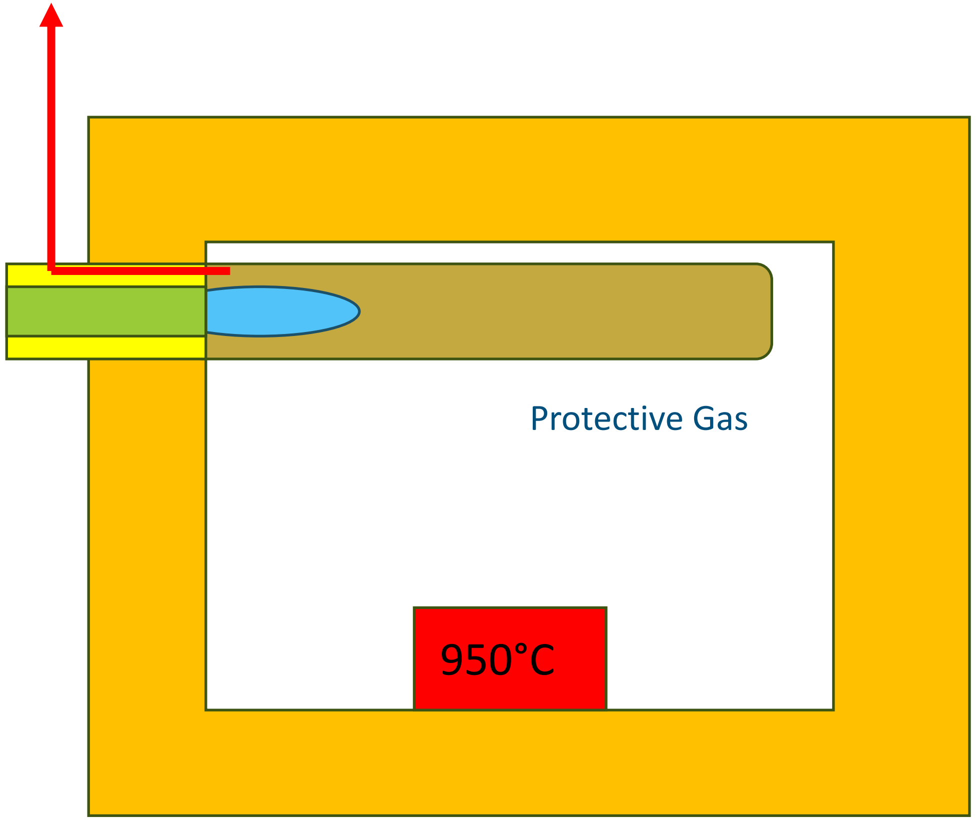
Pollution in combination with indirect heating in a small sized single ended radiant tube

1. German Rule 44.BImSchV
2. First experiences
3. Motivation for ultra Low NO_x
4. New Design Mach2®
5. Results
6. Summary



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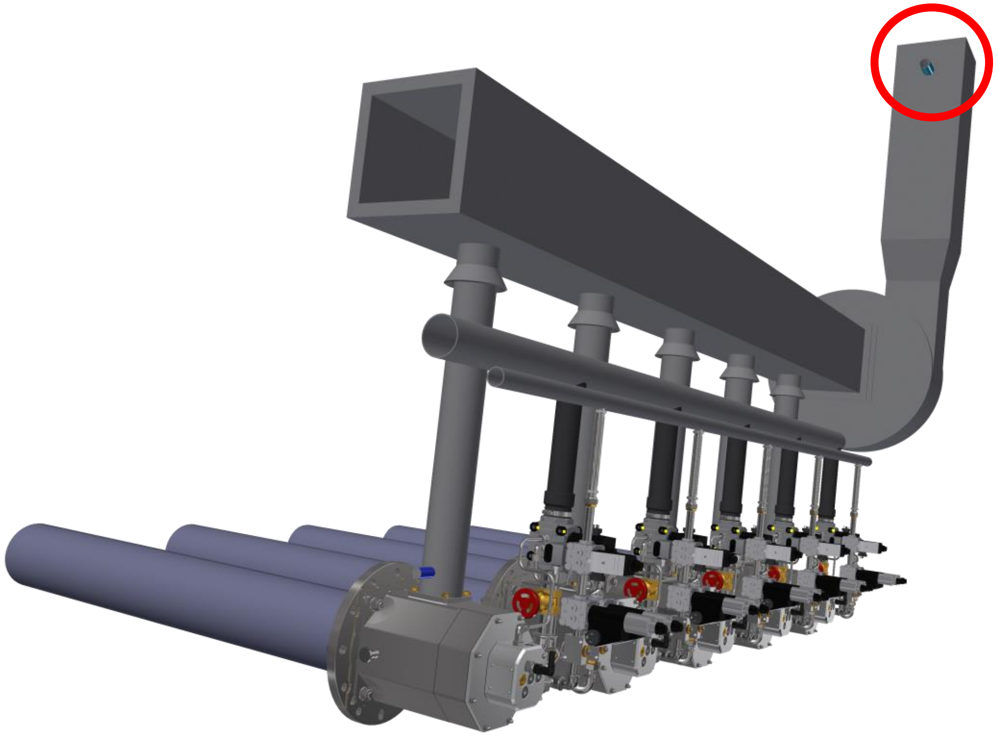
1. German Rule 44. BImSchV

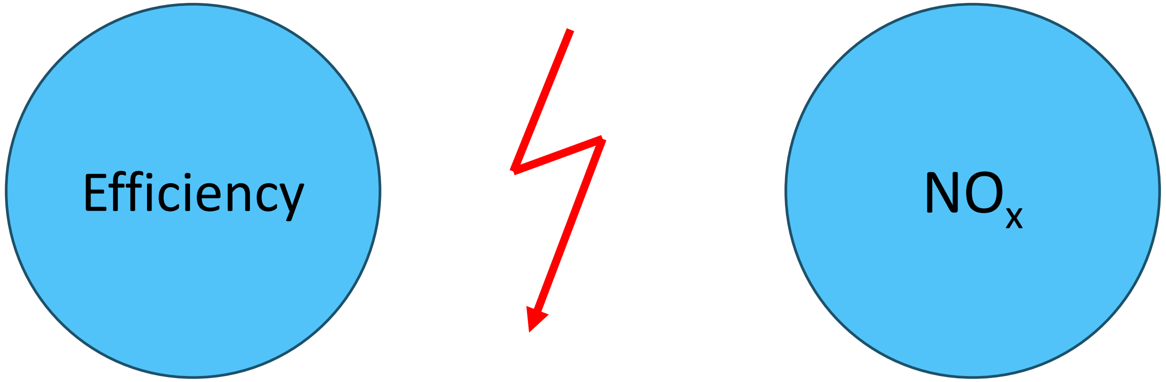
- Based on European Rule MCP 2015/2193
- 1 up to 10 MW
- Indirect Heating
- Gaseous fuel

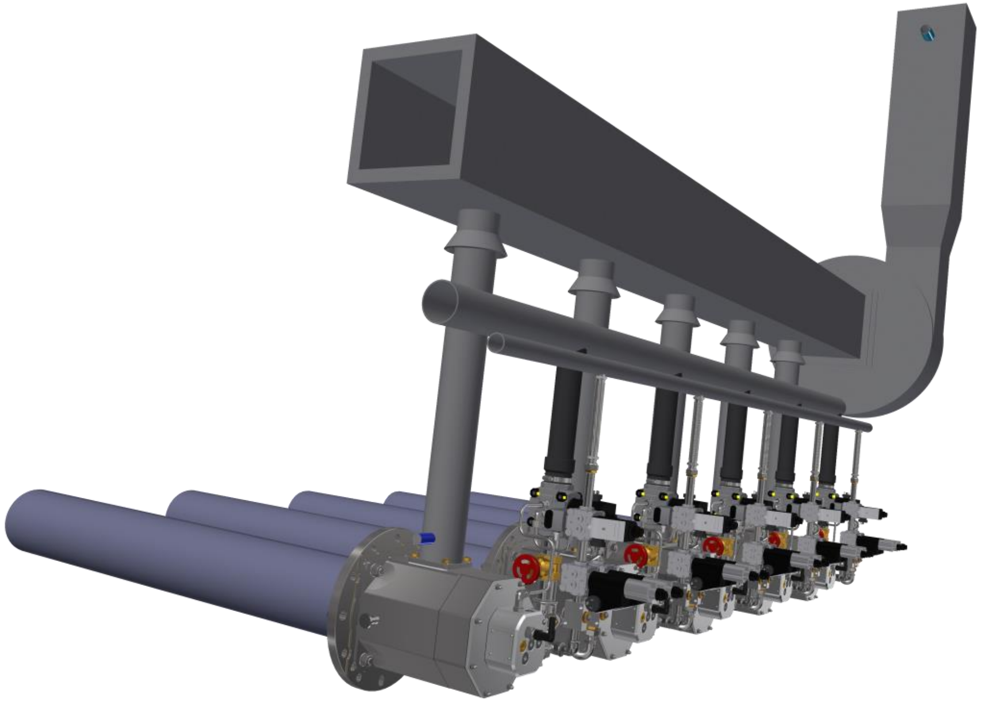
- Plant must be registered
- Valid since 1.1.2025
- Efficiency better than 91%
- NOx < 100mg/Nm³ @ 3% O2 in dry POC
- CO < 80mg/Nm³ @ 3% O2 in dry POC
- Measurement at the main stack



Only the knowledge to reduce NO_x

opens the option to increase efficiency





2. First experiences

1. Request for efficiency and NO_x-value

A 70% and 350 mg/Nm³ @ 3% O_2

B 70% and 100 mg/Nm³ @ 3% O_2

C 80% and 100 mg/Nm³ @ 3% O_2

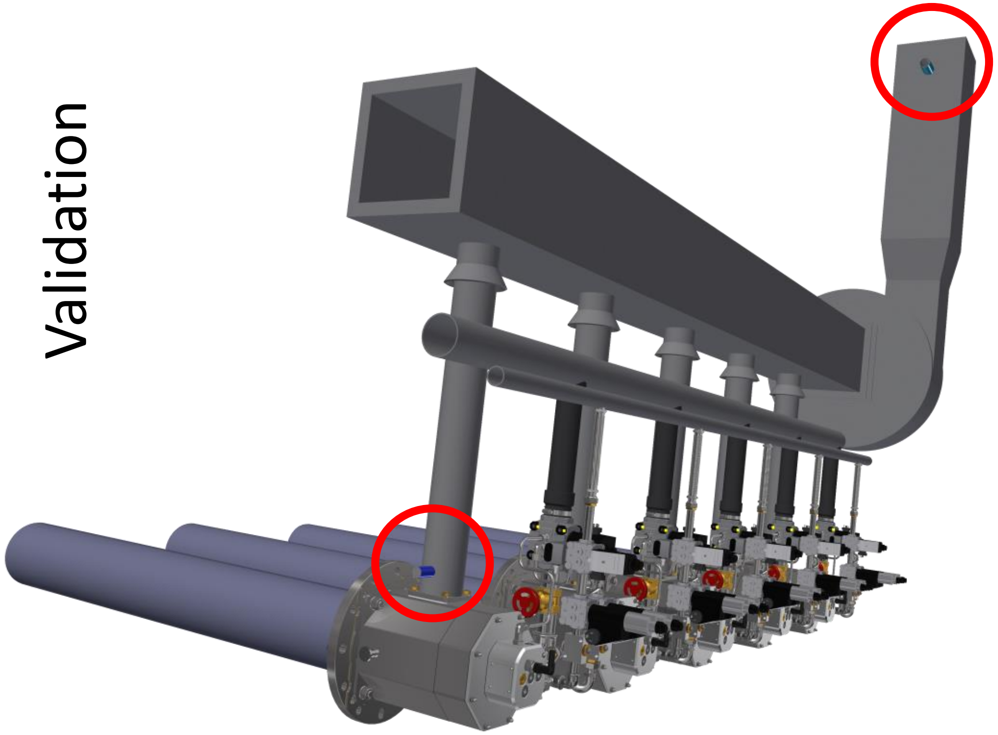
2. First experiences

1. Request for efficiency and NOx-value
   - Selection of combustion system
     - Geometrie of furnace
     - Temperature
     - Type of radiant tube and recuperator
     - Type of fuel
     - Net capacity for each radiant tube
     - Type of NOx-reduction-system

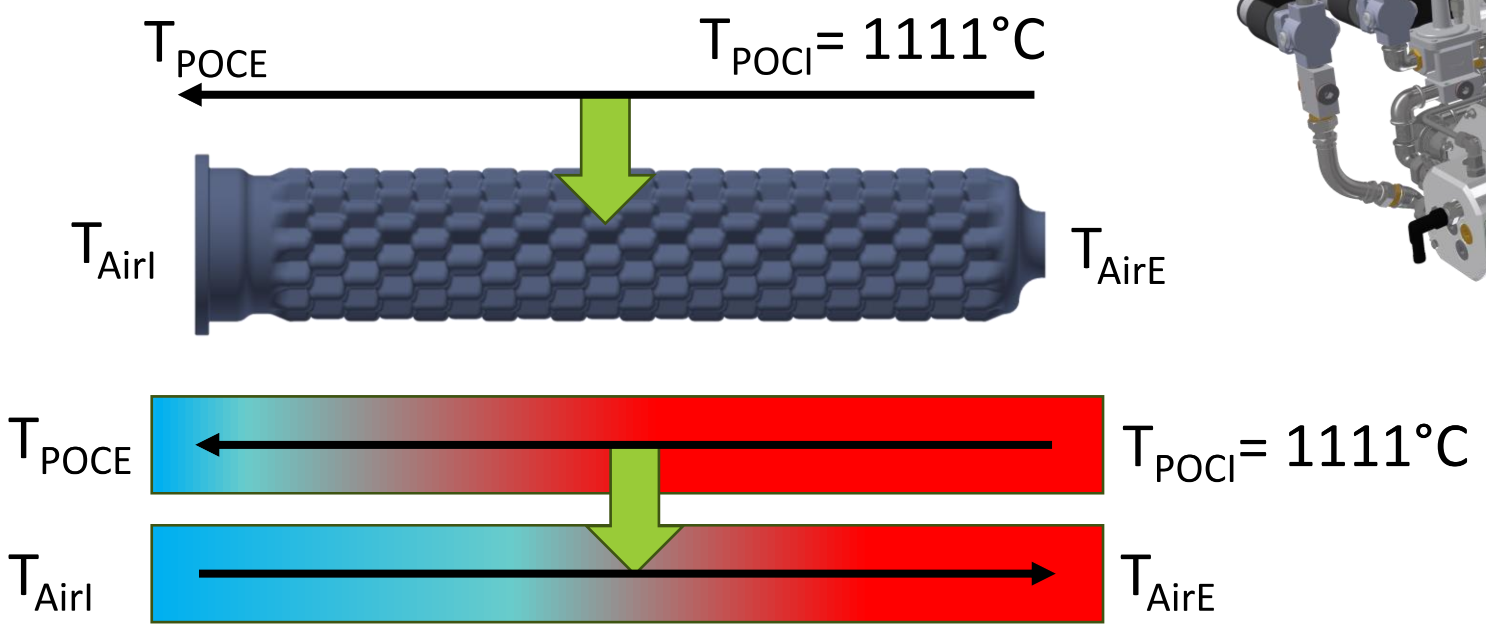
2. Laboratory test

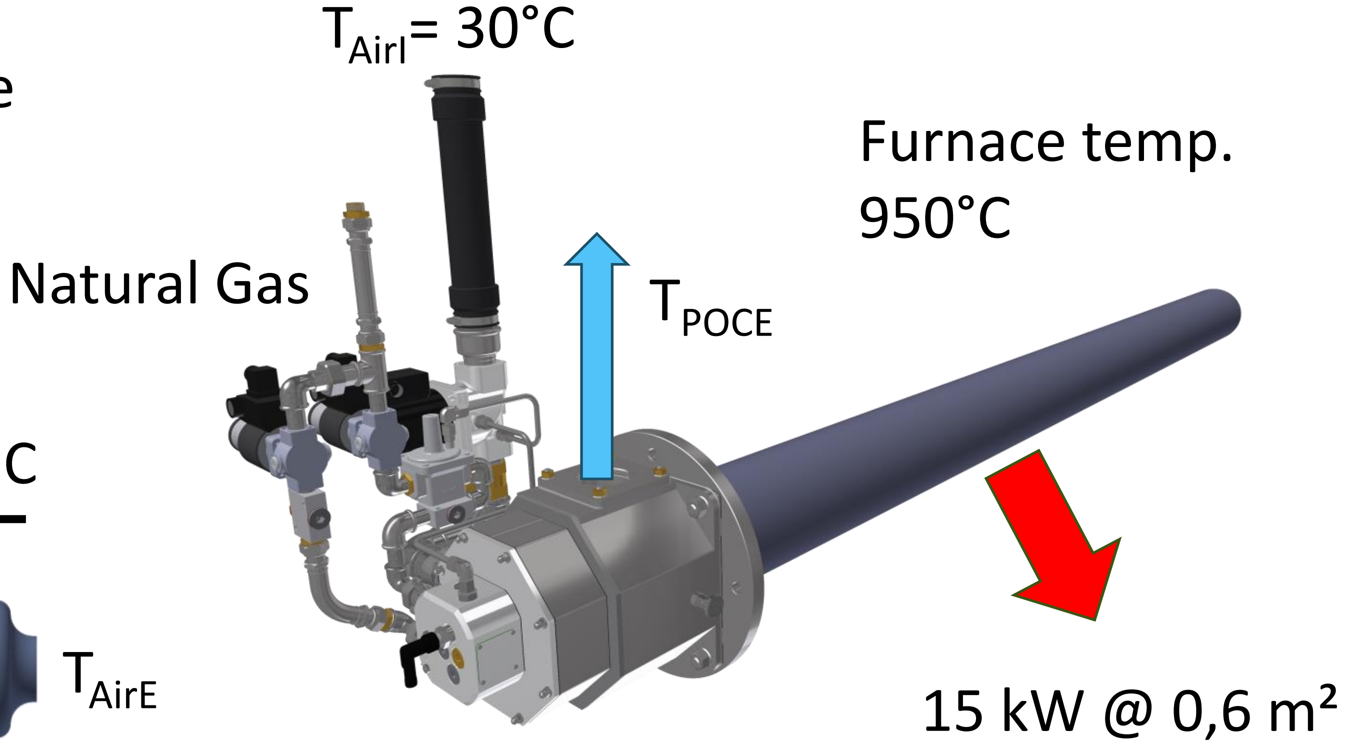
3. Measurement onsite
   - Individual burner
   - Main stack

Validation



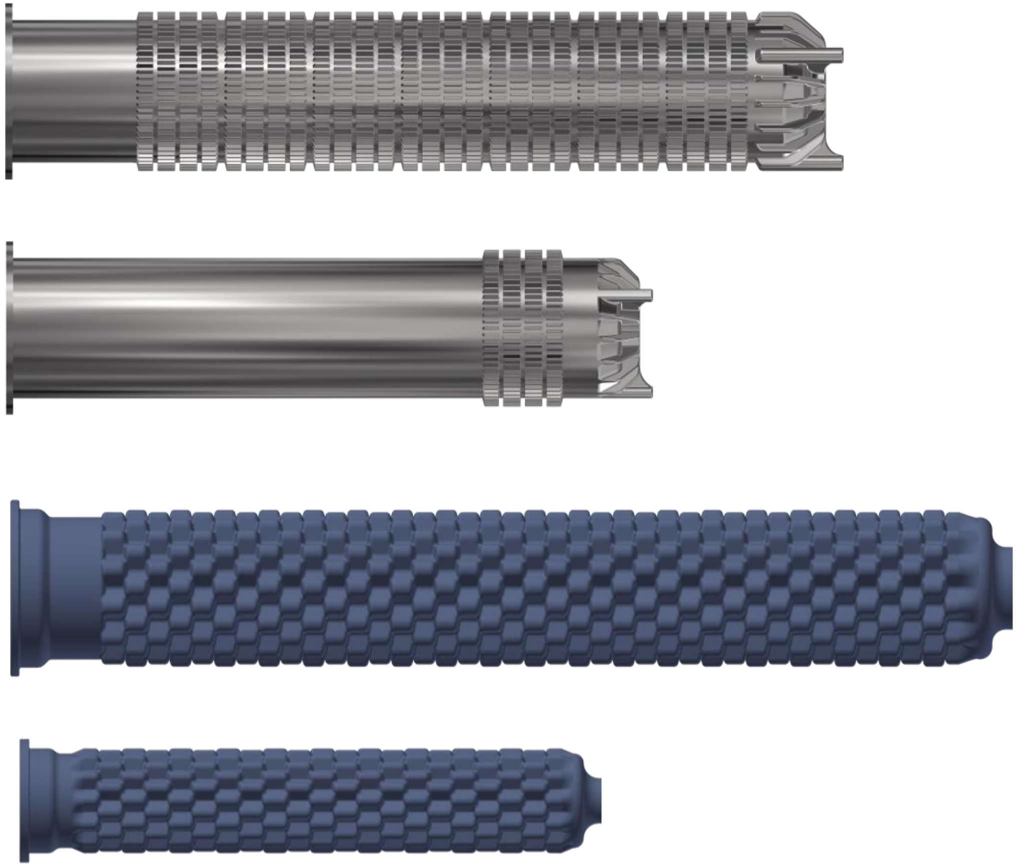
1. Request for efficiency and NO_x-value
   - Selection of combustion system





Type of
Recuperator

Portfolio by Econova



All for the same capacity

2. First experiences

Type of NO_x-reduction-system

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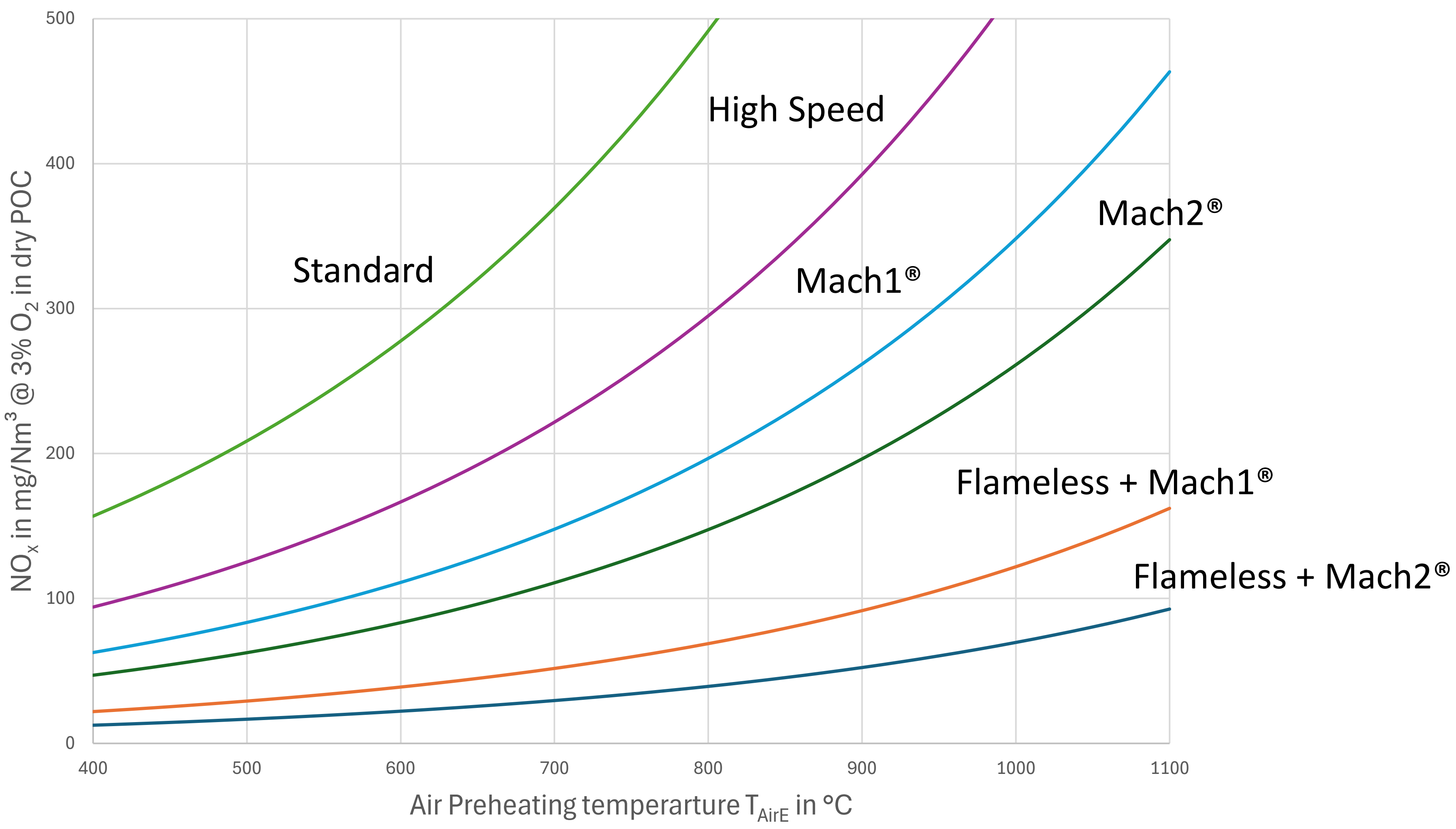
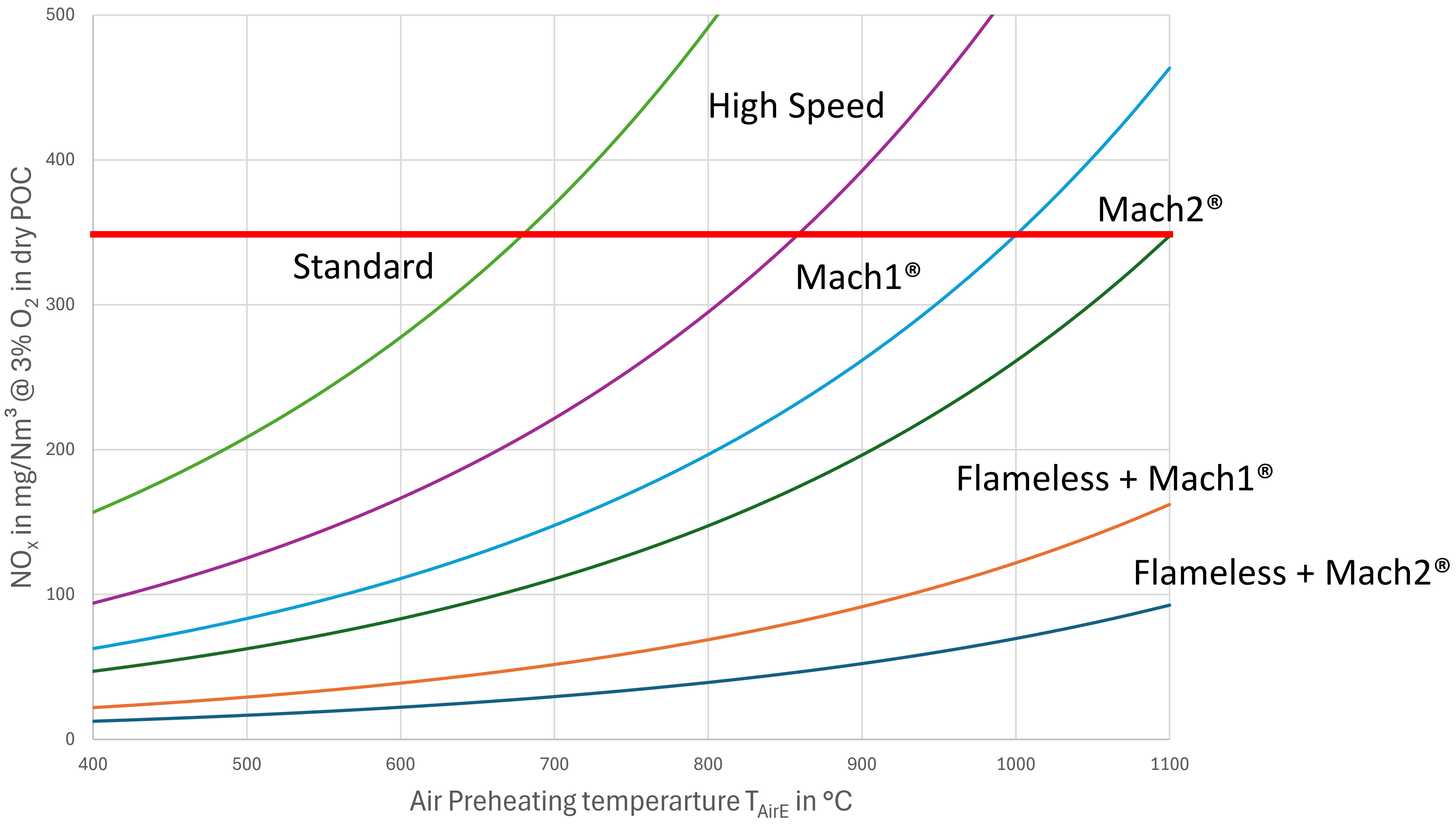


2. First experiences

Type of
NO_x-reduction-system

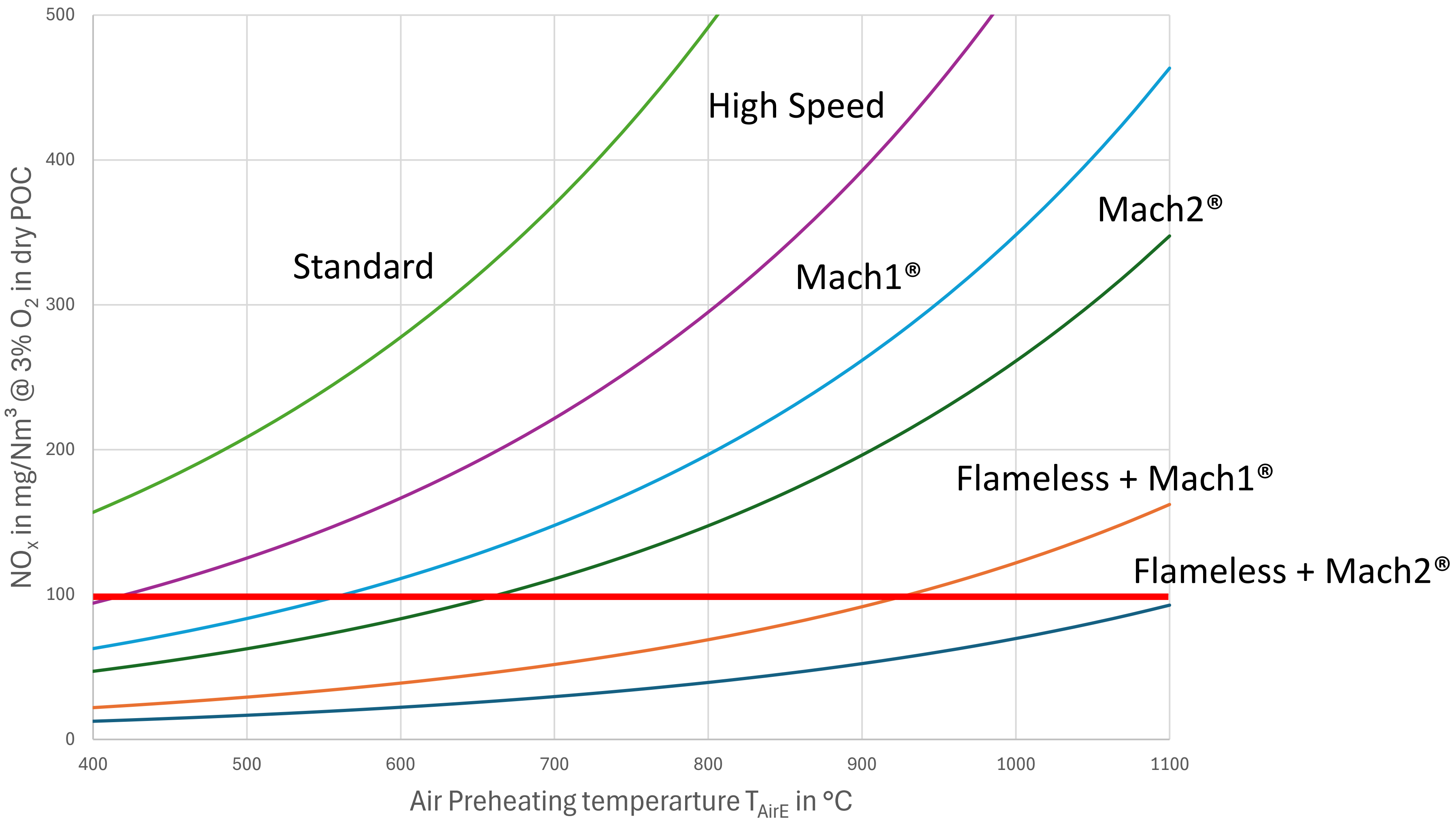
Portfolio by Econova



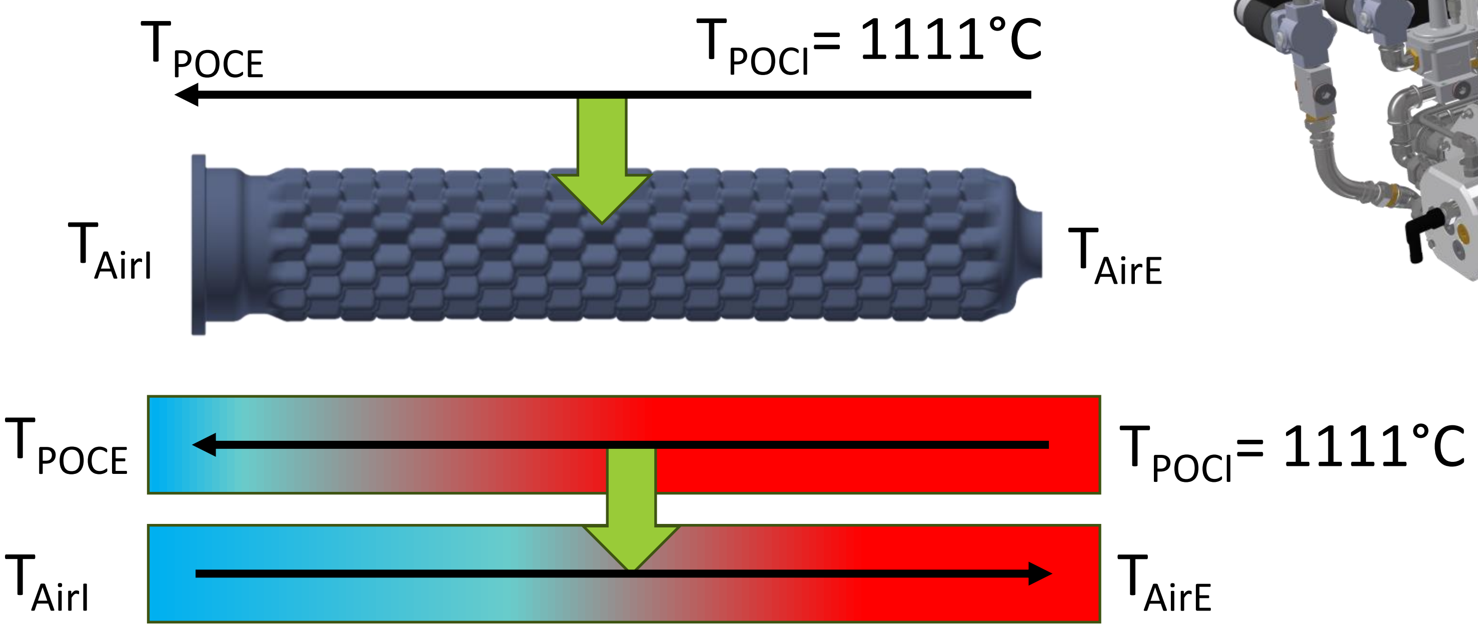
2. First experiences

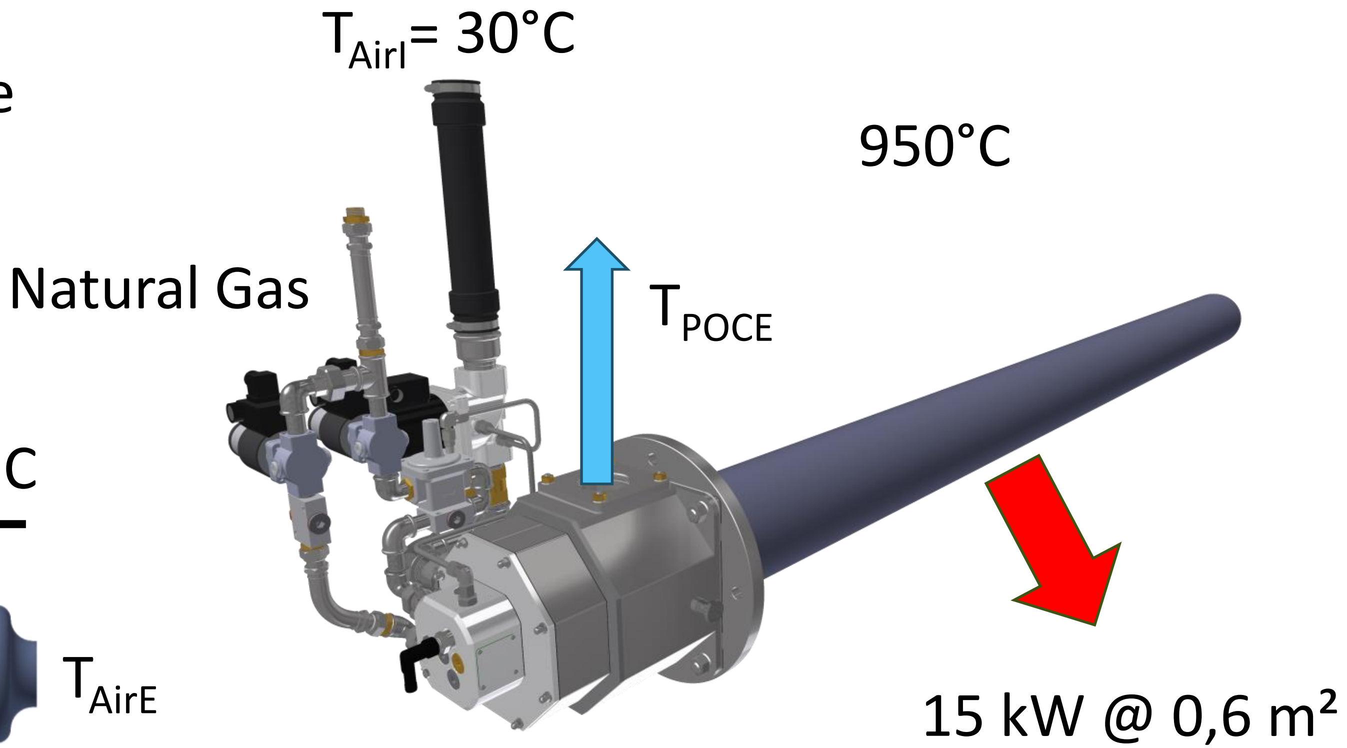
Type of
NO_x-reduction-system

Portfolio by Econova



1. Request for efficiency and NO_x-value
   - Selection of combustion system



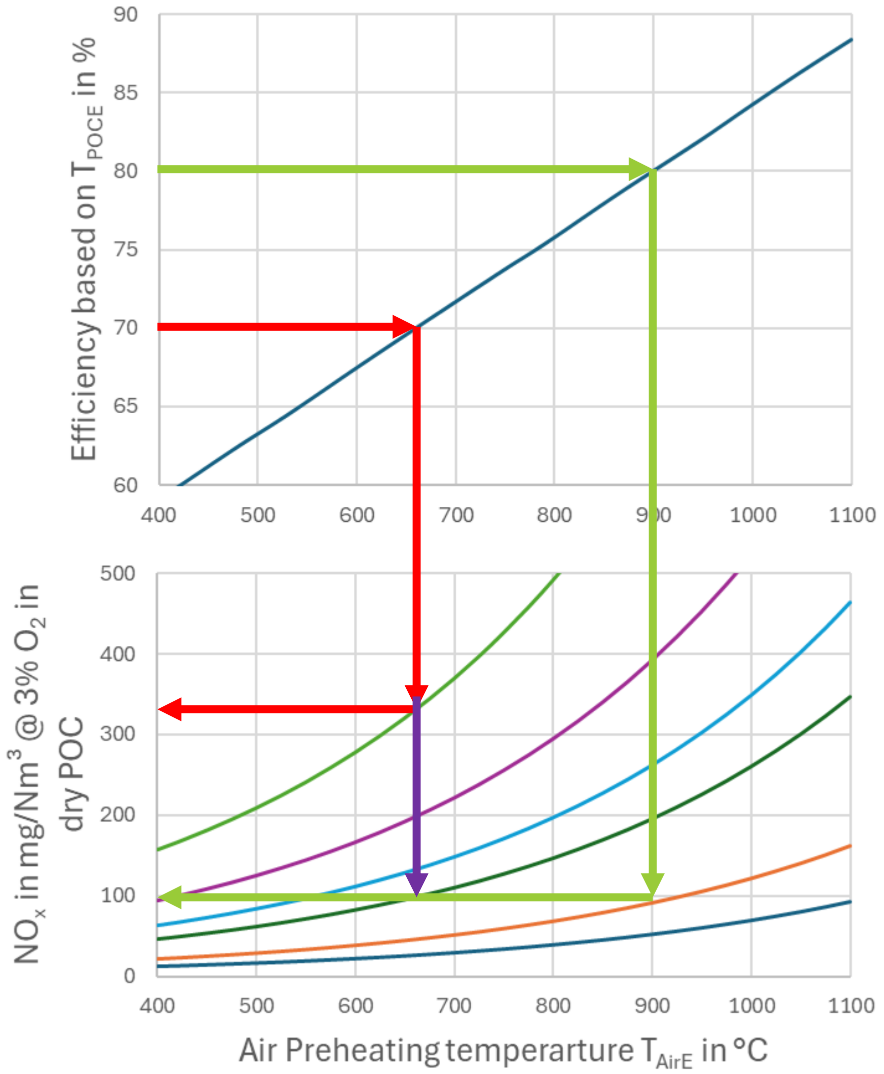


1. Request for efficiency and NO_x-value

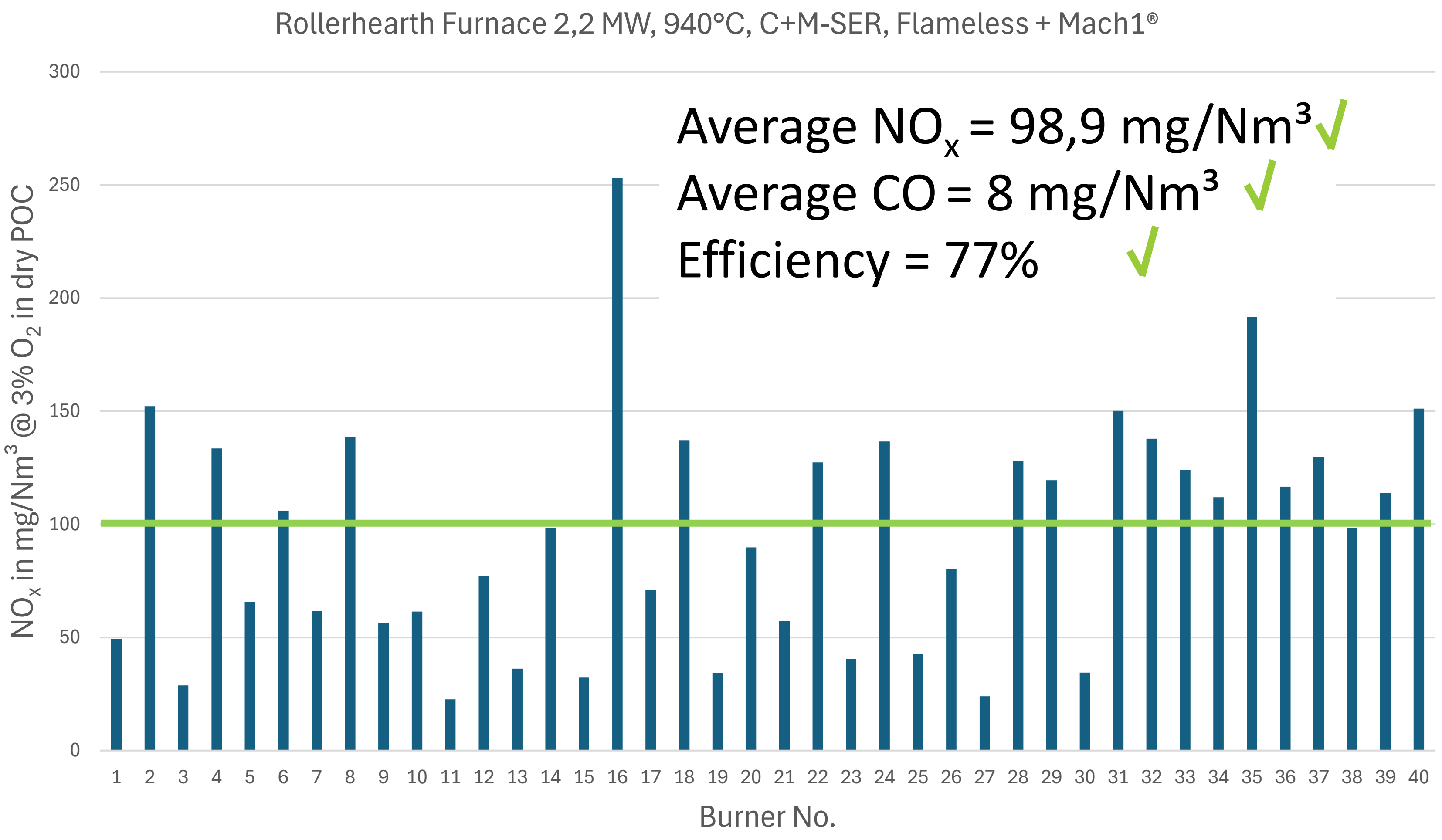
A 70% and 350 mg/Nm³ @ 3% O_2
NOx-reduction-system:
Standard

B 70% and 100 mg/Nm³ @ 3% O_2
NOx-reduction-system:
Mach1®

C 80% and 100 mg/Nm³ @ 3% O_2
NOx-reduction-system:
Flameless + Mach1®



2. Laboratory / Single burner

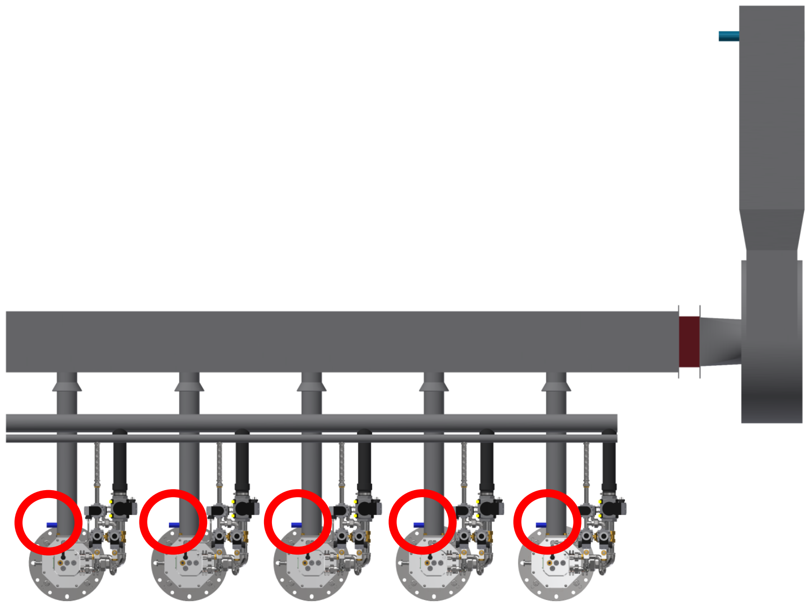


Laboratory

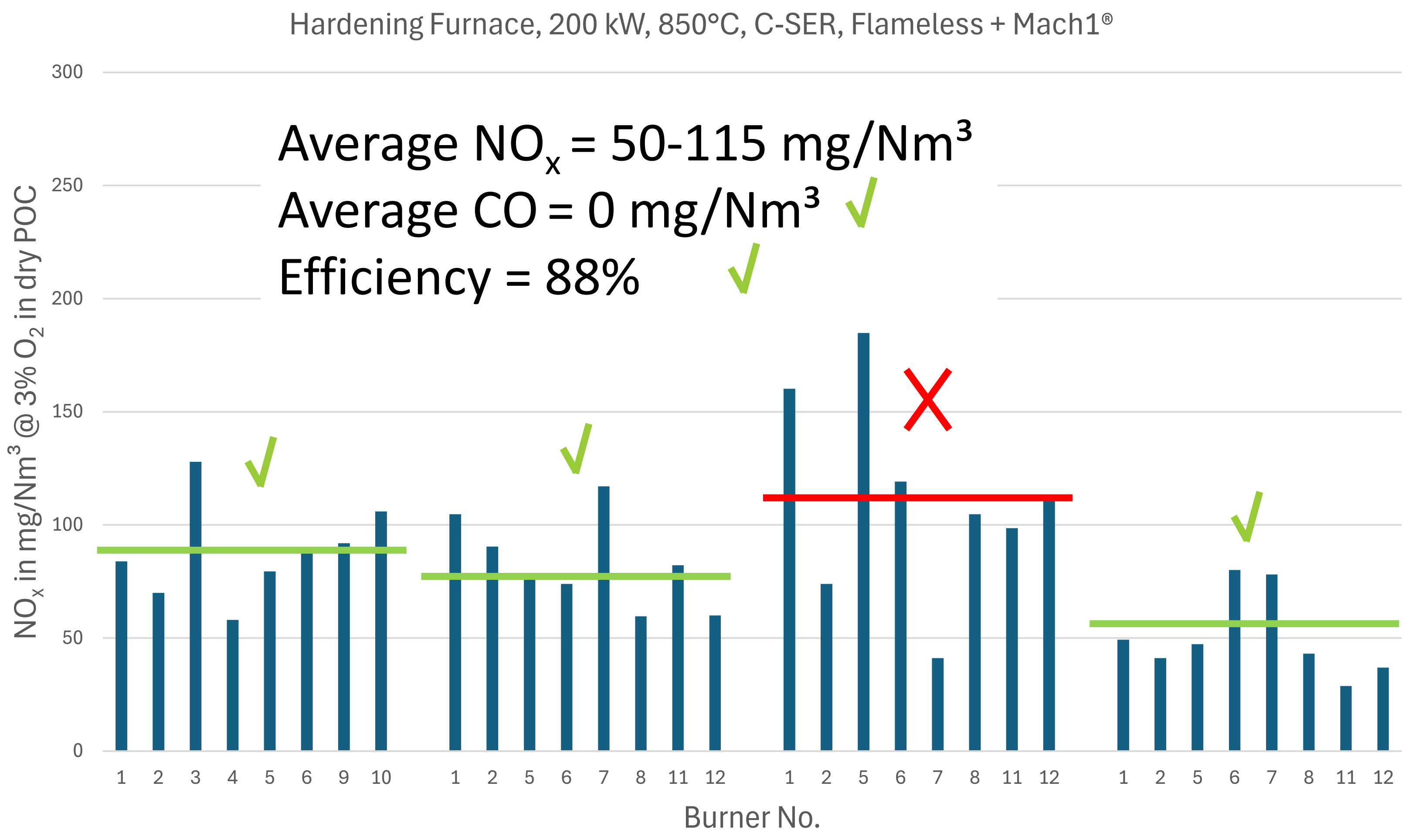
NO_x = 70 mg/Nm³

CO = 0 mg/Nm³

Efficiency = 75%



2. Laboratory / Single burner

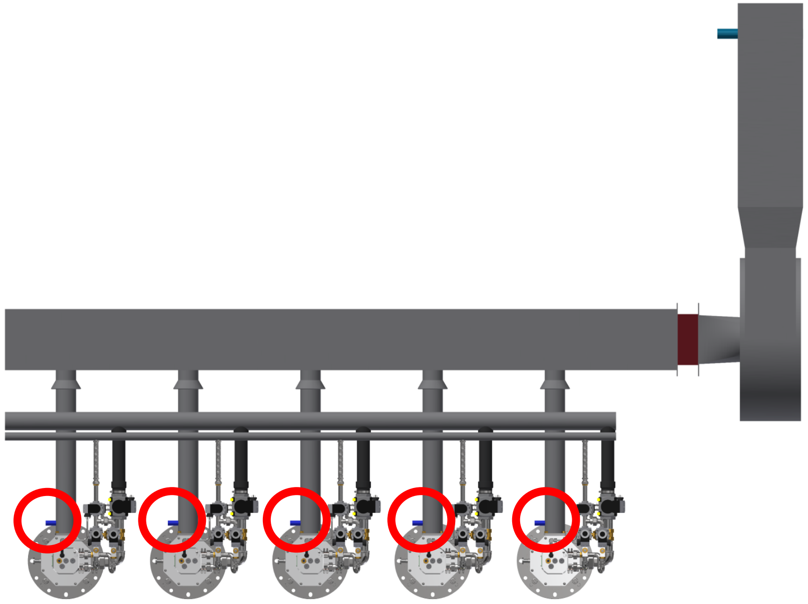


Laboratory

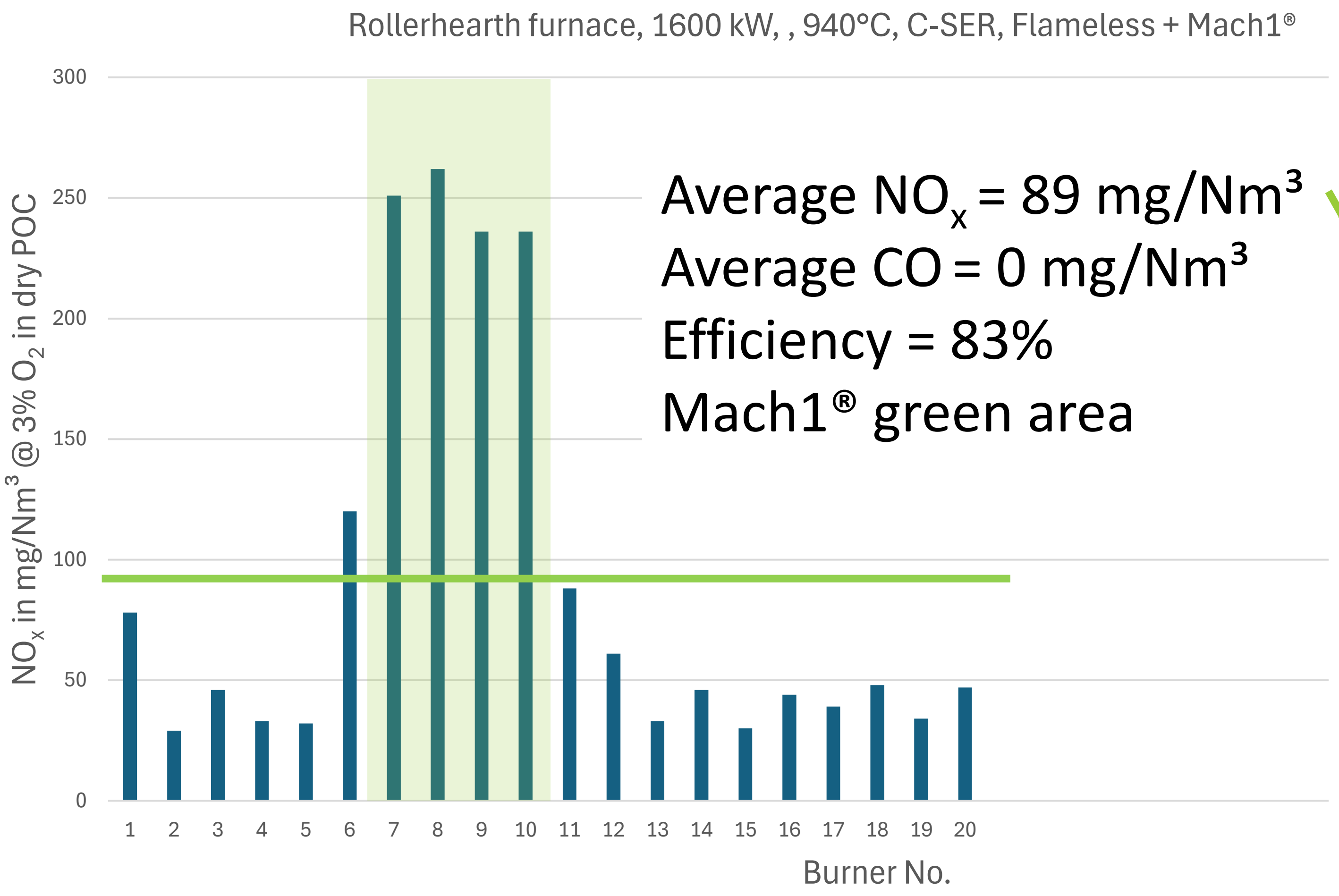
NO_x = 60 mg/Nm³

CO = 0 mg/Nm³

Efficiency = 83%



2. Laboratory / Single burner



Average NO_x = 89 mg/Nm³ ✓

Average CO = 0 mg/Nm³

Efficiency = 83%

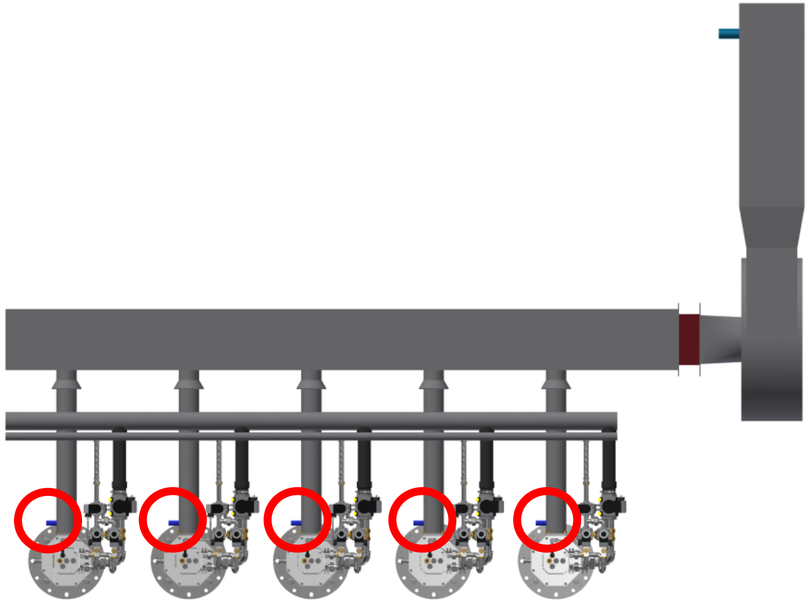
Mach1® green area

Laboratory

NO_x = 60 mg/Nm³

CO = 0 mg/Nm³

Efficiency = 80%



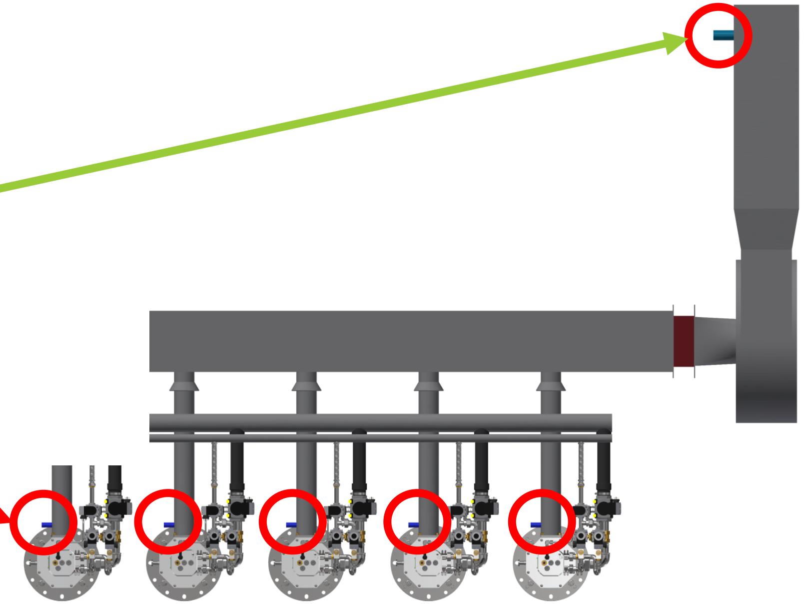
2. First experiences

Interim Summary

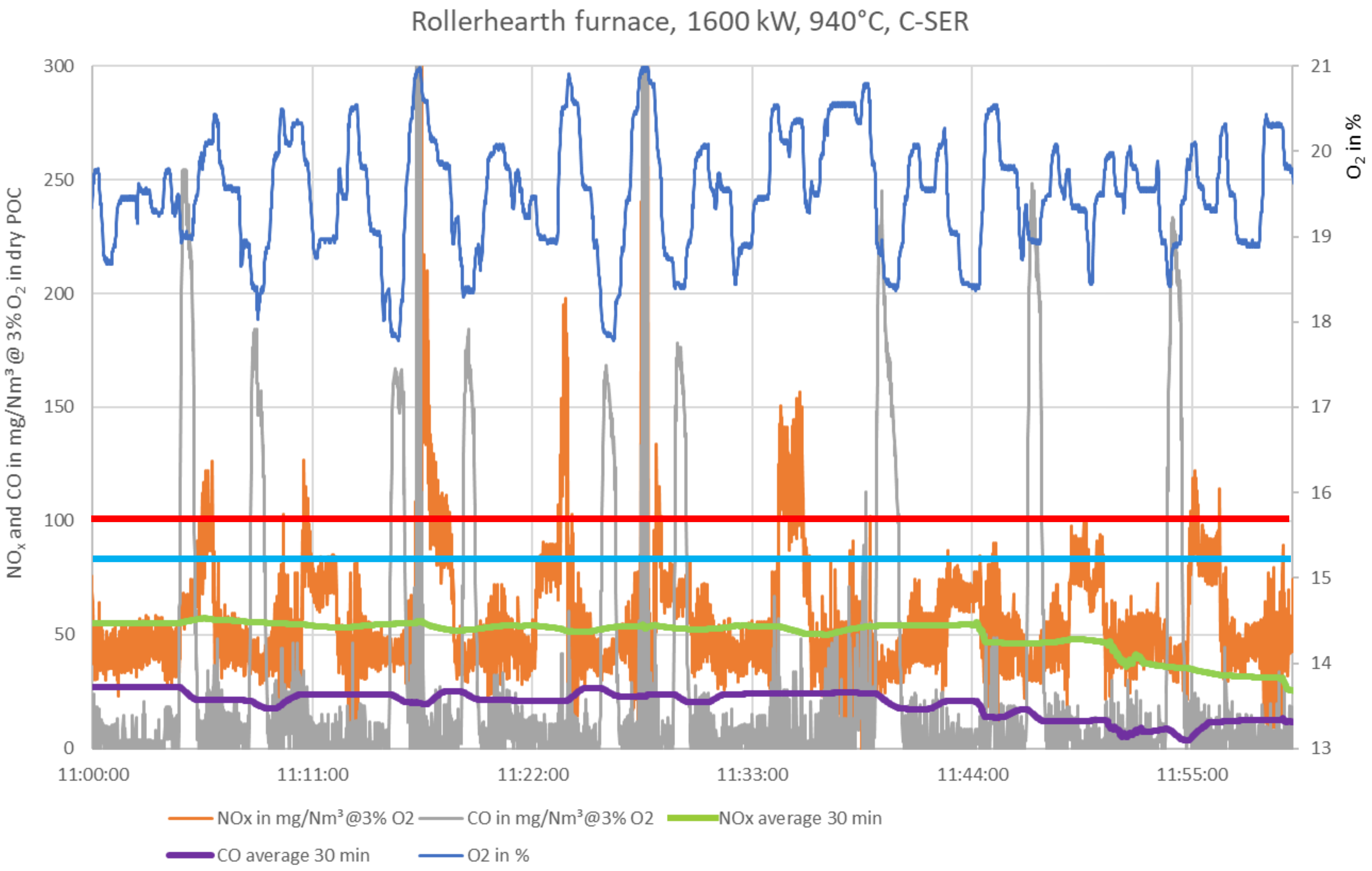
- Limit of 100 mg/Nm³ @ 3% O2 in dry POC is possible
- Fluctuation between the burners too high
- Potential of Flameless + Mach1® not fully used

- CO is not a problem
- Efficiency appr. 80% is realistic

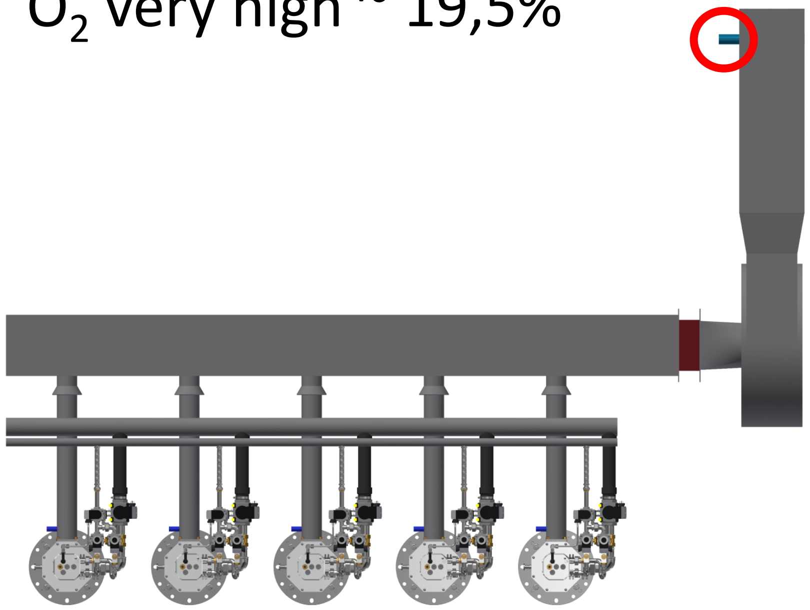
- Measurment not according 44. BImSchV



2. Measurement acc. 44. BImSchV



Average NO_x = 60 mg/Nm³
Average CO = 25 mg/Nm³
O_2 very high ~ 19,5%



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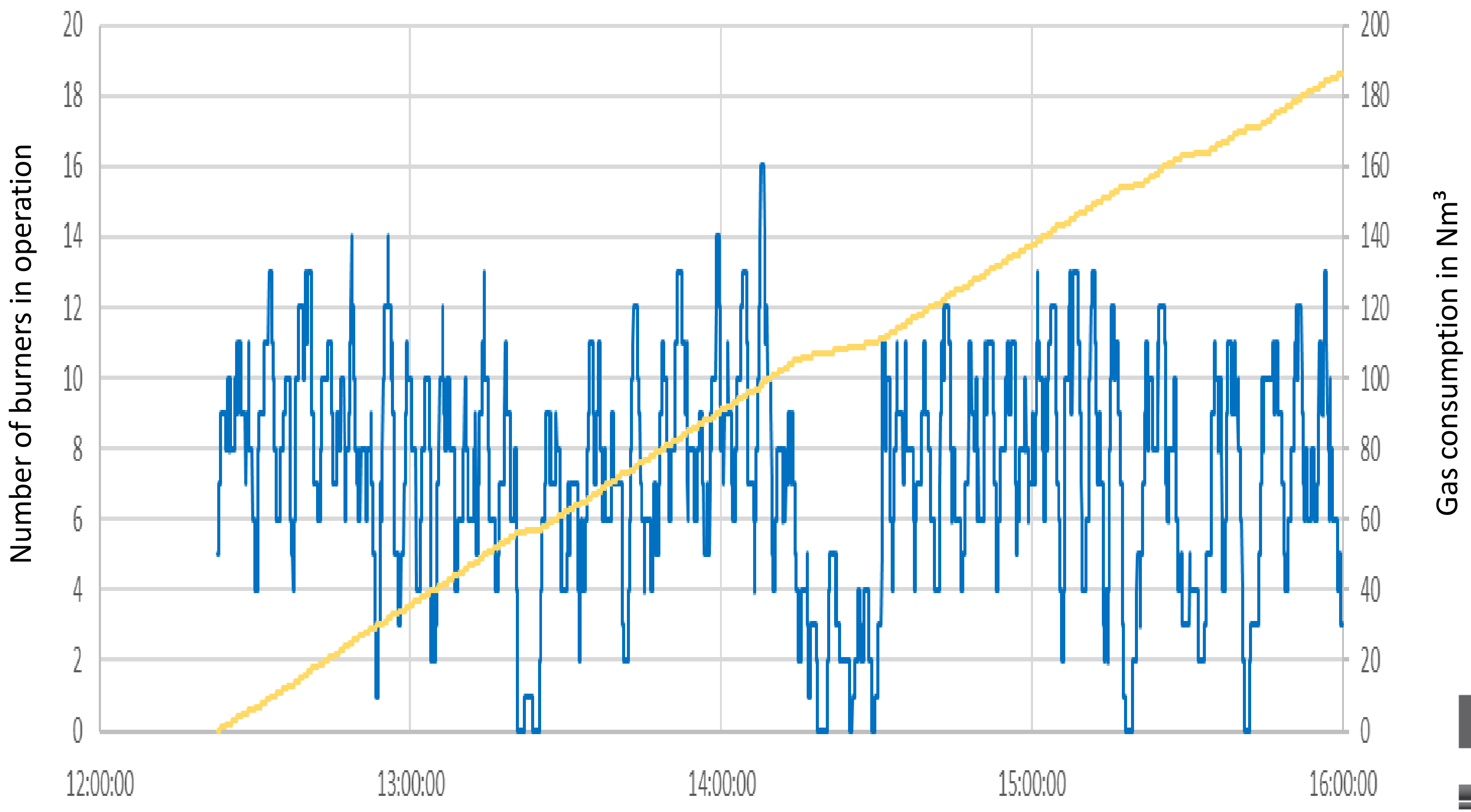
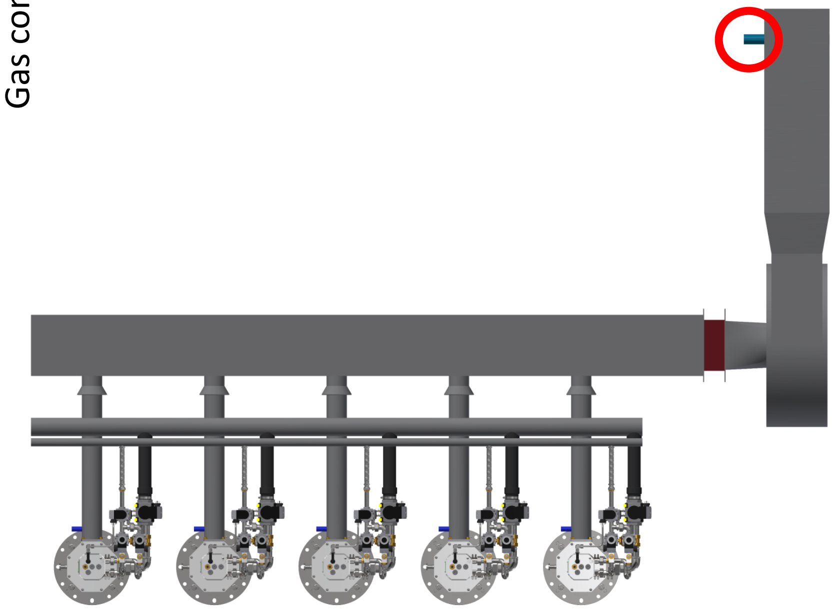


On-Off-Mode



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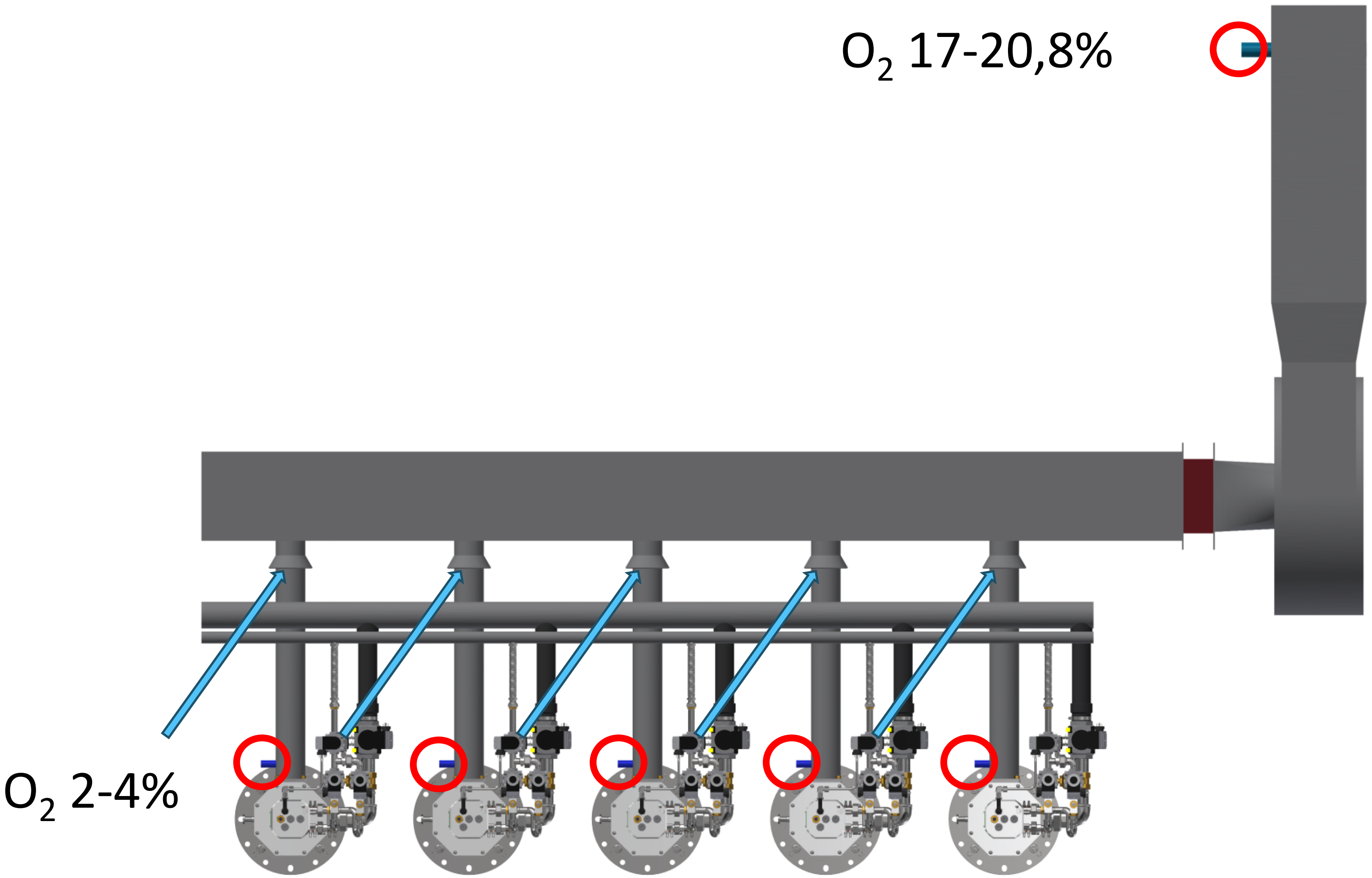


Dilution > 4 times
With fresh air

Reduction of
POC-temperature

Raw Data E_{MR} / ppm

Converted Data E_M / mg/Nm^3

Trimed Data E_B / mg/Nm^3 @ 3% O_2

Validated Data E_{BV} / mg/Nm^3 @ 3% O_2

CO NO NO_2

Molar mass / 0°C / 1013 hPa

O_2 measured in the main stack

Measurement error

$$E_B = \frac{21 - O_{2B}}{21 - O_{2M}} E_M$$

ΔO_{2M} mesasurement error

$$E_{BVmax} = \frac{21 - O_{2B}}{21 - (O_{2M} + \Delta O_{2M})} (E_M + \Delta E_M)$$

ΔE_M mesasurement error

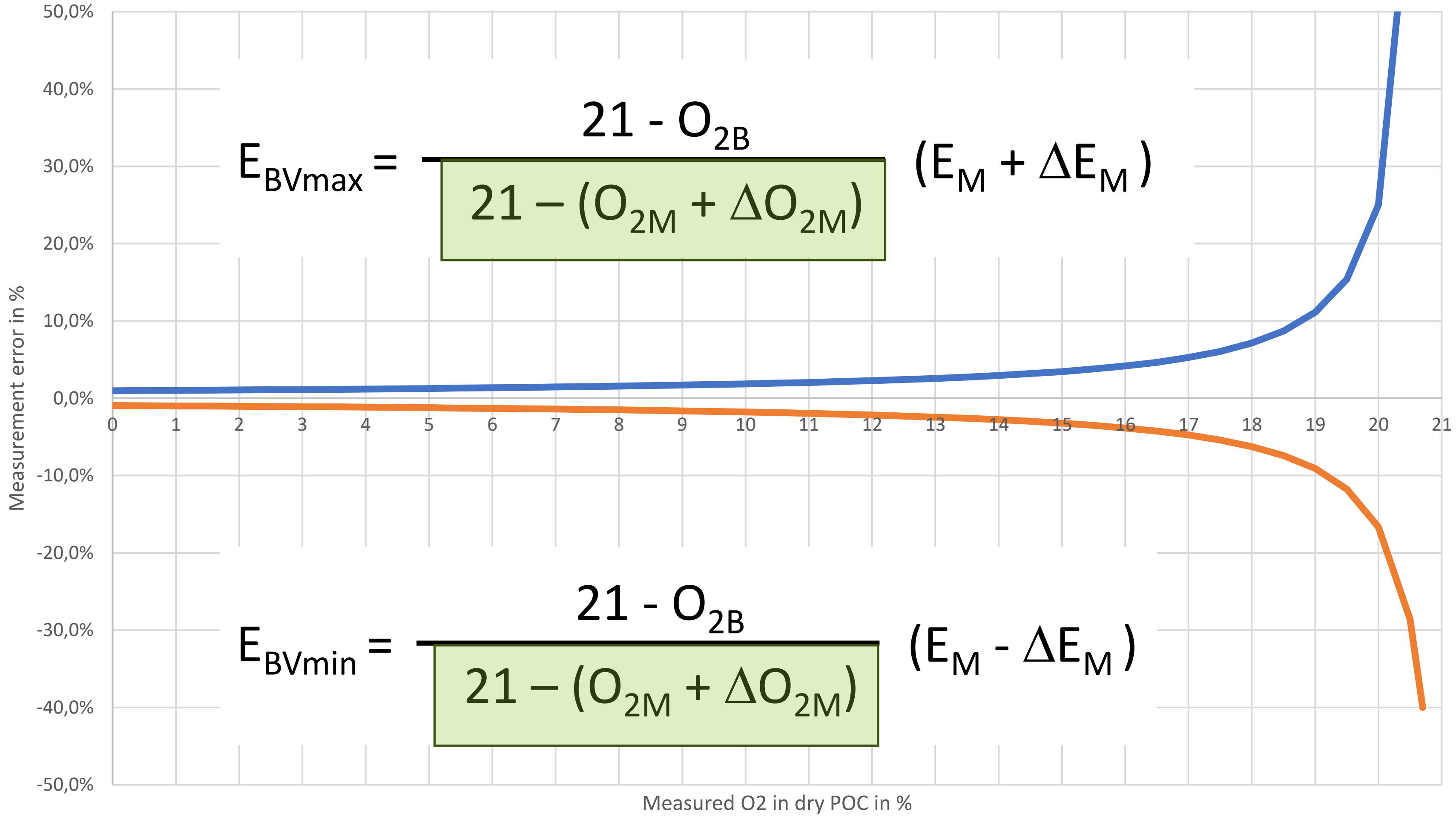
$$E_{BVmin} = \frac{21 - O_{2B}}{21 - (O_{2M} - \Delta O_{2M})} (E_M - \Delta E_M)$$

$NOx = NO + NO_2$

CO

Calculation of measurement error is simply additiv without using statistic methods for an easier overview.

2. Measurement error O_2



$$E_{BVmax} = \frac{21 - O_{2B}}{\boxed{21 - (O_{2M} + \Delta O_{2M})}} (E_M + \Delta E_M)$$

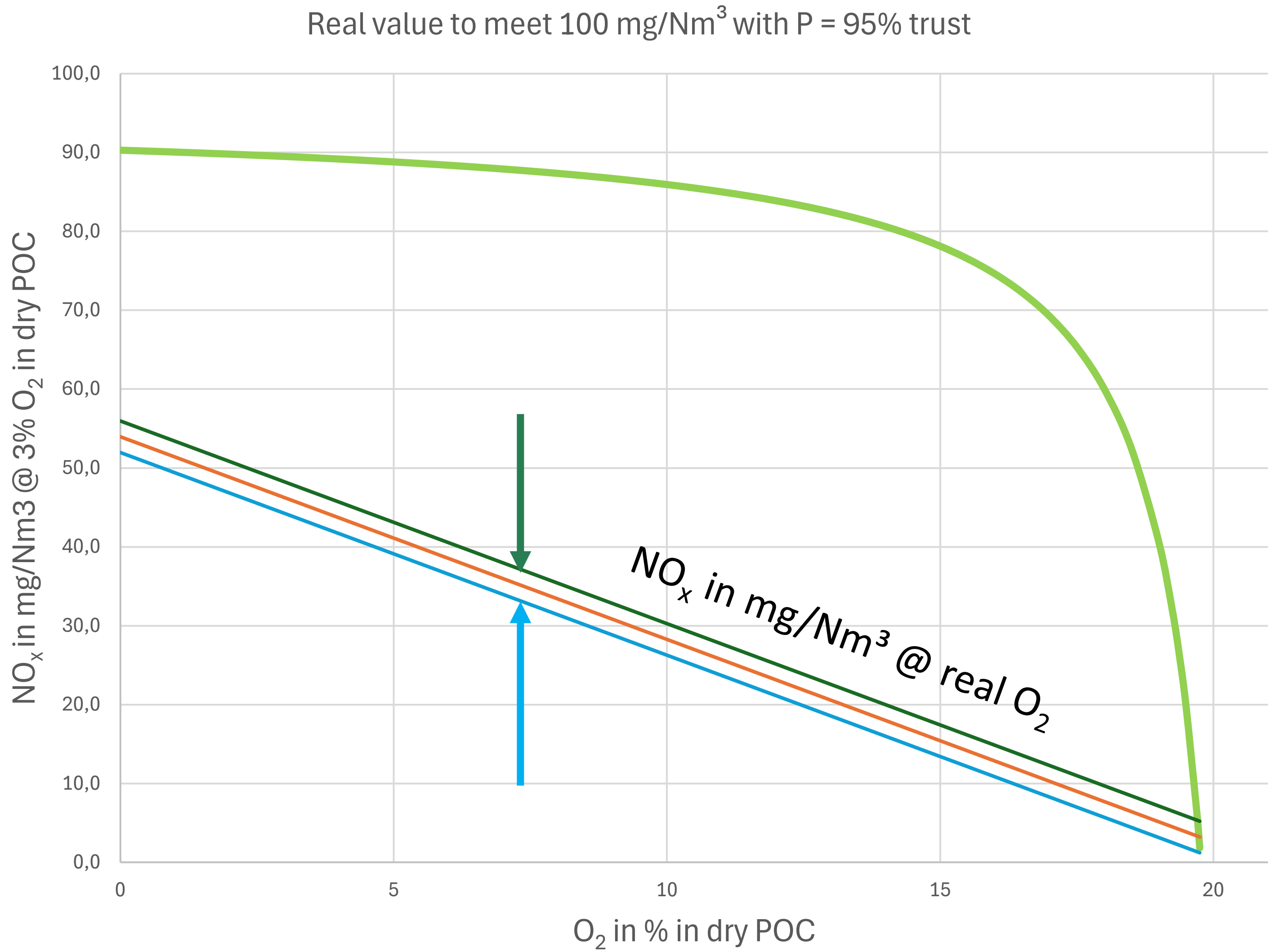
$$E_{BVmin} = \frac{21 - O_{2B}}{\boxed{21 - (O_{2M} + \Delta O_{2M})}} (E_M - \Delta E_M)$$

ΔO_{2M} = + 0,2% points

Example for a common measurement device

ΔO_{2M} = - 0,2% points

2. Real value to meet 44. BImSchV



ΔO_{2M} = + 0,2% points

ΔE_M mesasurement error ± 2 ppm (example)

$NOx = NO + NO_2$

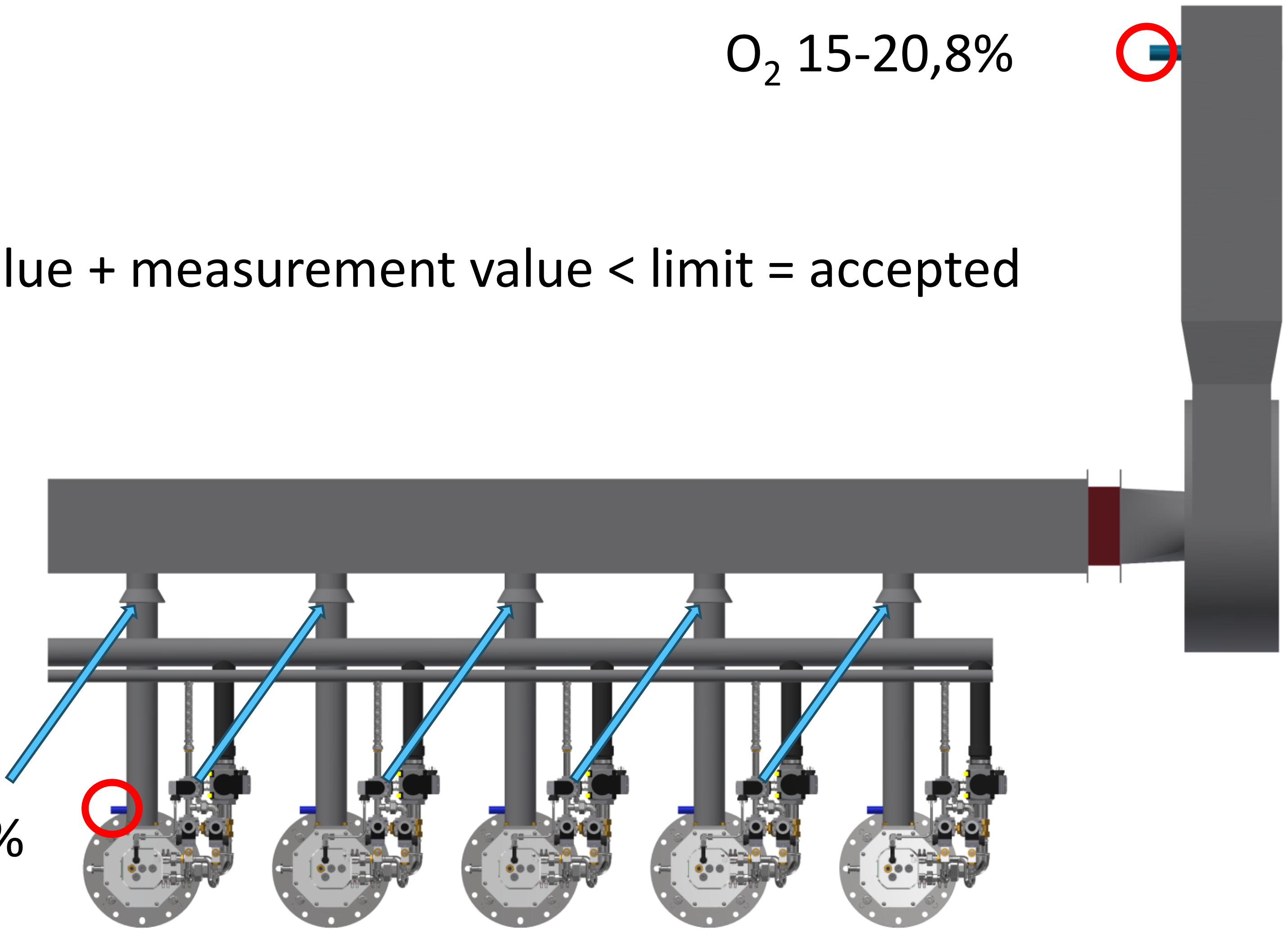
NO_2 appr. 5% of NO_x

2. Measurement acc. 44. BImSchV

O_2 15-20,8%

§ 31

Real value + measurement value < limit = accepted



O_2 2-4%

3. Motivation for ultra low NO_x

1. Request for efficiency and NO_x-value

D 85% and 80 mg/Nm³ @ 3% O_2

NO_x-reduction-system:
Flameless + Mach2®

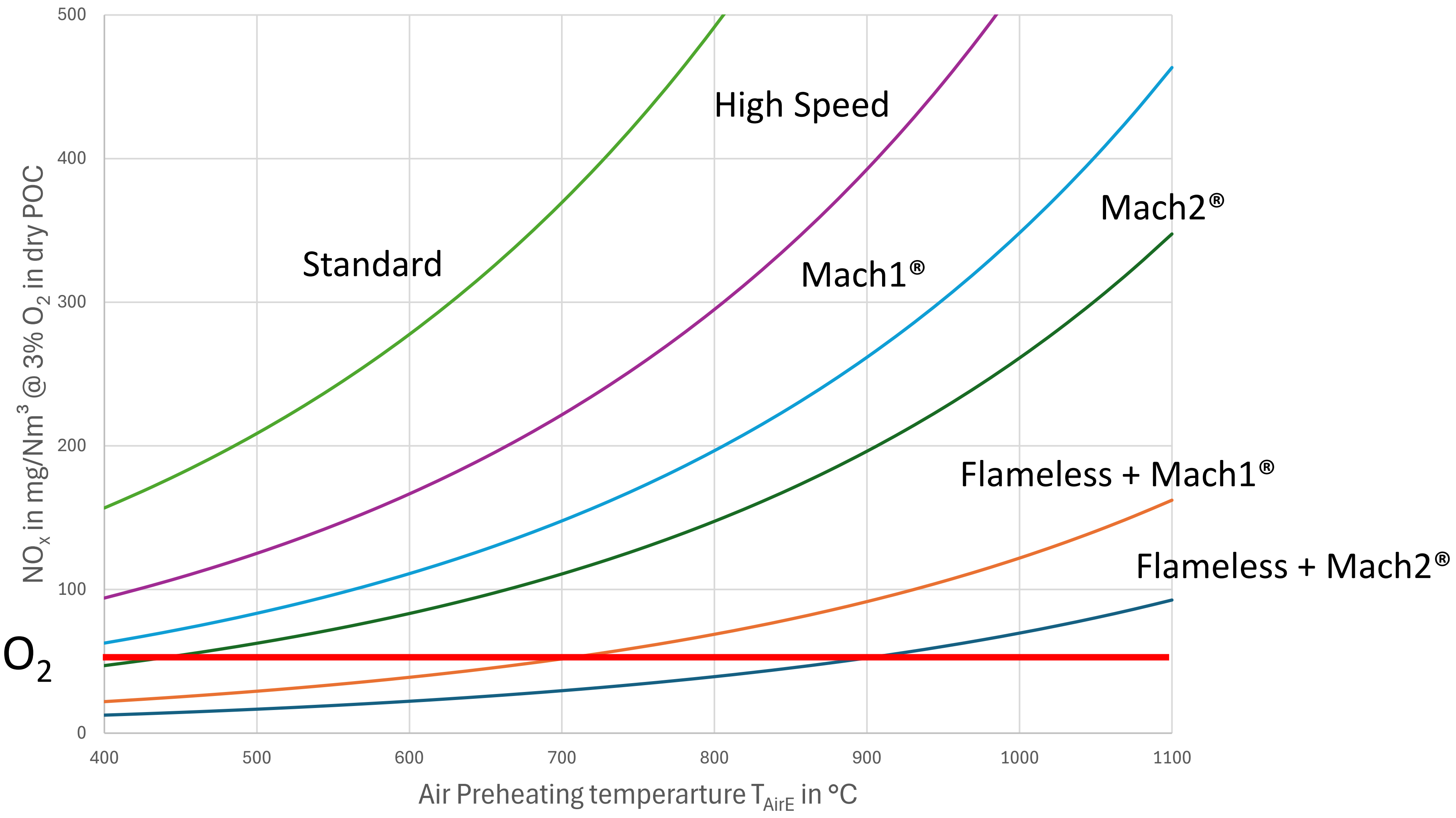
Expected dilution up to 17,5% O_2
30% Measurement error
NO_x < 56 mg/Nm³ @ 3% O_2

4. Flameless + Mach2®

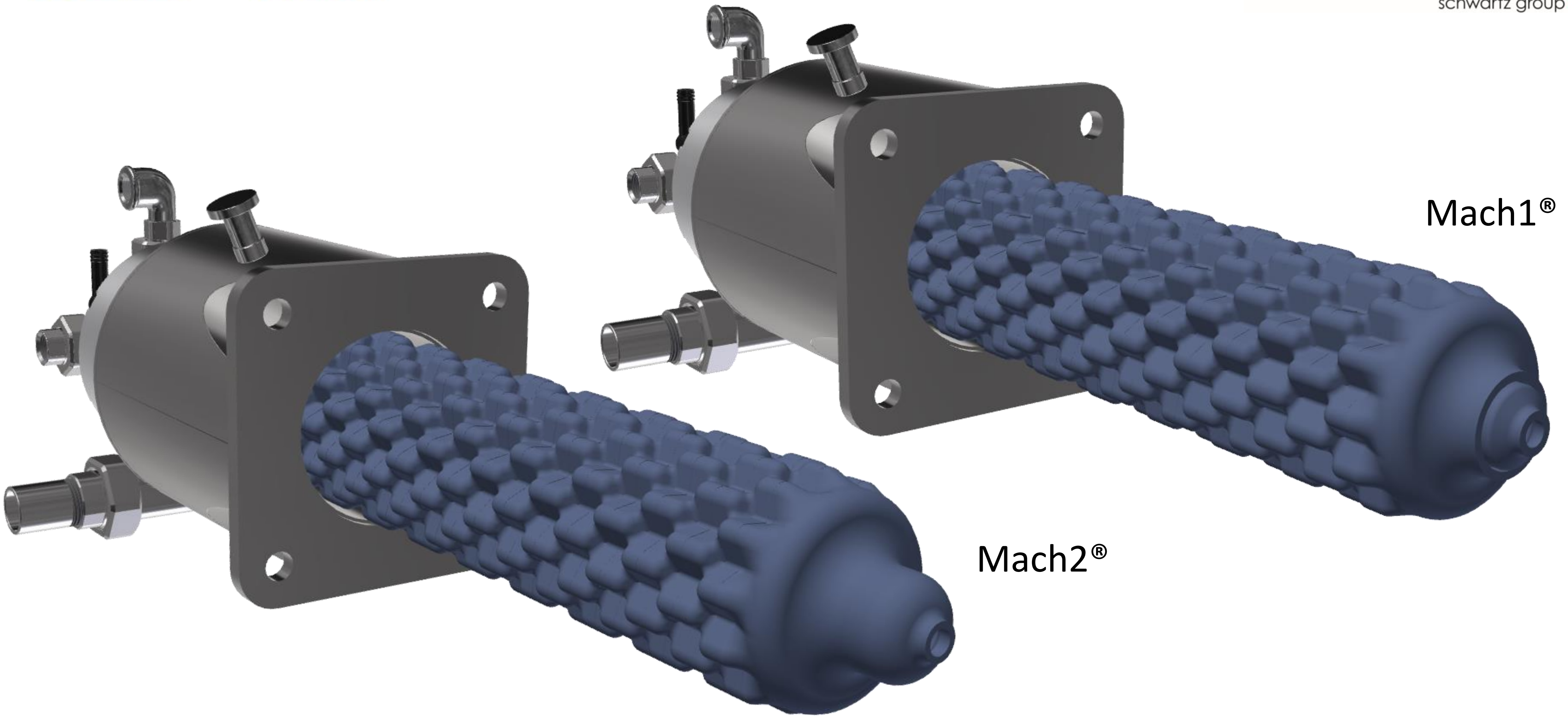
Type of
NO_x-reduction-system

Portfolio by Econova

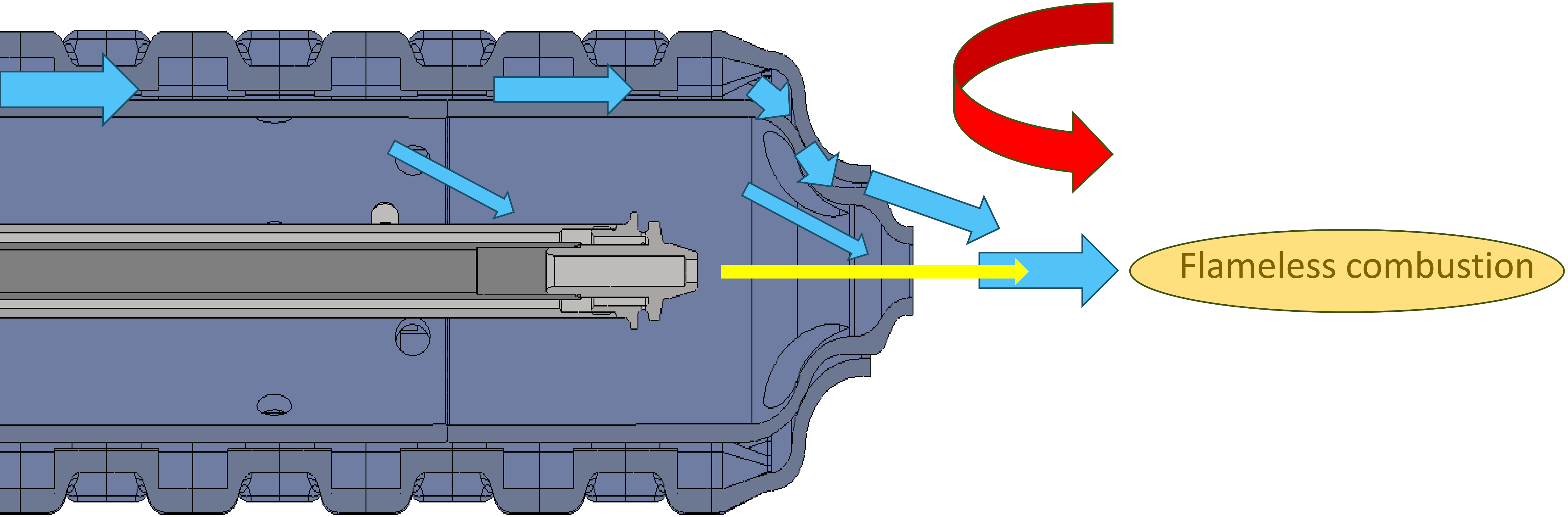
NO_x < 56 mg/Nm³ @ 3% O_2



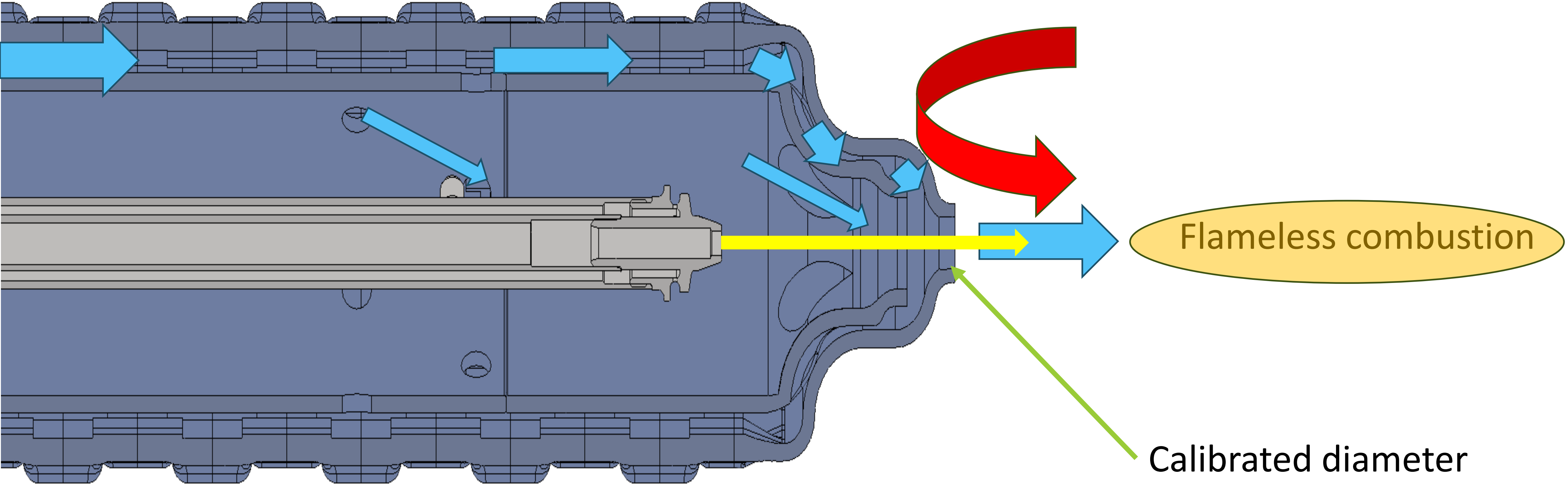
4. Flameless + Mach1®+2®



4. Flameless + Mach1®



4. Flameless + Mach2®

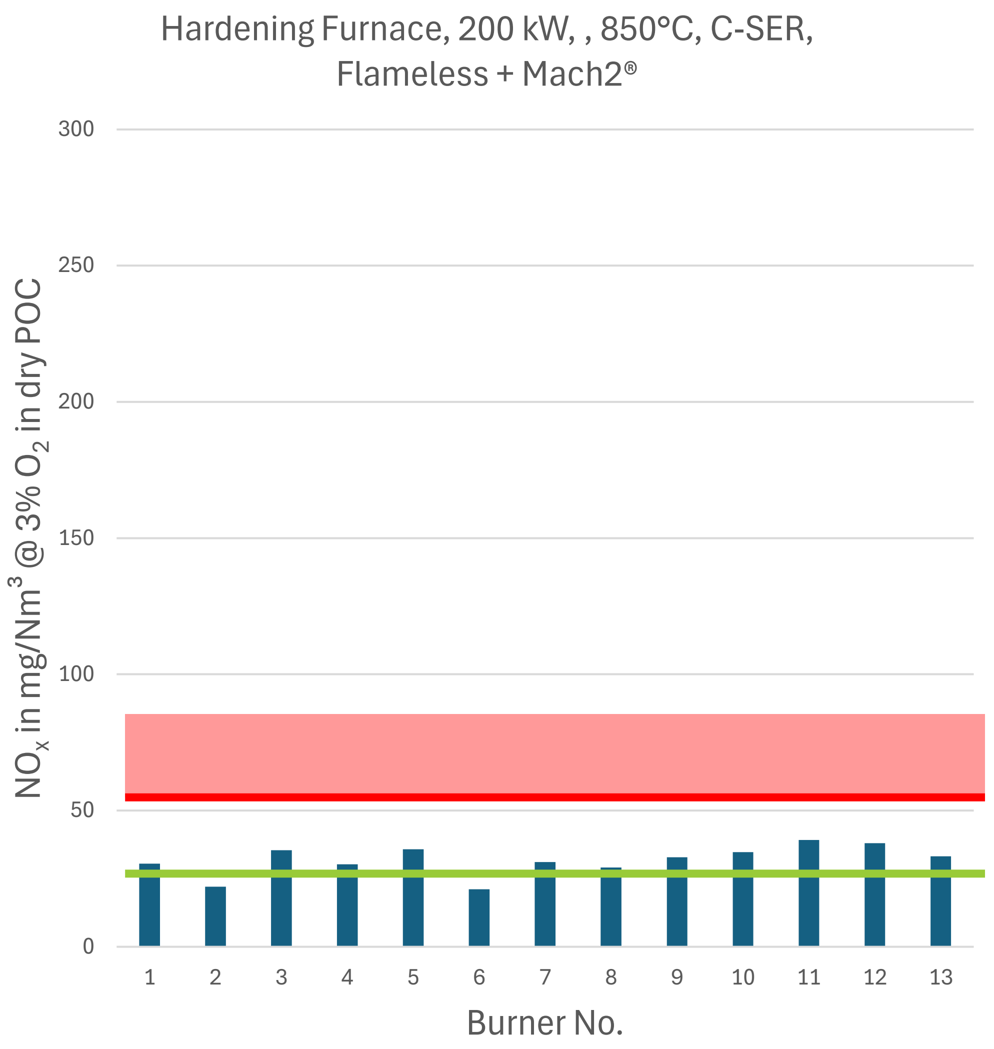


1. Request for efficiency and NO_x-value

D 85% and 80 mg/Nm³ @ 3% O_2

NO_x-reduction-system:
Flameless + Mach2®

Expected dilution up to 17,5% O_2
30% Measurement error
< 56 mg/Nm³ @ 3% O_2



6. Summary and Outlook

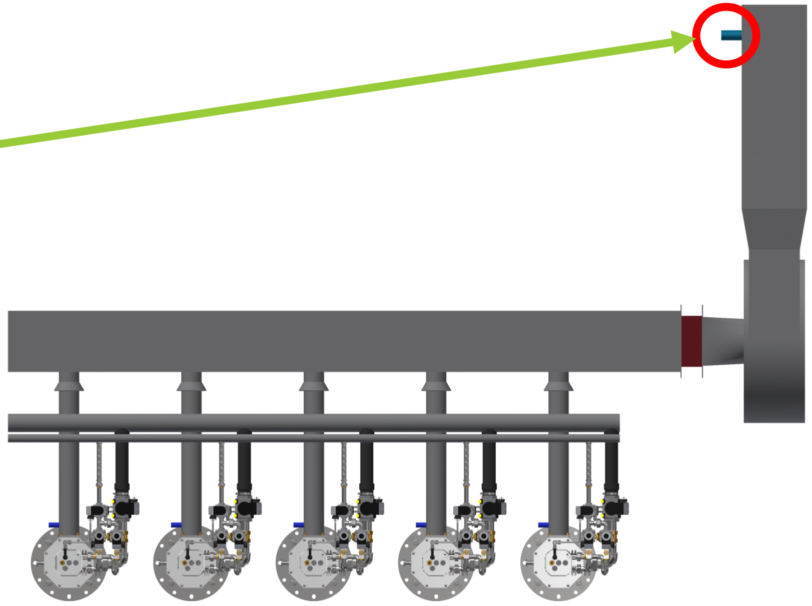
Summary

Limit of 56 mg/Nm³ @ 3% O2 in dry POC is possible
Fluctuation reduced by calibrated design

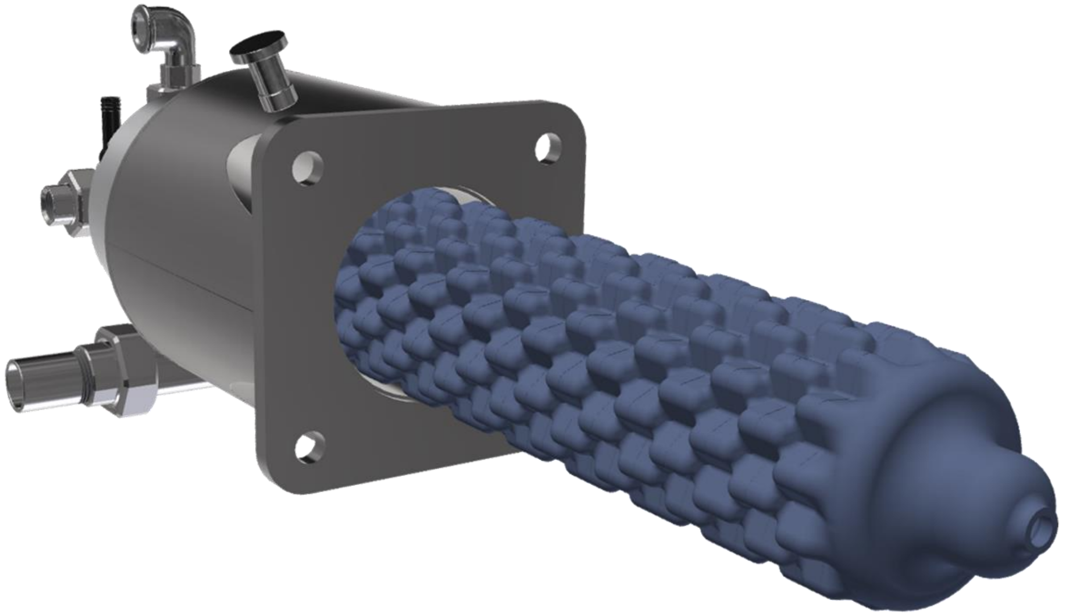
CO is not a problem
Efficiency appr. 80% is realistic

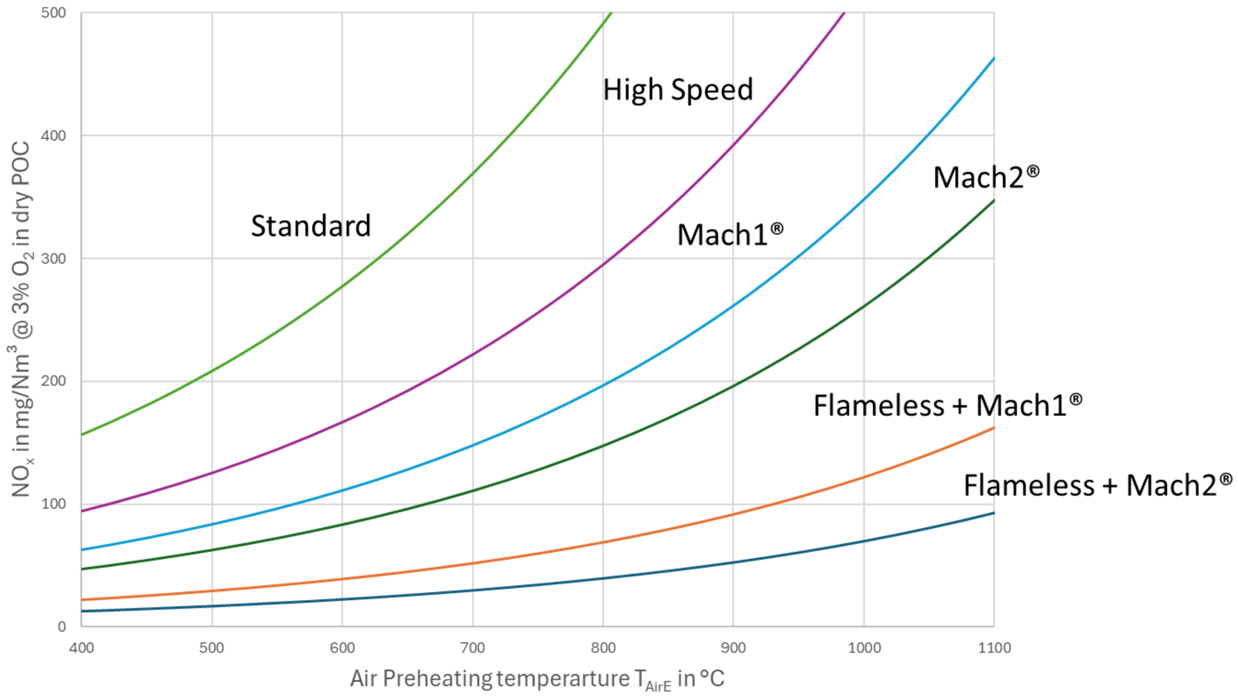
Measurment according 44. BImSchV
Dilution must be limited

Closed exhaust system with no dilution
will accept higher NO_x- values



Thank you for your attention





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