UMONS

38th IEA TLM 2016
Ruka, 27/06/2016

IEA COMBUSTION

In-Furnace Measurements of **species** and **temperature** during the **Mild Combustion** of a COG/BFG **Blend** on a **30 kW** chamber

energy
UMONS RESEARCH INSTITUTE FOR ENERGY

Thermal engineering and combustion unit

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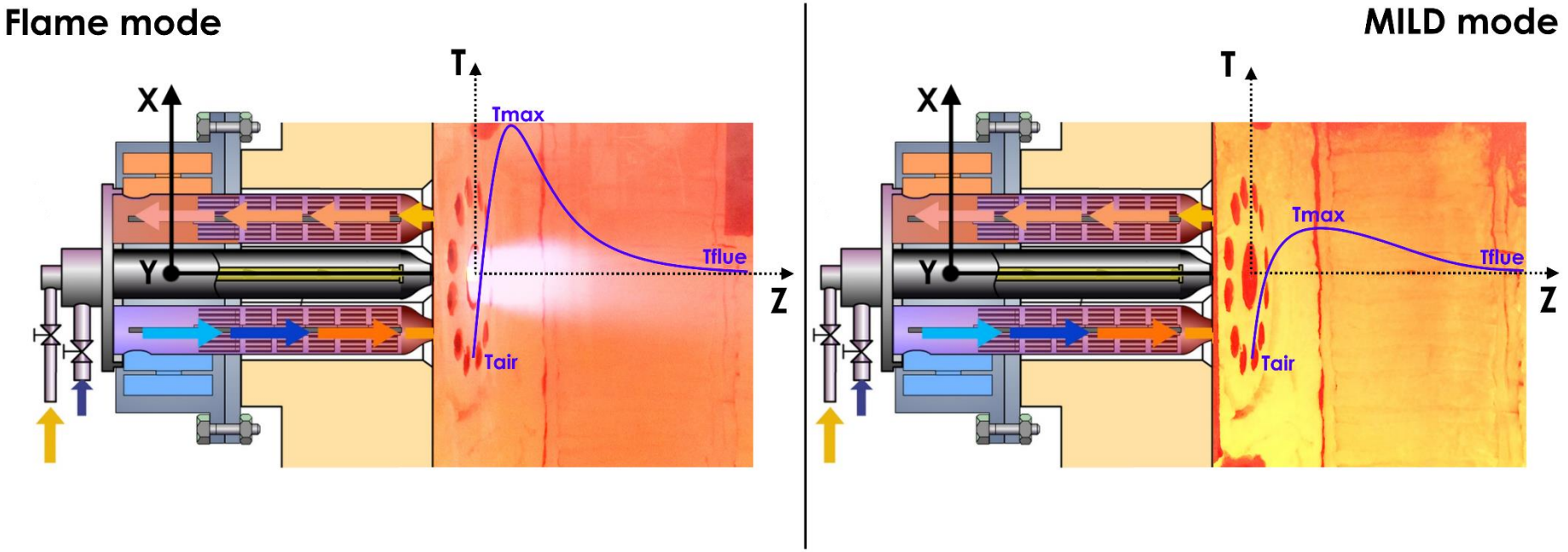
Classic VS MILD



UMONS's 200 kW semi-industrial furnace + Regemat 350 burner

How

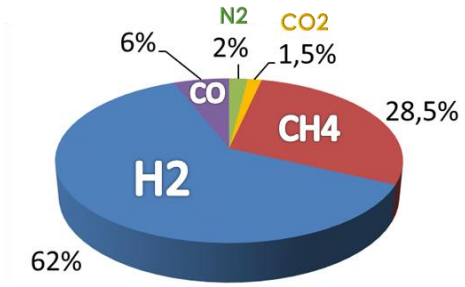
- High recirculation rates
- High T to get Auto-Ignition

Why

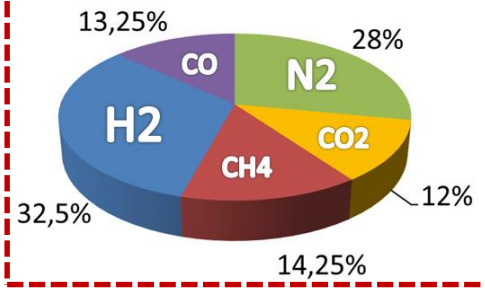
- Low CO & NOx emissions
- No more problems of flame front stabilization

Ref: CH4

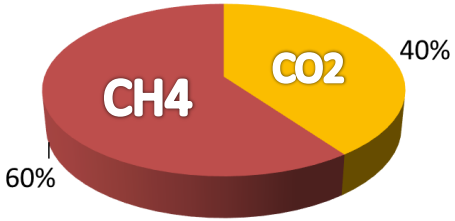
The Tested Fuels



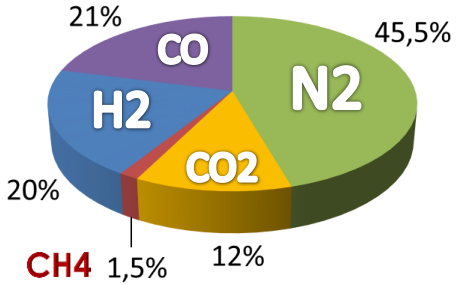
COG → LHV 49%



B50 → LHV 29%



Biogas → LHV 60%

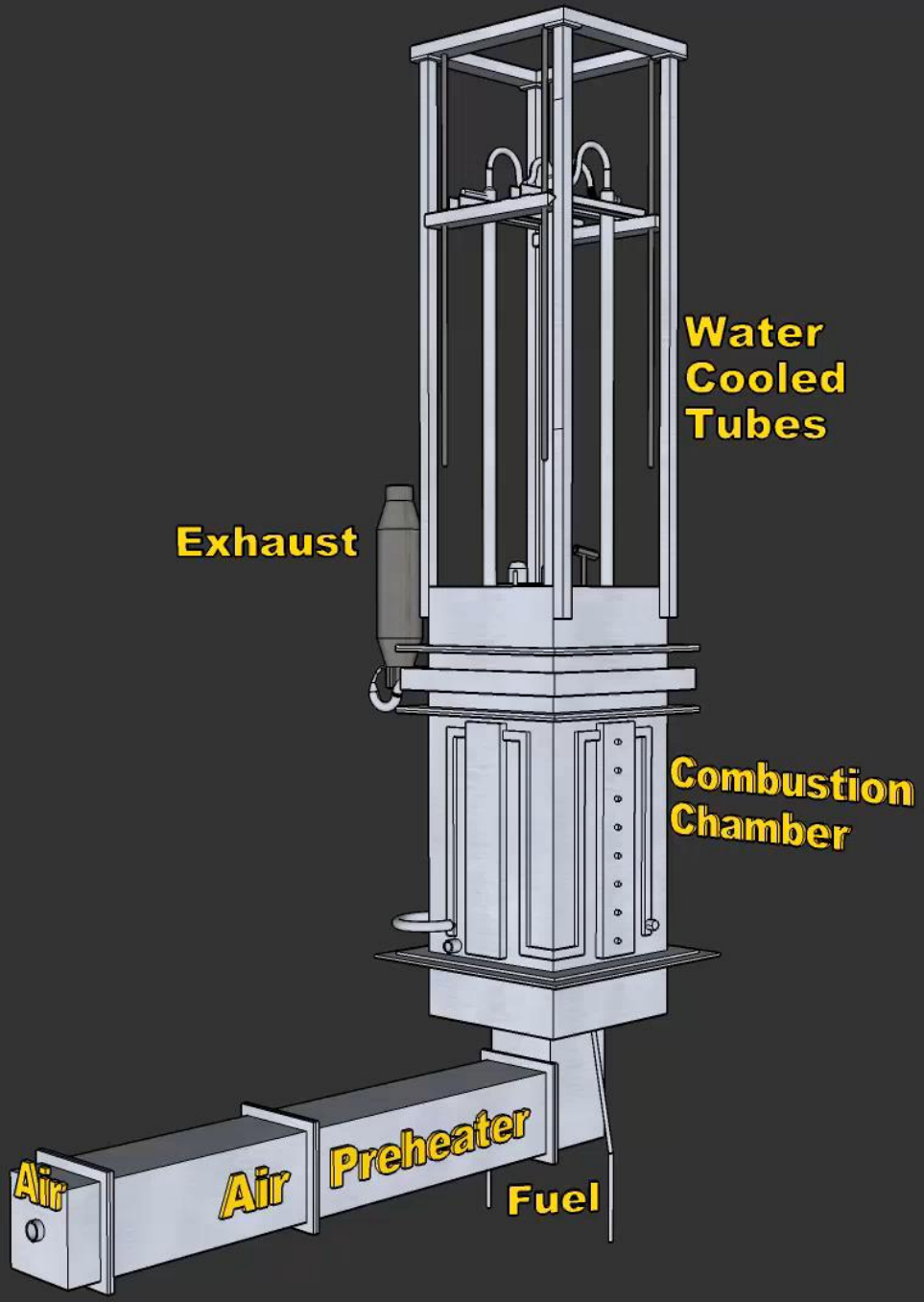


Syngas → LHV 15%

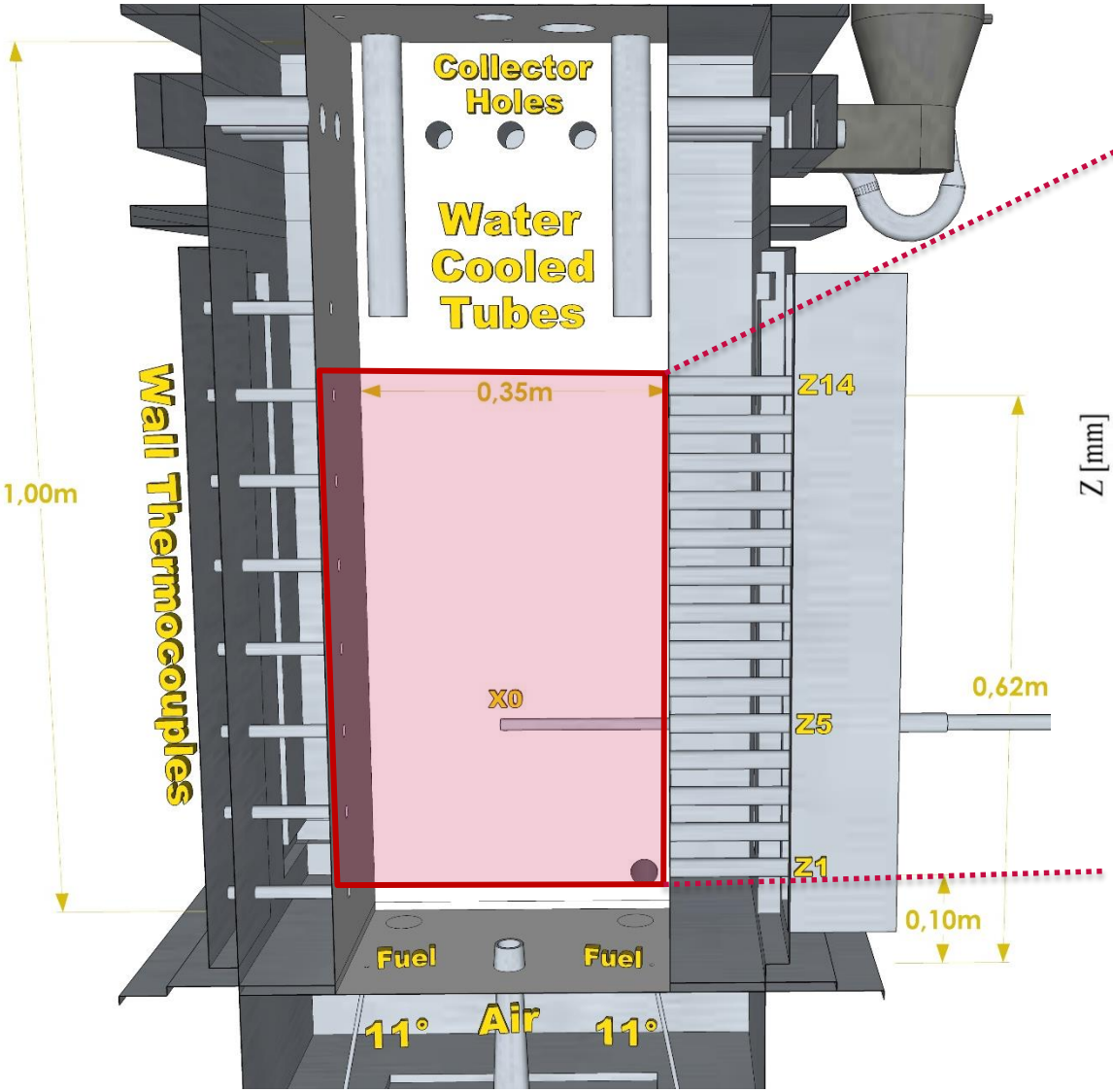
Investigated effects

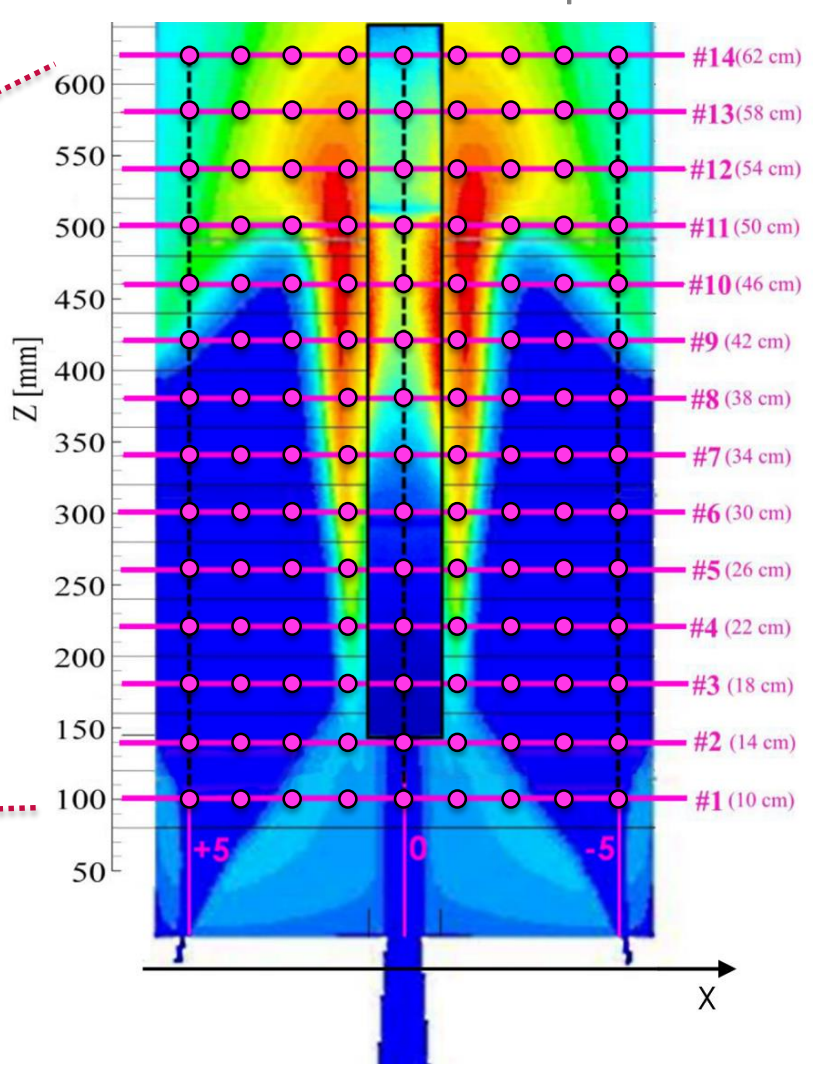
- Air Preheating
- Increase of the load on COG & B50 at low Tair
- CO2 dilution on CH4
- Ø variation for fuel injectors
- Fuel variation

In-furnace measurements of gas concentrations & T for the B50 Mild Combustion


Water
Cooled
Tubes
Exhaust
Combustion
Chamber
Air
Air
Preheater
Fuel

In-Furnace measurements: Map





Test Campaign 2015

8 Days Tests

- Fuel: **B50** - In-Furnace measures
- P_{comb}: **30 kW**
- Ø fuel injectors: **4,5 mm**
- Excess Air: **15%**
- Optical access: **closed**
- Water cooled tubes: **35 cm**
- Air preheating: **800**°C

Main Lab Works

Classical System

New myGC

In-Furnace measurements: before tests

- Fixing CO, H2 & NG leakages
- Insulation glue problem
- Water condensation at chimney
- Pipelines modification

Problems

- Best suction system for the pyroprobe
- p_{Head} on Venturi's tube for pyrometers
- myGC configuration tests
- Latencies study
- Optimization of the procedures

Optimizations

In-Furnace measurements: timing

1. Start the test
2. 1h 30min to get Air at 800°C
3. Start NG → 1h 30min of MILD combustion
4. Switch to B50 → 1h to get stable state
5. Start sampling → 7 min each measure
   + switching to the next level

1h 30min for a complete profile

In-Furnace measurements: the job

Gas Sampling Probe

Pyrometer Probe

In-Furnace measurements: the job

Gas Sampling Probe

Pyrometer Probe

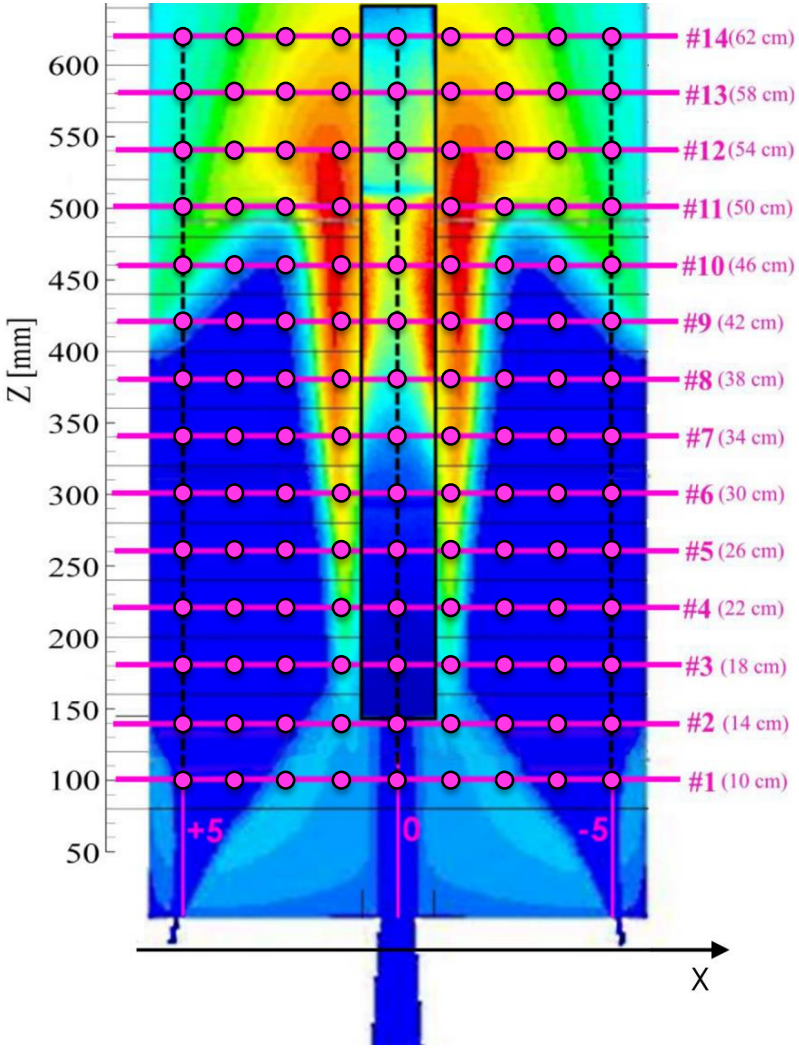
In-Furnace measurements: the job

Gas Sampling Probe

Pyrometer Probe

In-Furnace measurements: the results

OH* - Sim VS Exp



154 mapped points (11x14)

Classical System

- T
- O2 - CO2(x2) - CO(x2) - CH4 – NO

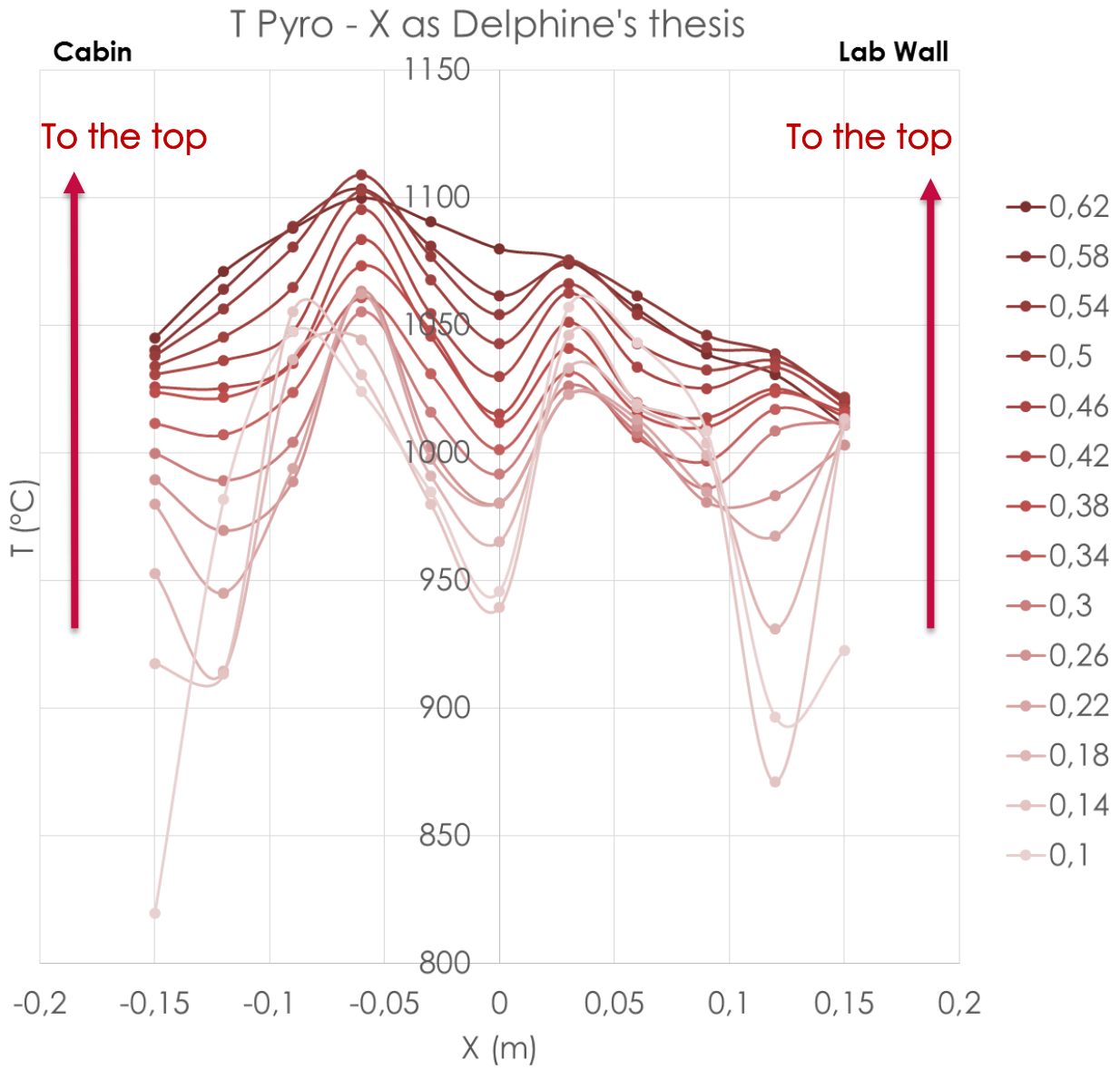
New myGC (x2)

- H2 - O2 - CO – CH4

…& 60 flue gases measures at exhaust

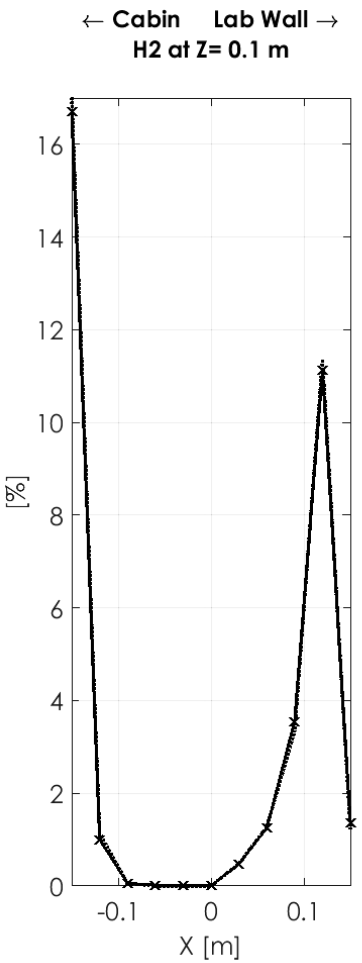
676 Samples!

In-Furnace measurements: T_{flue}

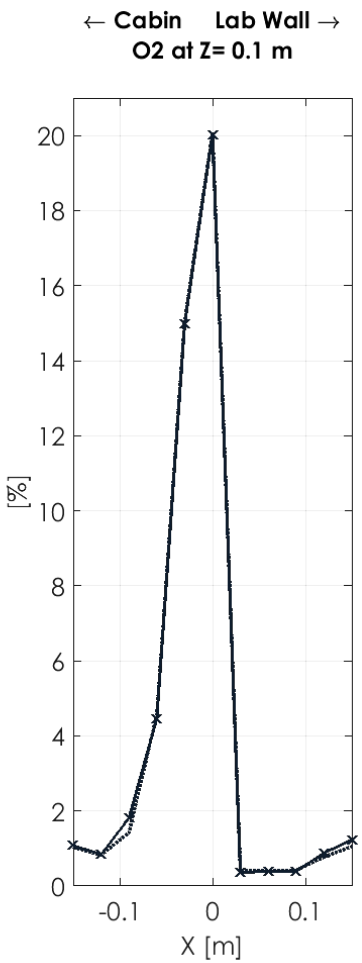


Labview Data

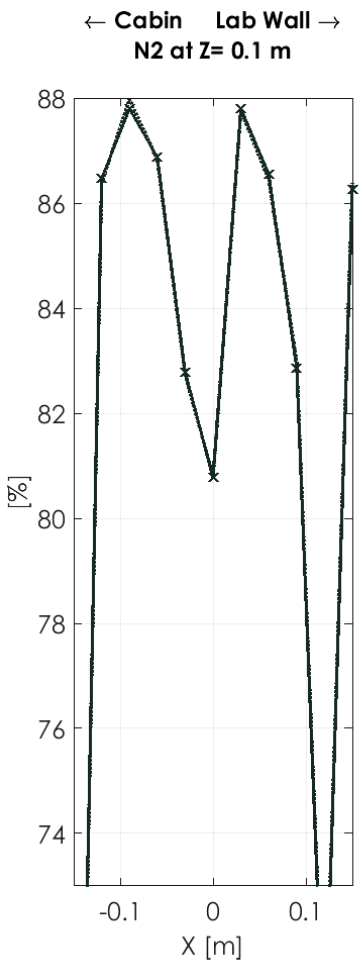
In-Furnace measurements: myGC profiles



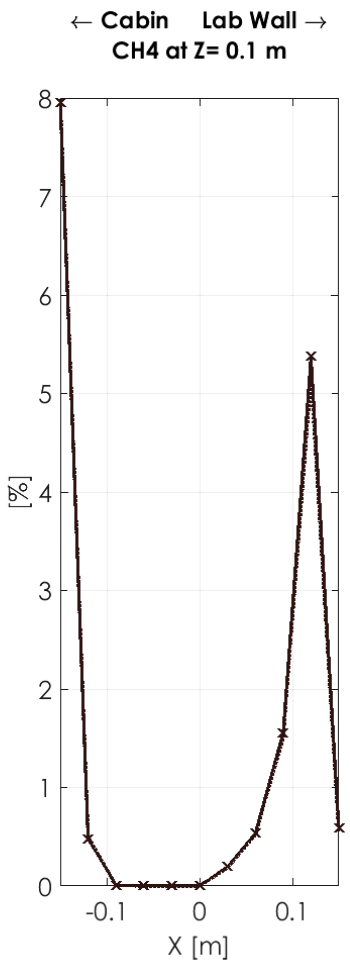
H2



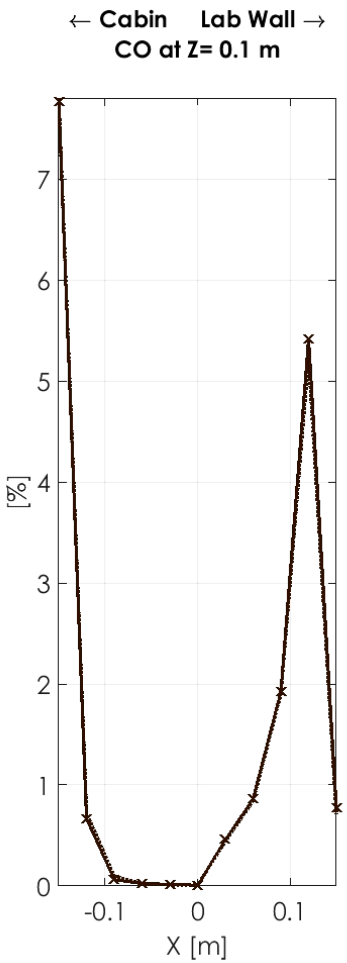
O2



N2



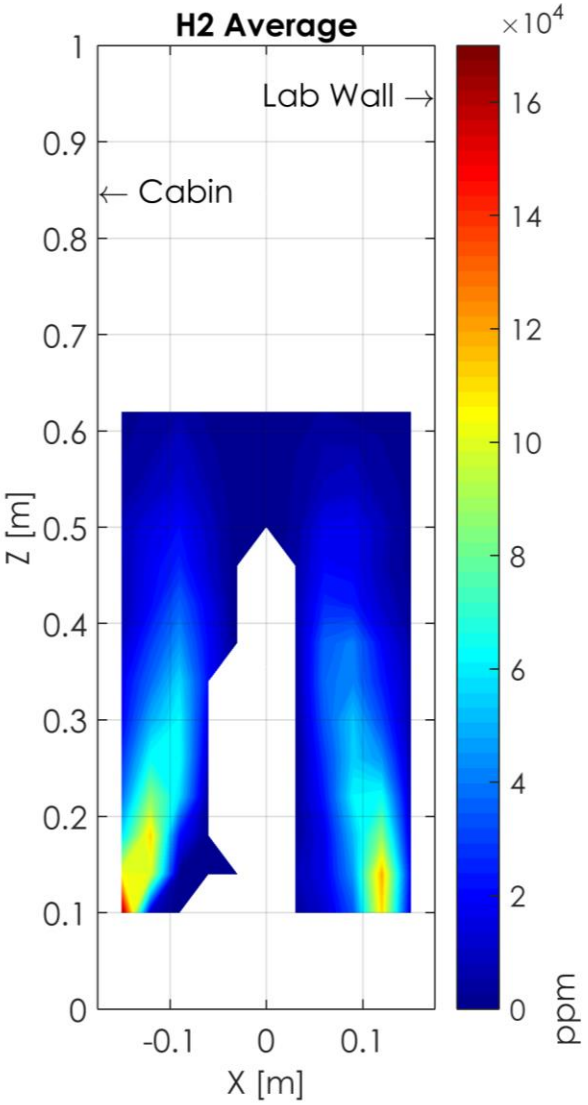
CH4

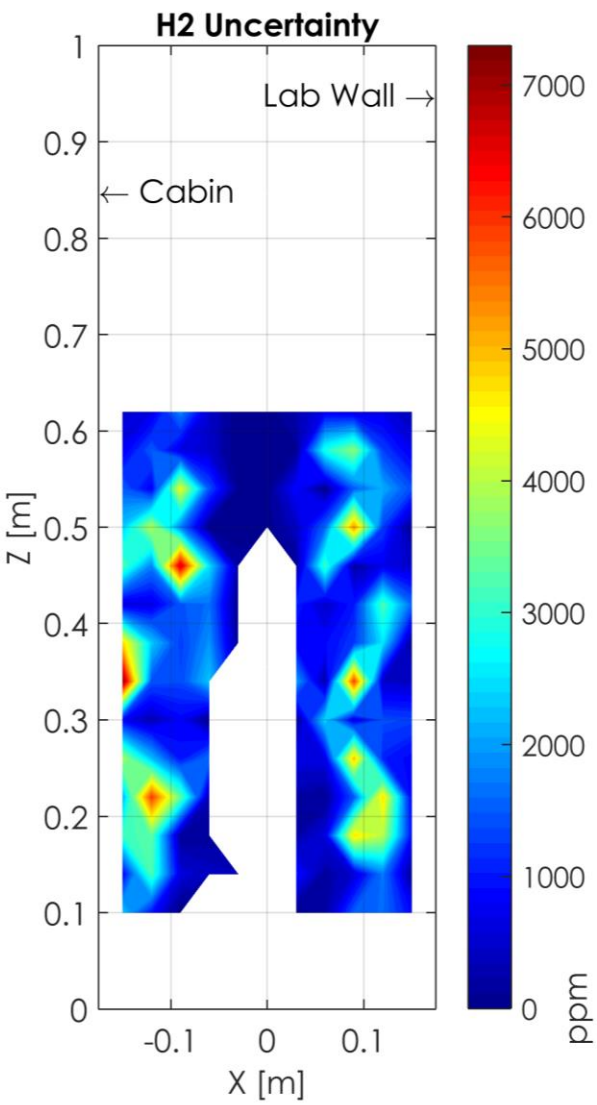


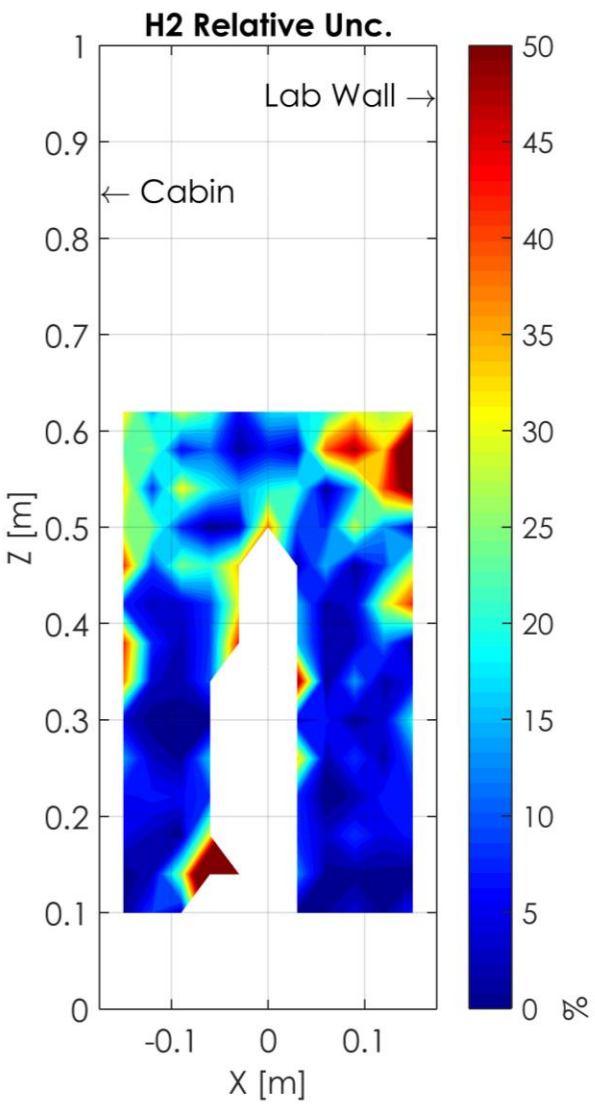
CO

In-Furnace measurements: H2

myGC data

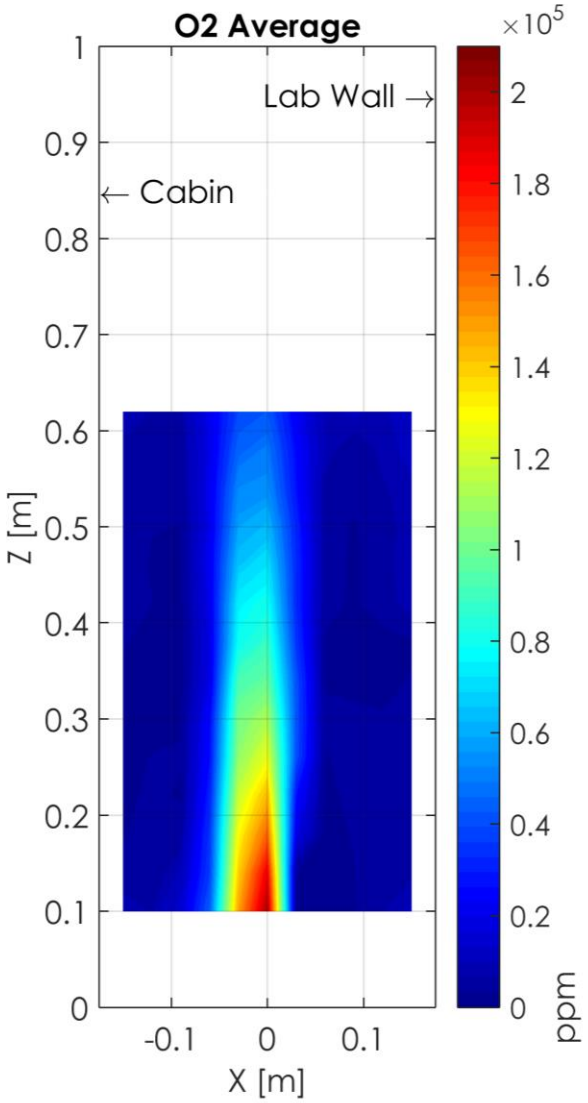


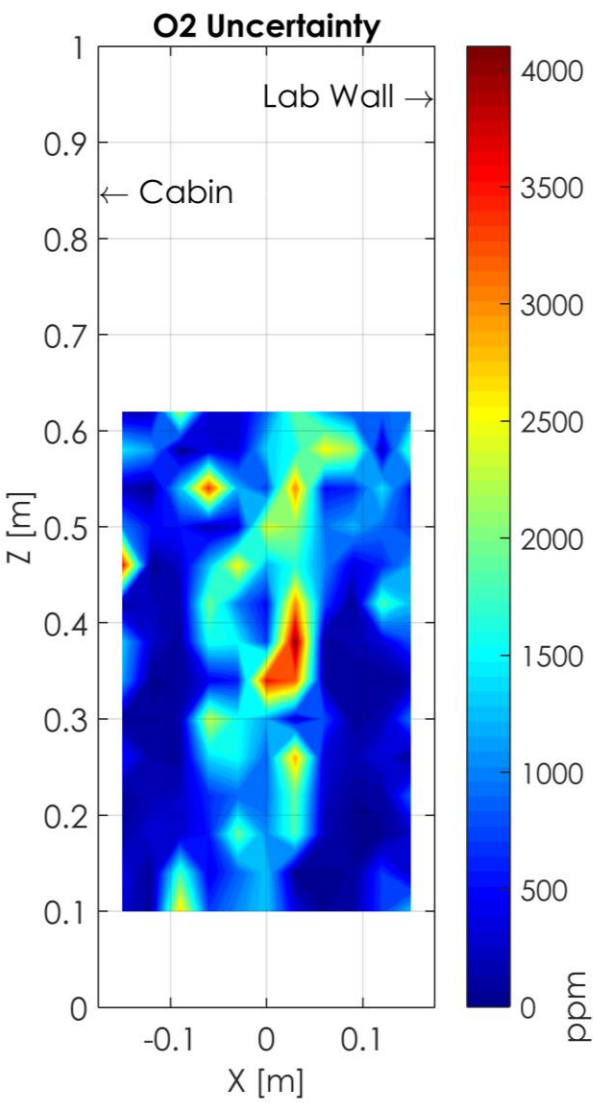


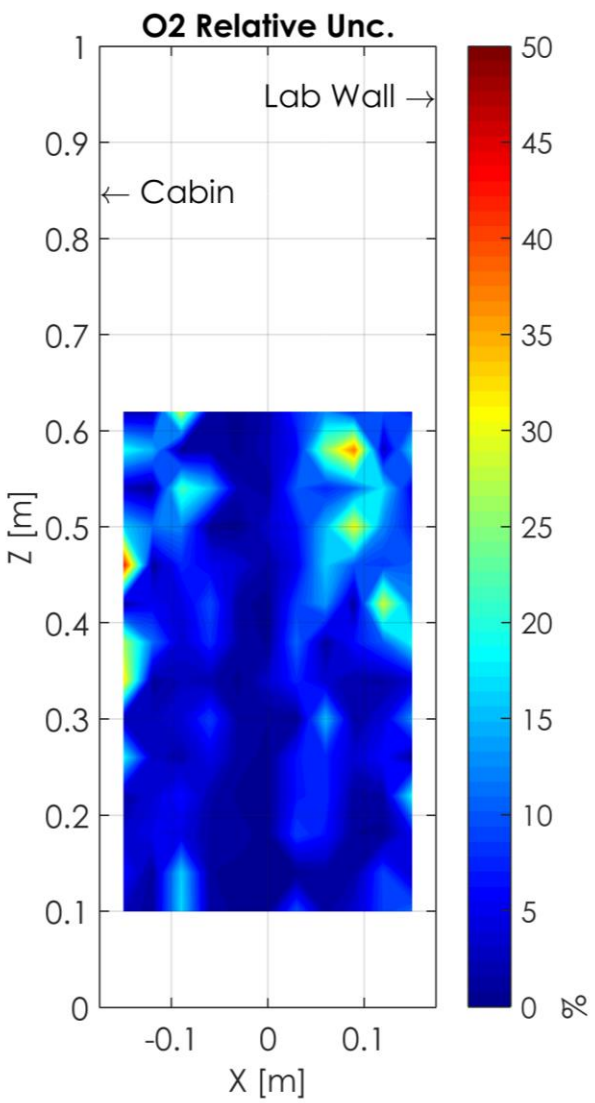


In-Furnace measurements: O2

myGC data

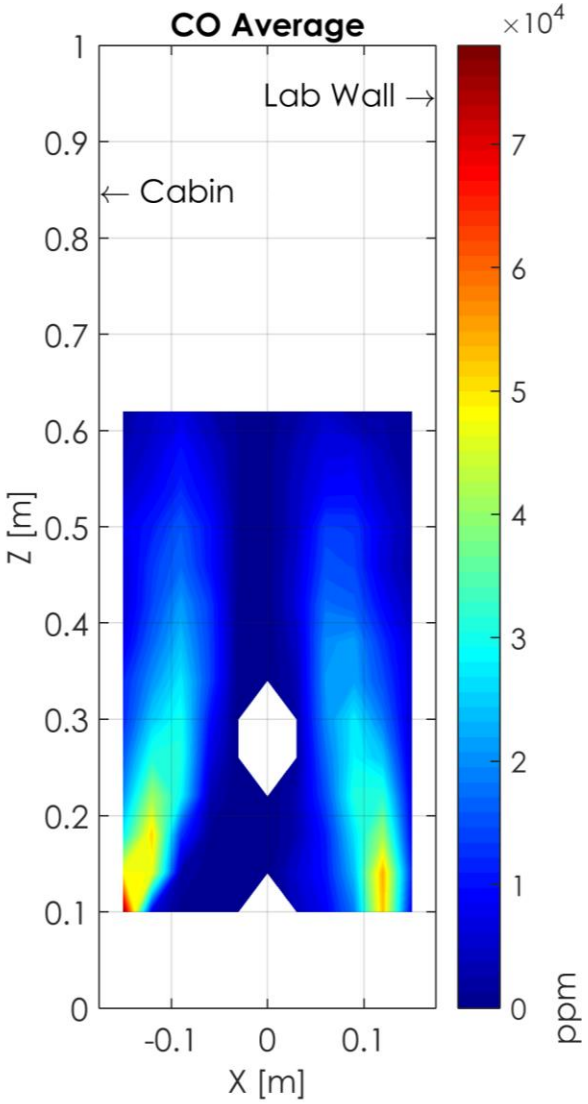


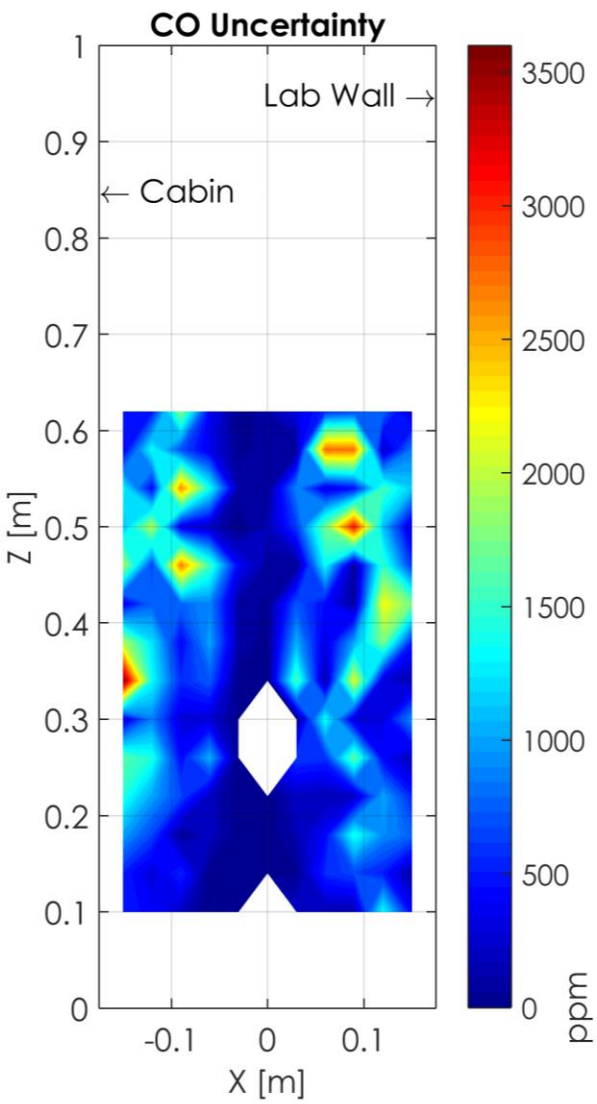


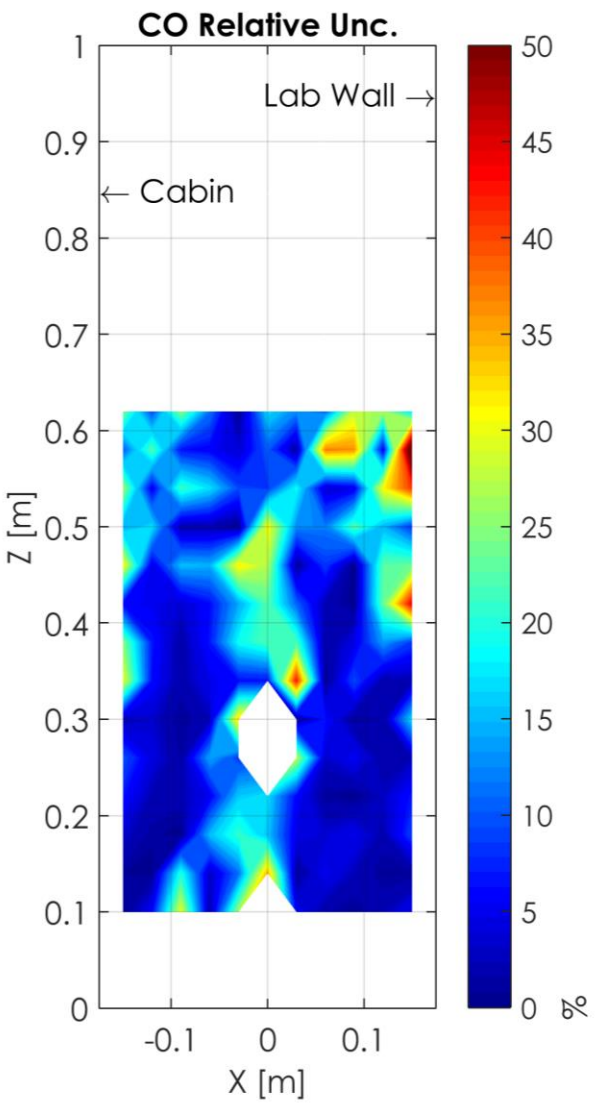


In-Furnace measurements: CO

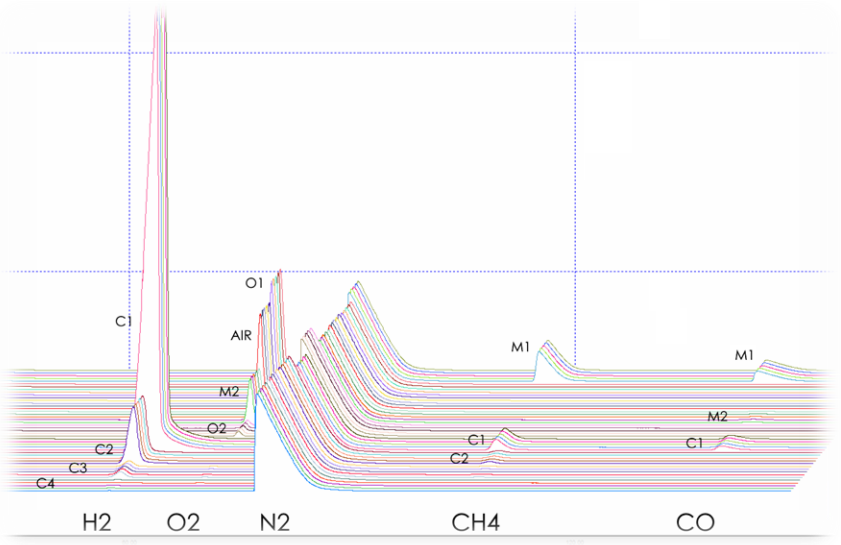
myGC data







Behind the Uncertainties



Modified Least Square approach

$$A = \beta_1 + \beta_2 x + e - \beta_2 \omega$$

2 error sources:
- e → myGC
- ω → gas bottle

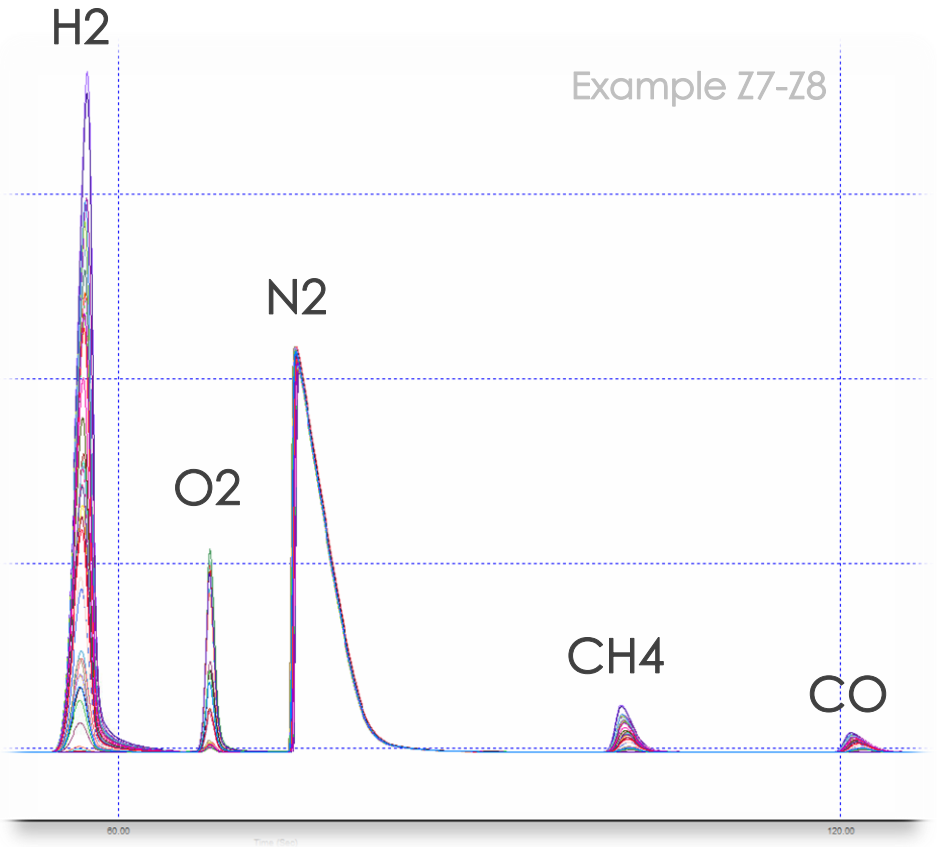
- BIAS
- Inconsistency
- Heteroscedasticity

$$var(b_2) = \frac{var(e)}{\sum_{i=1}^{N}(x_i - \bar{x})^2} + b_2^2 \sum_{i=1}^{N} w_i^2 var(\omega_i)$$

$$var(b_1) = var(e)\frac{\sum_{i=1}^{N} x_i^2}{N\sum_{i=1}^{N}(x_i - \bar{x})^2} + b_2^2 \frac{var(\omega)}{N} + b_2^2 \bar{x}^2 \sum_{i=1}^{N} w_i^2 var(\omega_i) - \frac{2\bar{x}}{N} b_2^2 \sum_{i=1}^{N} w_i var(\omega_i)$$

$$cov(b_1, b_2) = -\frac{var(e)\bar{x}}{\sum_{i=1}^{N}(x_i - \bar{x})^2} - b_2^2 \bar{x}^2 \sum_{i=1}^{N} w_i^2 var(\omega_i) + \frac{b_2^2}{N} \sum_{i=1}^{N} w_i var(\omega_i)$$

Behind the Uncertainties



$$x = \frac{A - b_1}{b_2}$$

Once the 3rd error source(σ_A) is estimated…

The error propagation

$$\sigma_x^2 = \left(\frac{\partial x}{\partial b_1}\right)^2 var(b_1) + \left(\frac{\partial x}{\partial b_2}\right)^2 var(b_2) + \left(\frac{\partial x}{\partial A}\right)^2 \sigma_A^2 + 2\frac{\partial x}{\partial b_1}\frac{\partial x}{\partial b_2} cov(b_1, b_2)$$

Conclusions & Work in progress

- Good coherence of the data
  - Next
    - Matching the data from different GA
    - Finalize & extend uncertainty model
- There are asymmetries ➡ understanding of sources
- Long & short sampling ➡ understanding of fluctuations related to the fluid dynamics
- Additional data
  - Next
    - effect of probe insertion in the chamber
    - changes of power balances during the days

Thank you

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