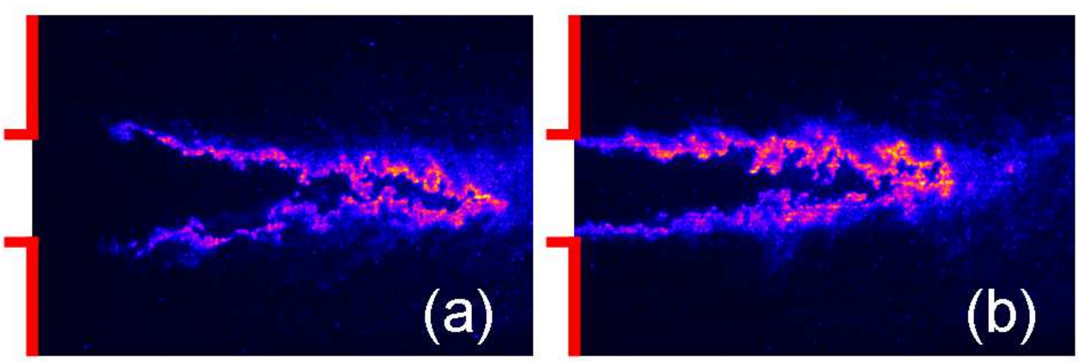
Mechanisms of Flashback*

1. ~~Core flow flashback~~
2. ~~Combustion induced vortex breakdown (CIVB)~~
3. ~~Combustion instability induced flashback~~
4. **Boundary layer flashback (BLF)**

*Lieuwen, T., McDonell, V., Santavicca, D., and Sattelmayer, T., 2008, "Burner Development and Operability Issues Associated with Steady Flowing Syngas Fired Combustors," Combustion Science and Technology, **180**, pp. 1169-1192.

Boundary Layer Flashback

H_2-N_2 70-30, P = 10 bar, T_0 = 623 K, u_0 = 40 m/s, Φ ~ 0.3



(a) Typical operation

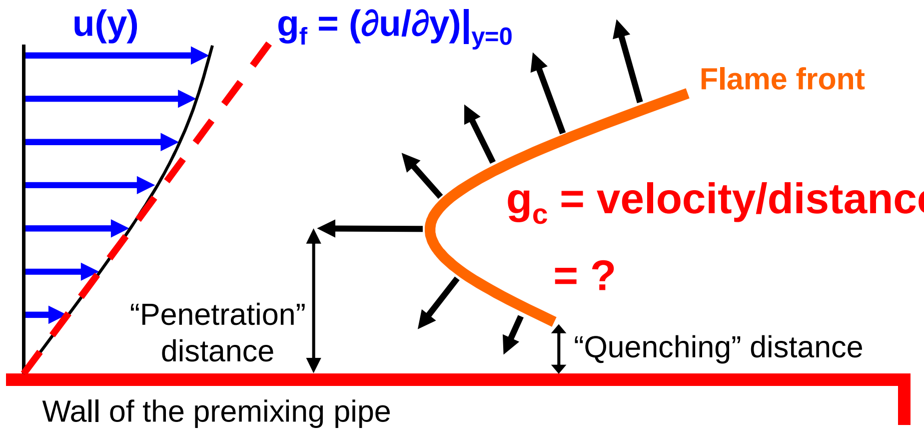
(b) "Flame anchoring"/Flashback

Model for Laminar/Turbulent BLF*

Flashback: $g_f \leq g_c$

Laminar: $g_f = \partial u/\partial y = 8 \cdot u_0 \cdot d^{-1}$ $g_c = 3 \cdot S_{L0}^2/(2 \cdot b^{0.5} \cdot \alpha)$

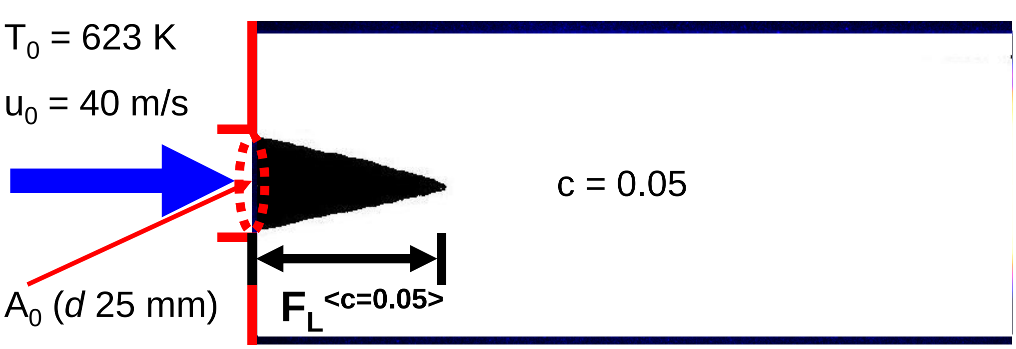
Turbulent: $g_f = 0.03955 \cdot u_0^{1.75} \cdot \nu^{-0.75} \cdot d^{-0.25}$ $g_c = ?$



*Lewis, B. and von Elbe, G., 1943, "Stability and Structure of Burner Flames," Journal of Chemical Physics, **11**, pp. 75-97.

S_T: Evaluation

Continuity: $\rho_0 \cdot A_0 \cdot u_0 = \rho_0 \cdot A_{f,\ averaged} \cdot S_T$



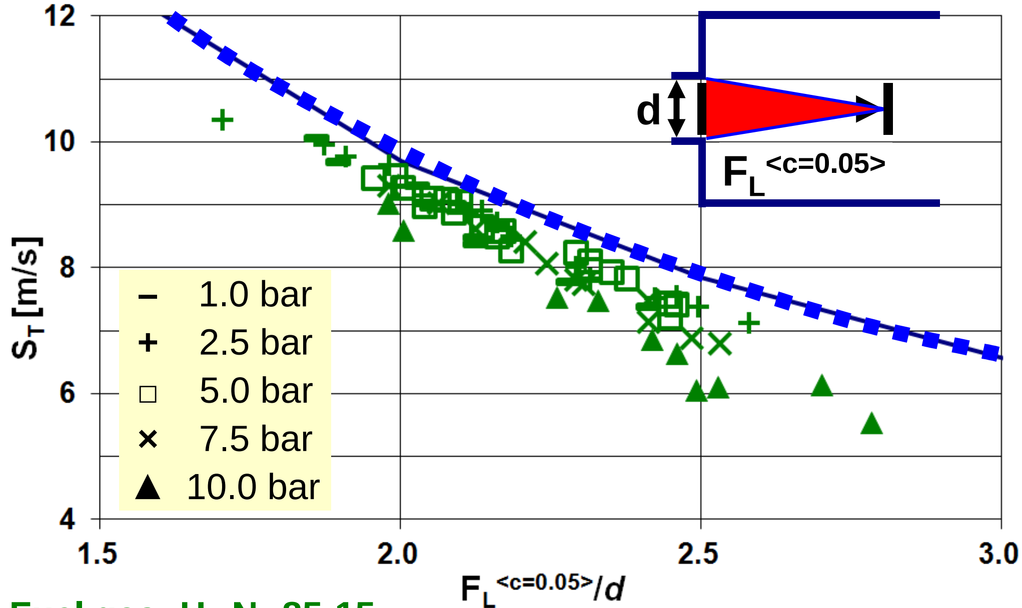
"Progress variable (c)" approach:

c = 0 → fresh mixture

c = 1 → completely burnt gas

S_T vs. Normalized Flame Length

$S_{T,\,cone} = u_0\,[1 + 4\,(F_L^{<c=0.05>}/d)^2]^{-0.5}$

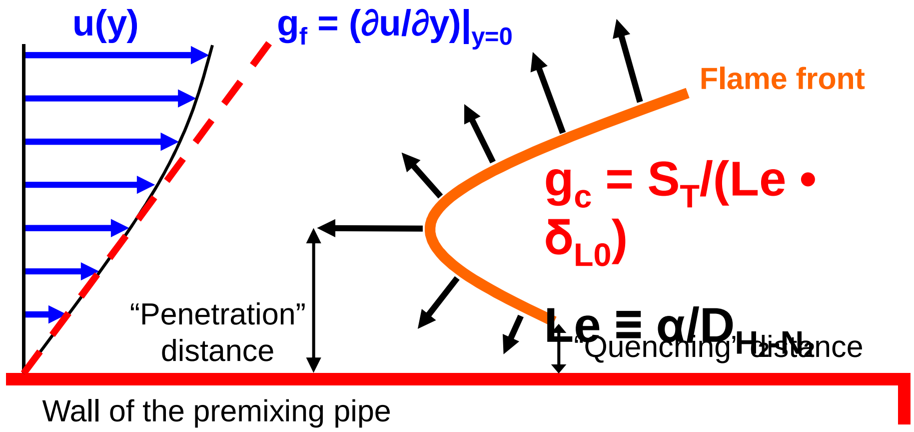


Fuel gas: H_2-N_2 85-15

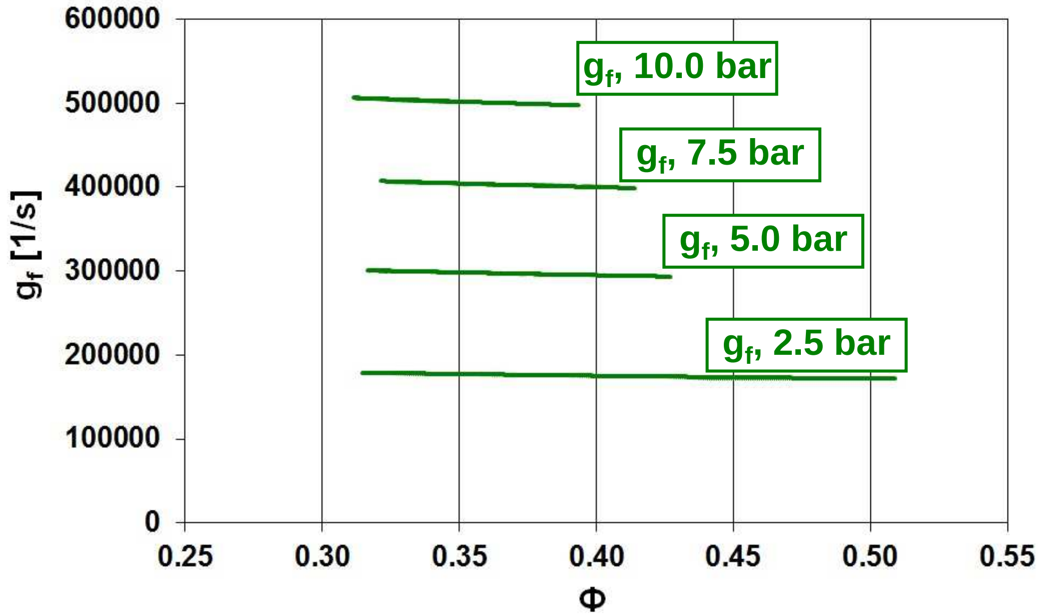
Model for Turbulent BLF

Flashback: $g_f \leq g_c$

Turbulent: $g_f = 0.03955 \cdot u_0^{1.75} \cdot \nu^{-0.75} \cdot d^{-0.25}$ g_c = ?



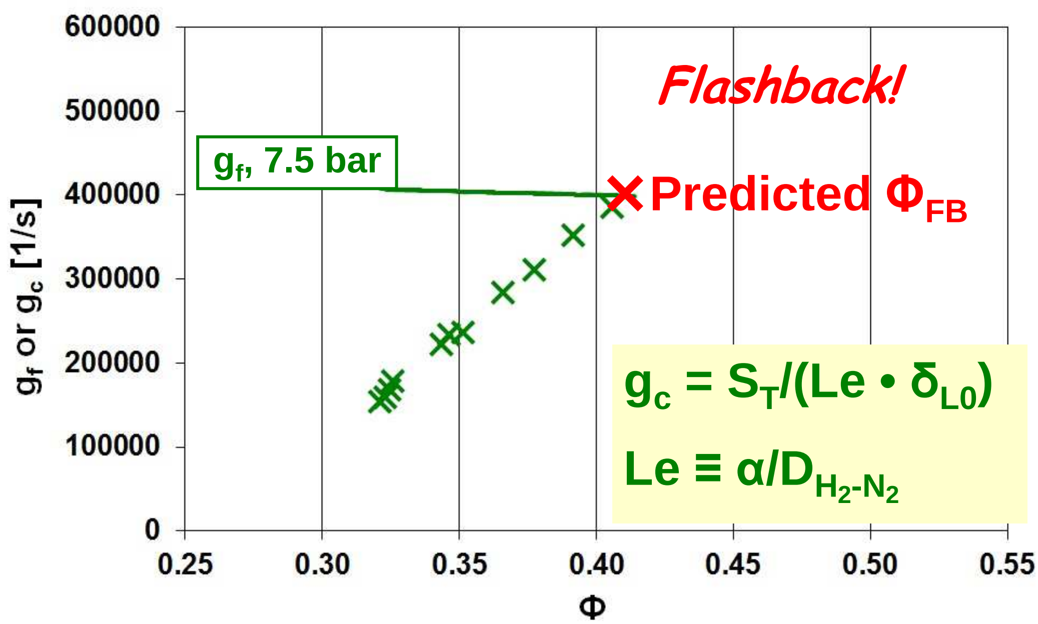
g_f vs. g_c: Predicting the Flashback Limit (1/3)



Fuel gas: H_2-N_2 85-15

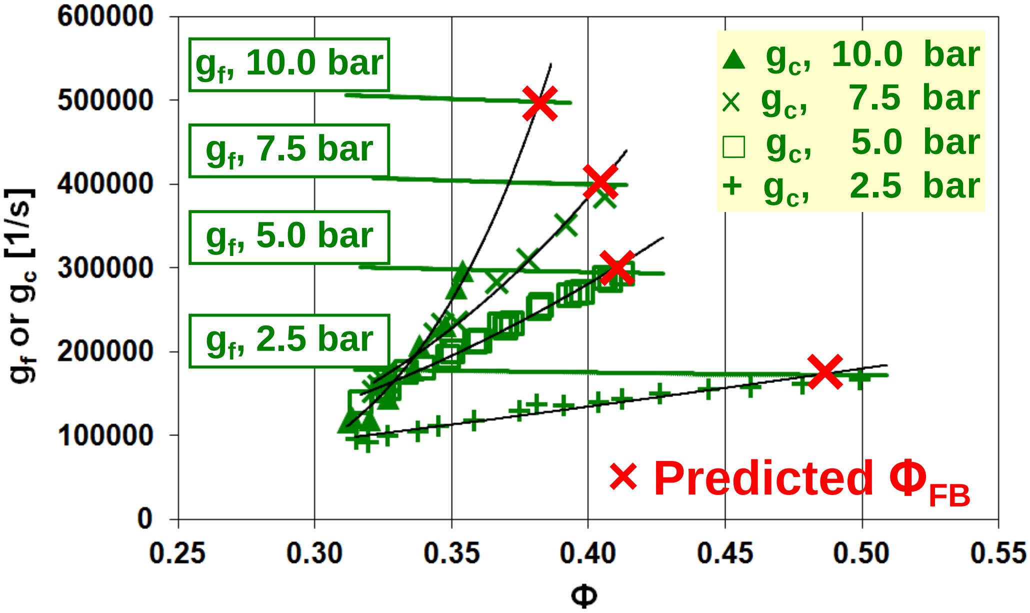
$$g_f = 0.03955 \bullet u_0^{1.75} \bullet \nu^{-0.75} \bullet d^{-0.25}$$

g_f vs. g_c: Predicting the Flashback Limit (2/3)



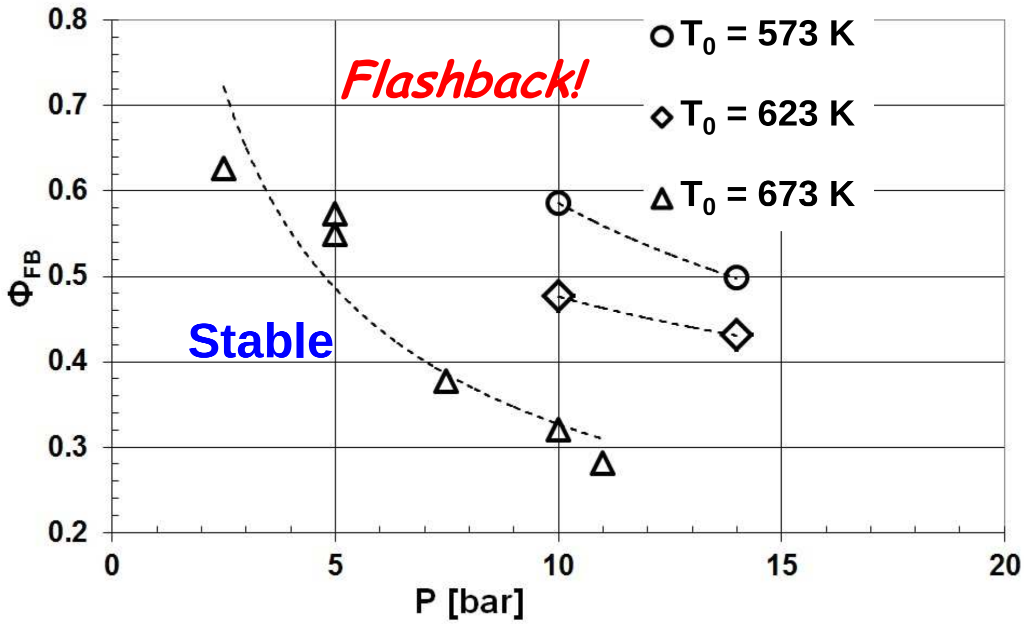
Fuel gas: H_2-N_2 85-15

g_f vs. g_c: Predicting the Flashback Limit (3/3)



Fuel gas: H_2-N_2 85-15

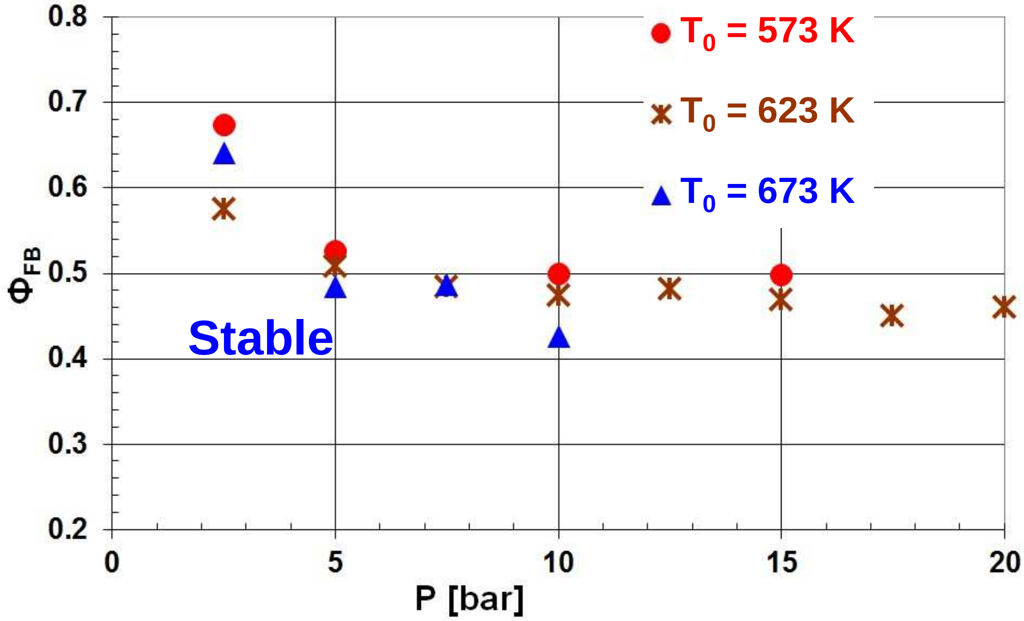
Measured Φ_{FB}: Syngas*



Fuel gas: H_2-CO 50-50

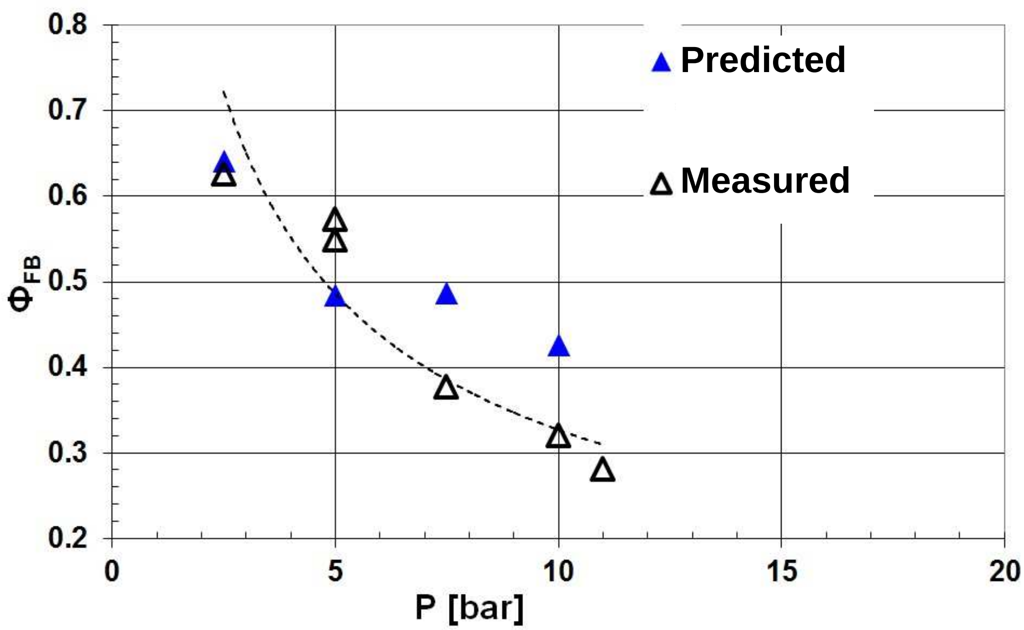
*Daniele, S., Jansohn, P., and Boulouchos, K., 2010, "Flashback Propensity of Syngas Flames at High Pressure: Diagnostic and Control," GT2010-23456, *Proceedings of ASME Turbo Expo 2010*, Glasgow, UK.

Predicted Φ_{FB}: Syngas



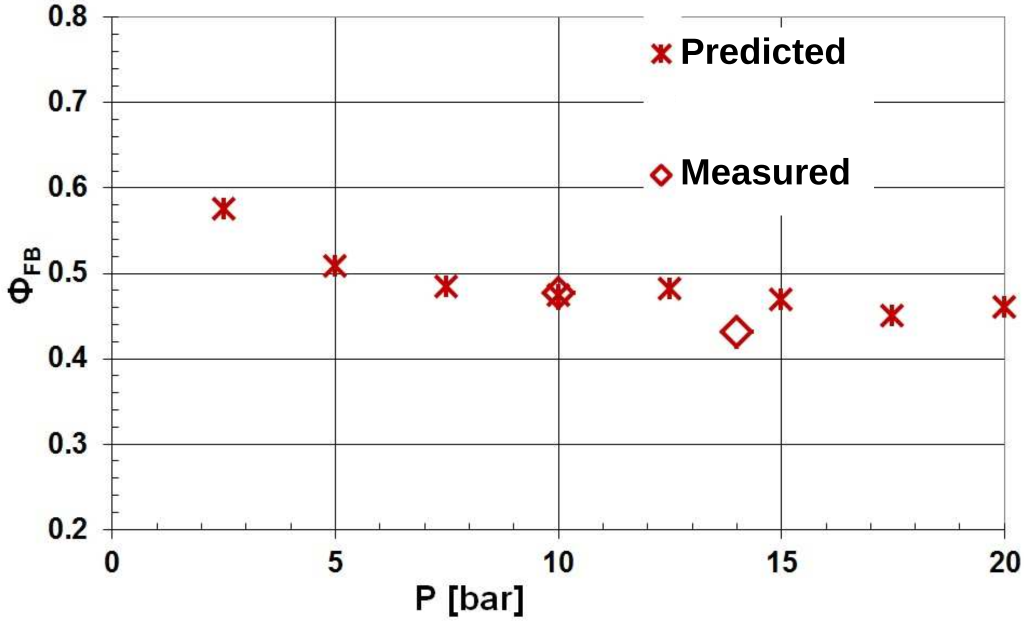
Fuel gas: H_2-CO 50-50

Φ_{FB}: Syngas, T_0 = 673 K



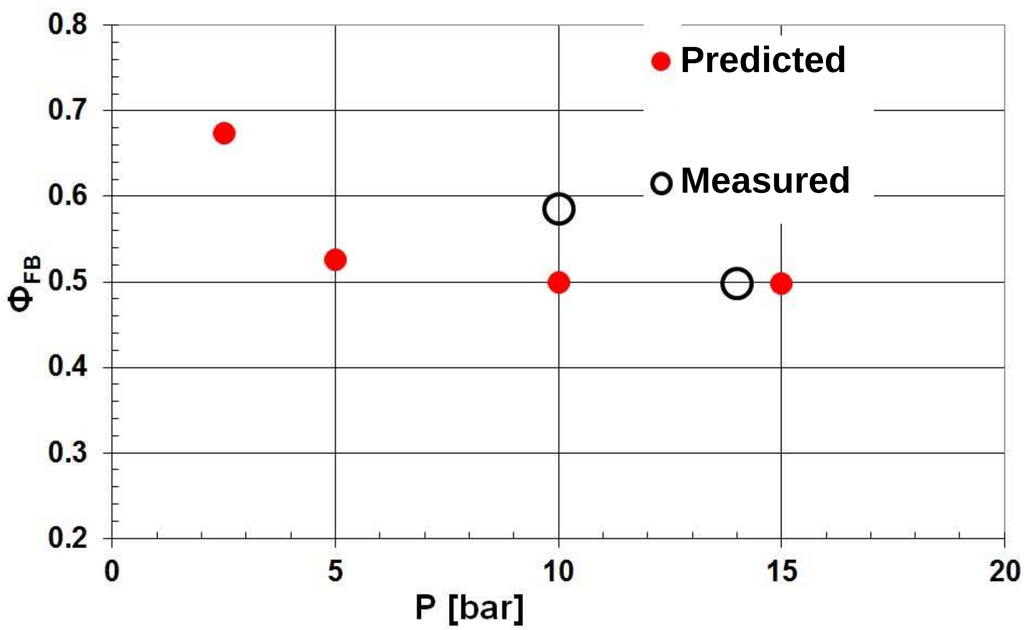
Fuel gas: H_2-CO 50-50

Φ_{FB}: Syngas, T_0 = 623 K



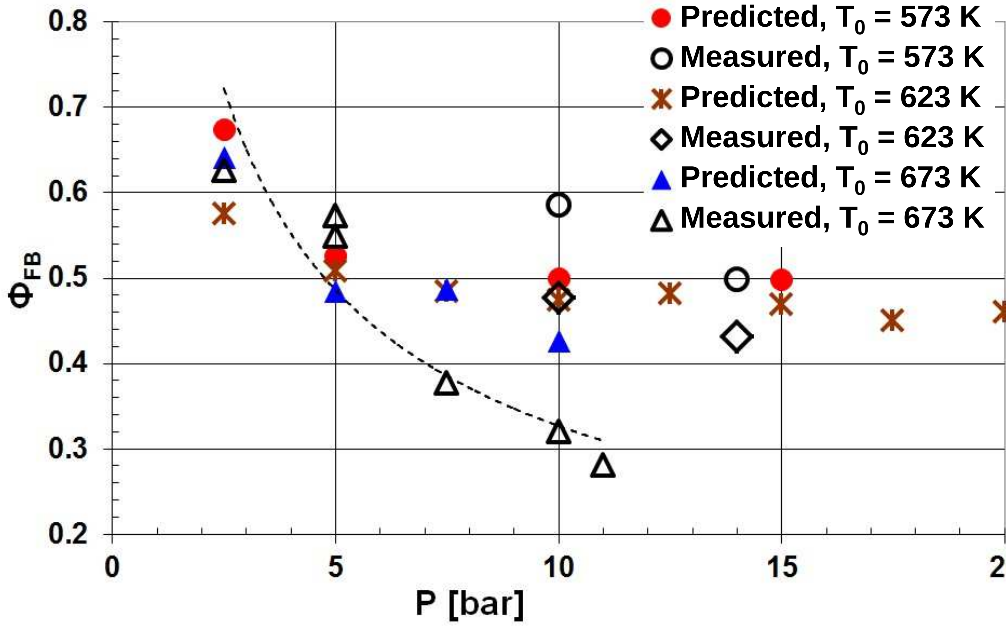
Fuel gas: H_2-CO 50-50

Φ_{FB}: Syngas, T_0 = 573 K



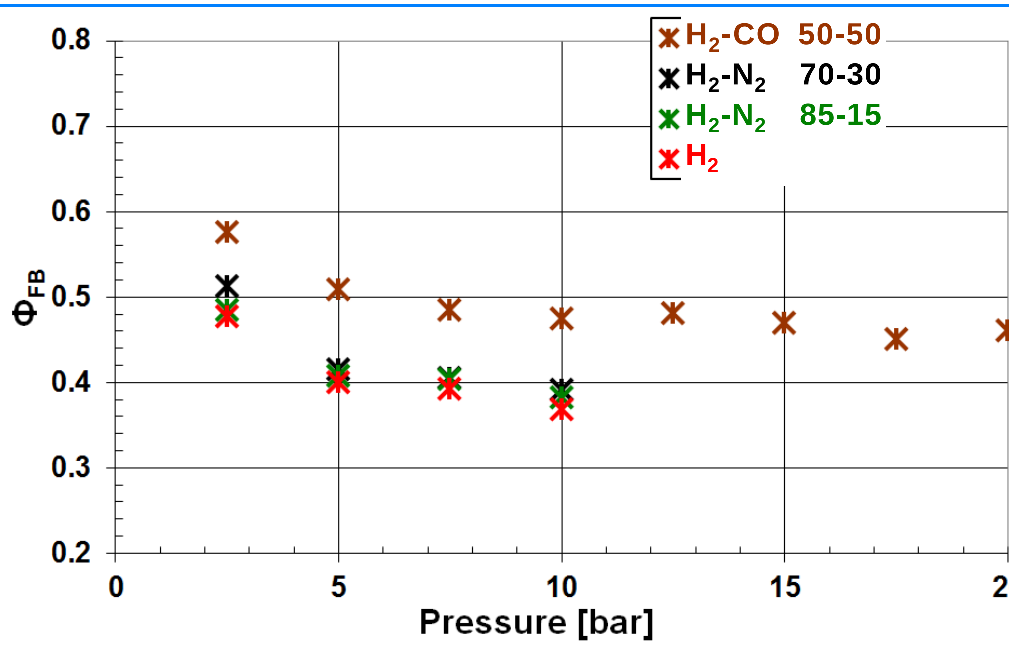
Fuel gas: H_2-CO 50-50

Measured & Predicted Φ_{FB}: Syngas

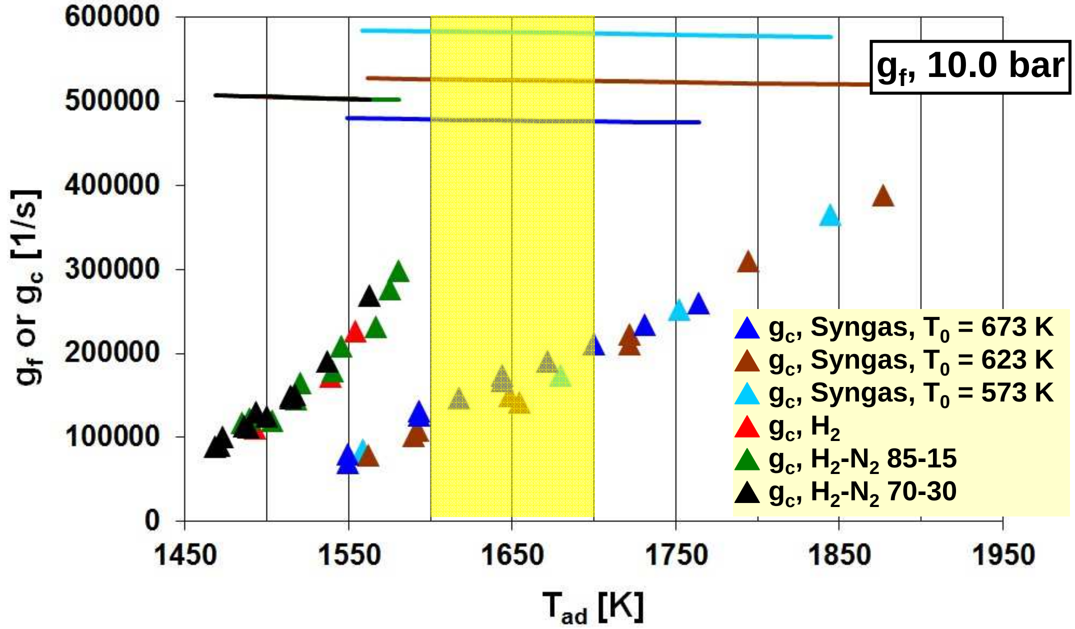


Fuel gas: H_2-CO 50-50

Predicted Φ_{FB} : Syngas & H_2-Rich

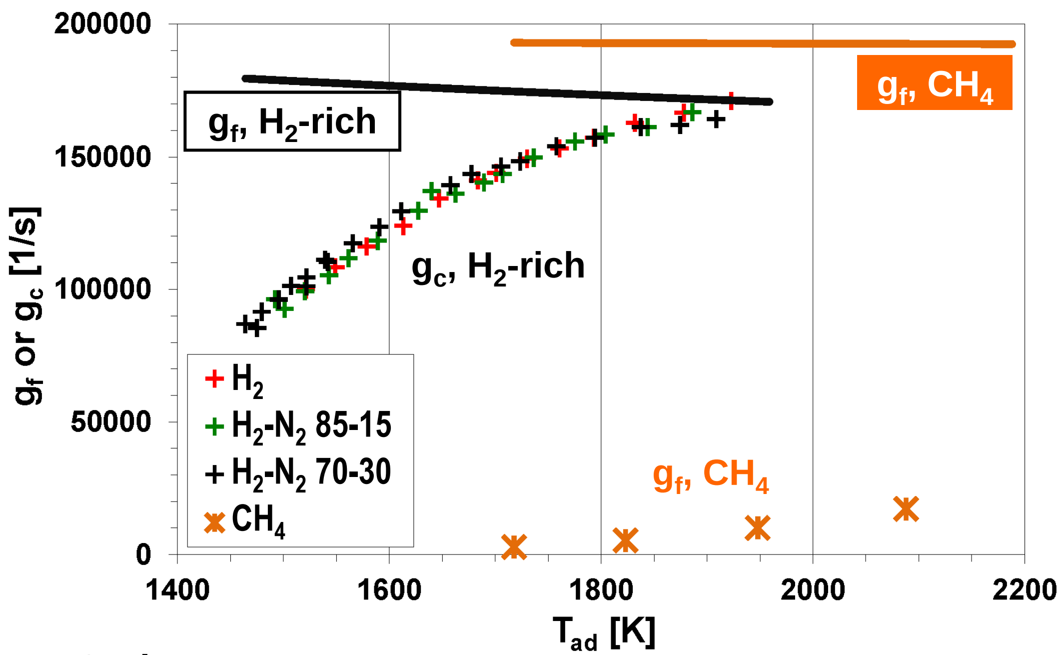


Velocity Gradients vs. T_{ad}: Syngas & H_2-Rich



P = 10 bar

Velocity Gradients vs. T_{ad}: CH_4 & H_2-Rich



P = 2.5 bar

Summary (1/2)

❖ One of the concerns about introducing the natural gas-fired combined cycle power plants to Switzerland is the accompanying emissions of green house gases.

❖ In order to comply with the limits on CO_2 emissions, the carbon capture and sequestration (CCS) techniques have to be implemented.

❖ If the carbon capture is done prior to the combustion process, the hydrogen content in the fuel gas is significantly increased ("H_2-rich"), and this leads to higher propensity of flashback.

Summary (2/2)

❖ For steady flowing combustors (e.g., gas turbine combustor), the flashback in the turbulent boundary layer is one of the major operational issues when burning these H_2-rich fuels.

❖ An indicator that predicts specifically the occurrence of this flashback mode is developed in PSI, which could be further implemented to qualify various burner designs.

Thank you!