Petroleum coke and refuse-derived fuel co-firing enhanced with hydrogen in an industrial cement kiln - a CFD study

PIOTR JÓŹWIAK[1,2,3,*], JAROSŁAW HERCOG[1,2], ARKADIUSZ BARAN[1,2,3]

[1] INSTITUTE OF POWER ENGINEERING - RESEARCH INSTITUTE,
MORY 8, 01-330 WARSAW, POLAND

[2] CENTER FOR HYDROGEN TECHNOLOGIES (CTH2), INSTITUTE OF POWER ENGINEERING,
AUGUSTÓWKA 36, 02-981 WARSAW, POLAND

[3] INSTITUTE OF HEAT ENGINEERING, WARSAW UNIVERSITY OF TECHNOLOGY,
NOWOWIEJSKA 21/25, 00-665 WARSAW, POLAND

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SCOPE OF THE WORK

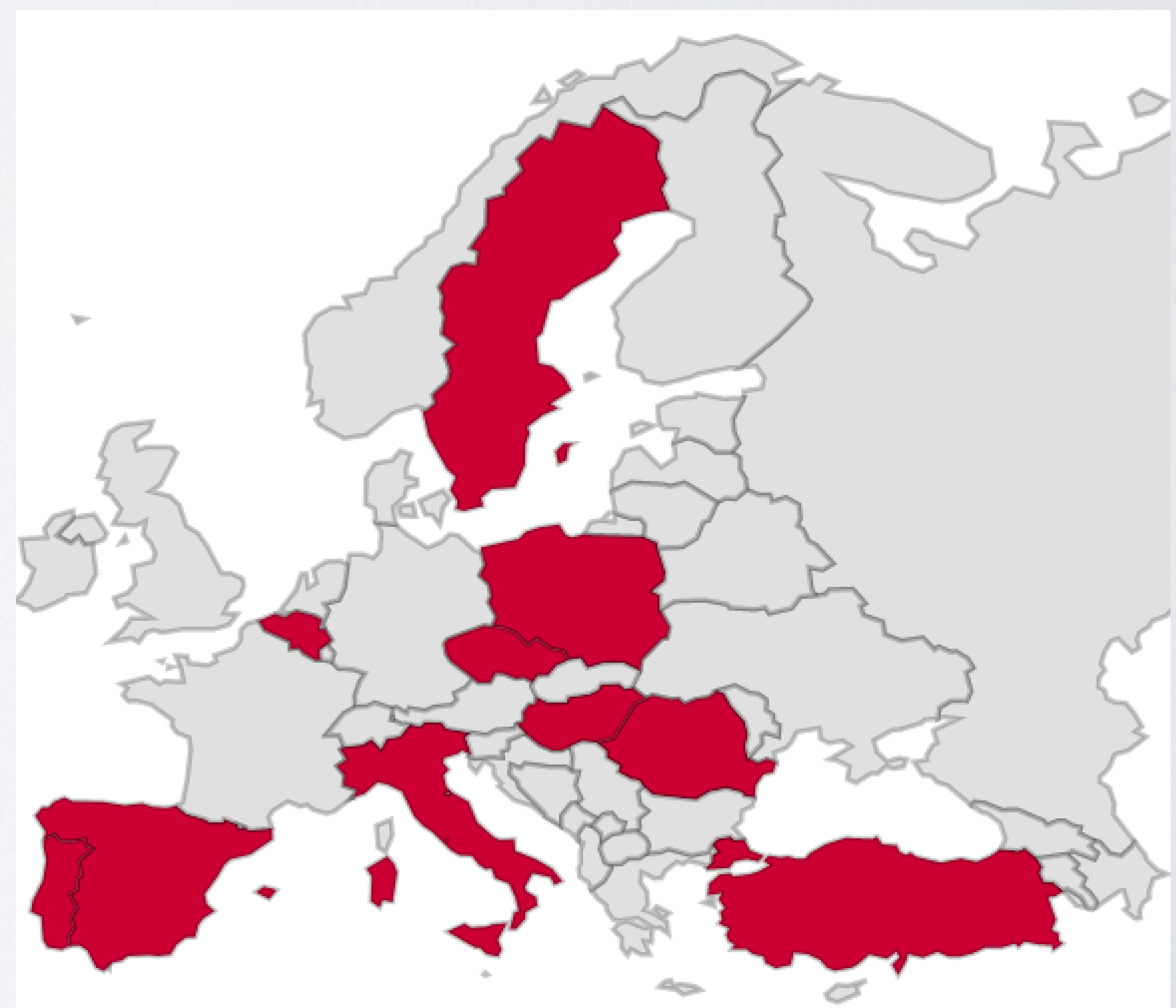
- cement - background information
- motivation
- current state: burner, fuels
- kiln CFD model development
- results
- conclusion

RETROFEED

Implementation of a smart **retro**fitting framework in the process industry towards its operation with variable, bio-based and circular **feed**stock

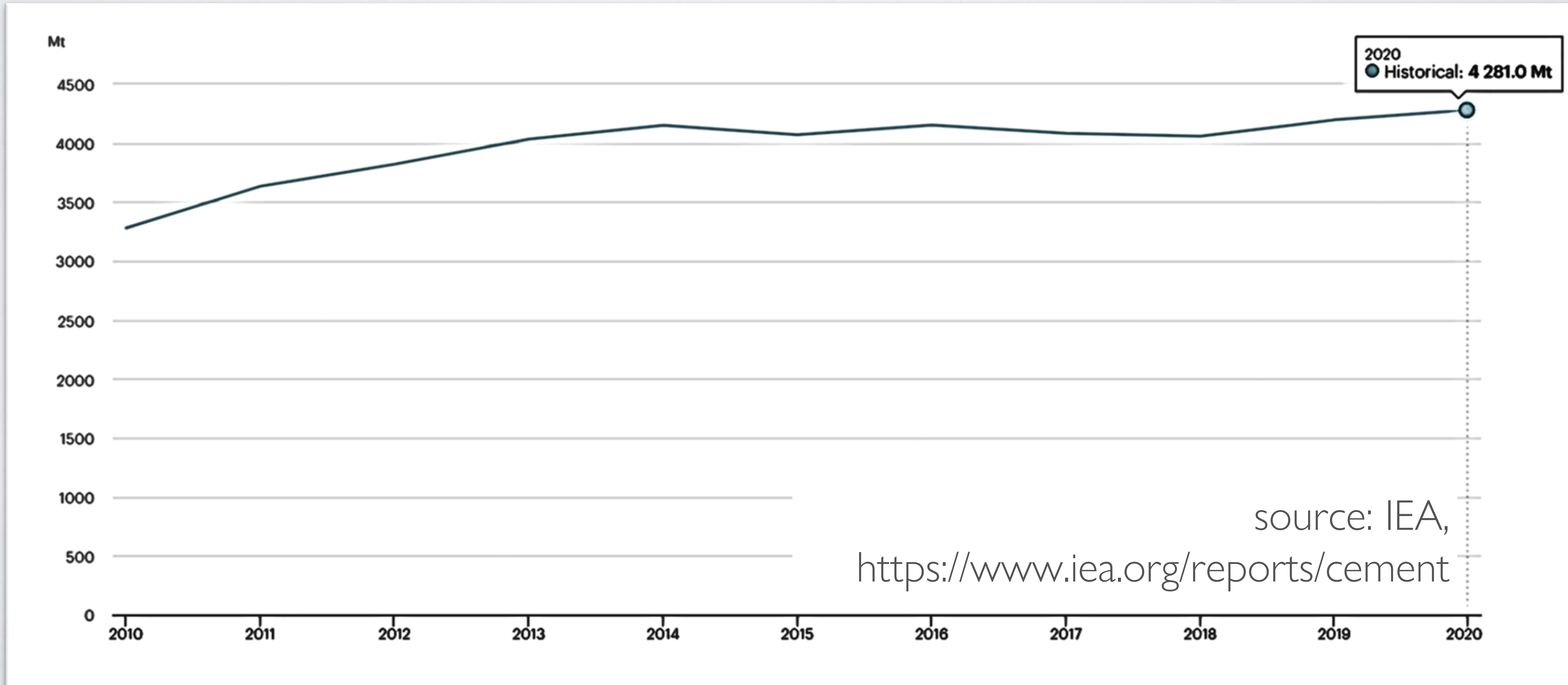
Objective:
to enable the use of a bio-based and circular feedstock in process industries

Time period: 01.11.2019 – 31.10.2023
Total budget: 15 645 076.88 €



BACKGROUND

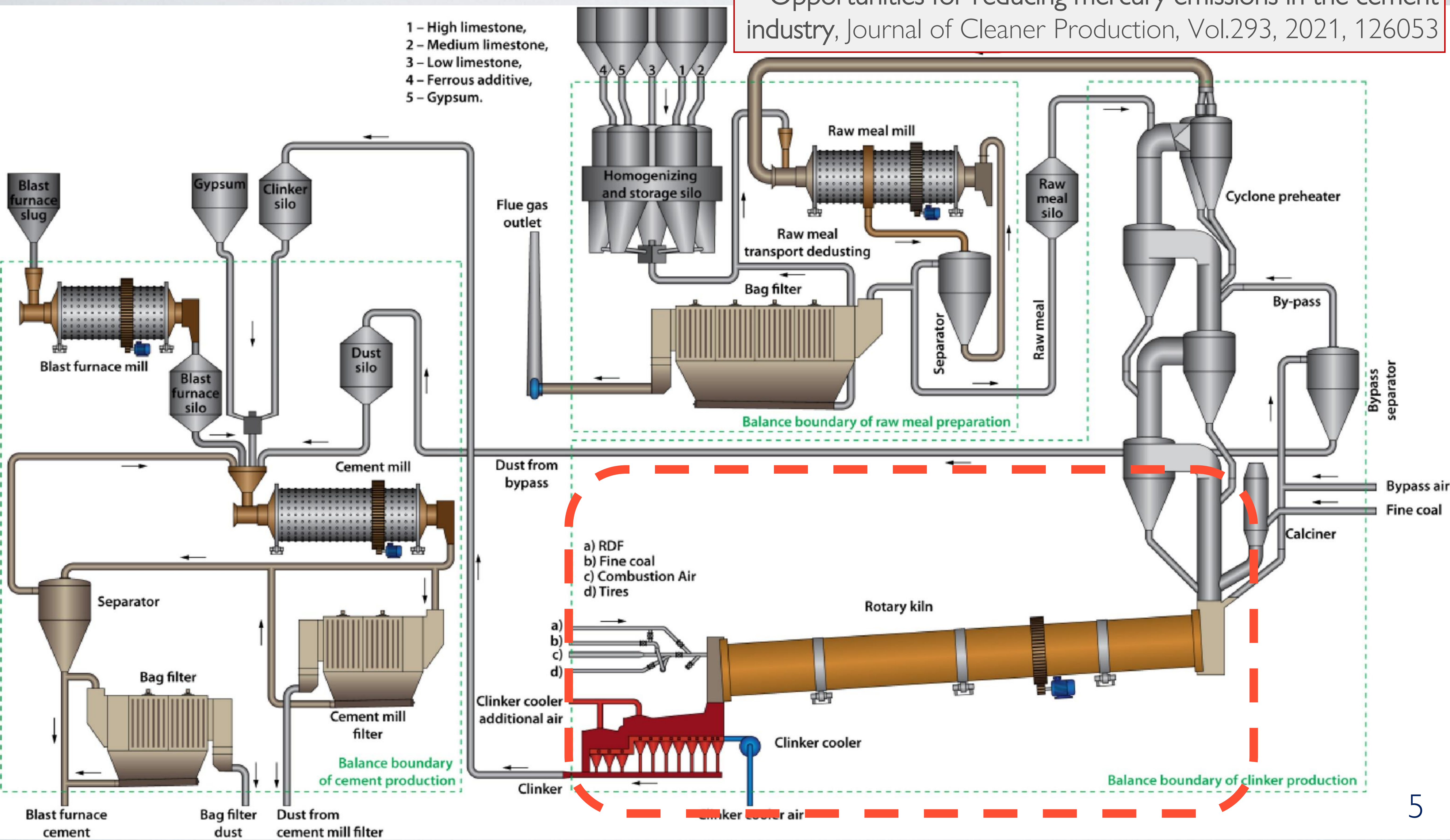
- Cement is most widely used man-made material in the world: annual production exceeds 4 bln t, and accounts for ca. 8% of the global CO_2 emissions (intensity: 0.59 t CO_2 / t cement)



source: IEA,
https://www.iea.org/reports/cement

BACKGROUND

source: K. Kogut, J. Górecki, P. Burmistrz, Opportunities for reducing mercury emissions in the cement industry, Journal of Cleaner Production, Vol.293, 2021, 126053

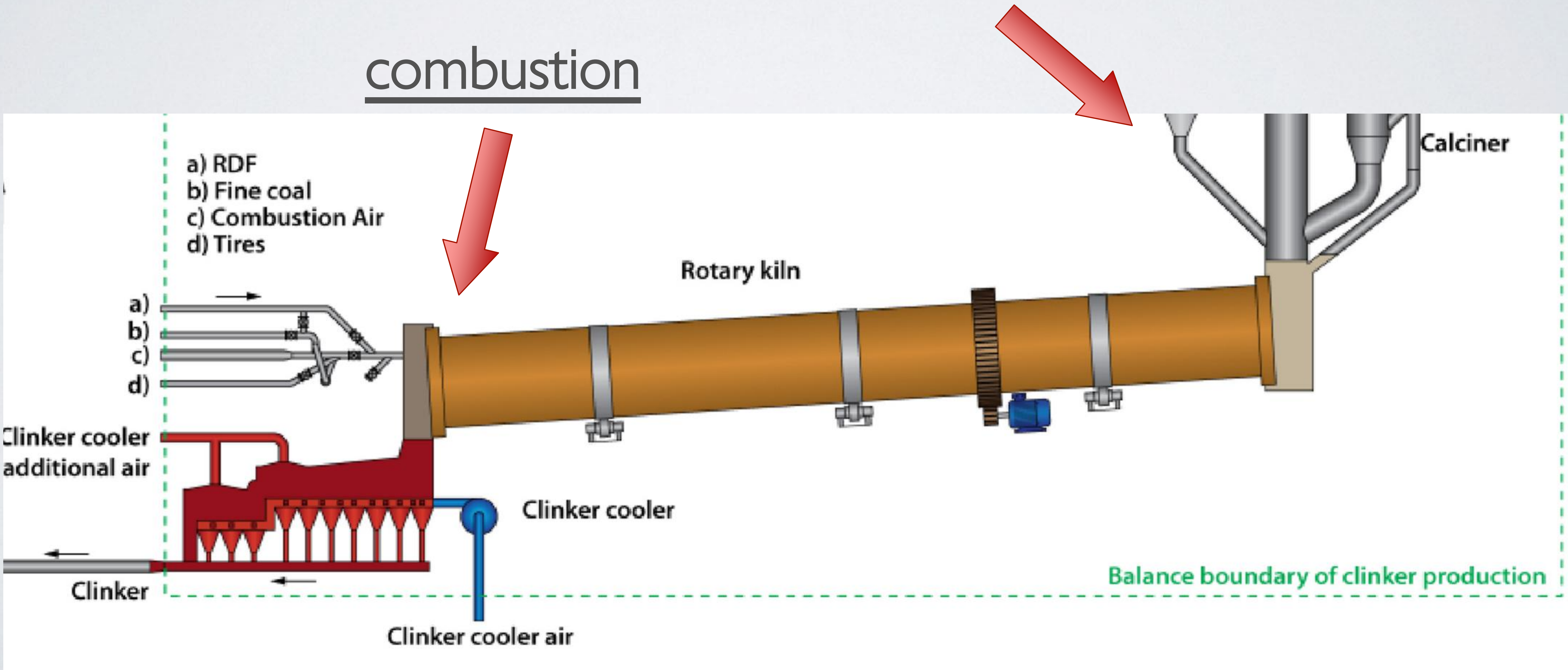


BACKGROUND

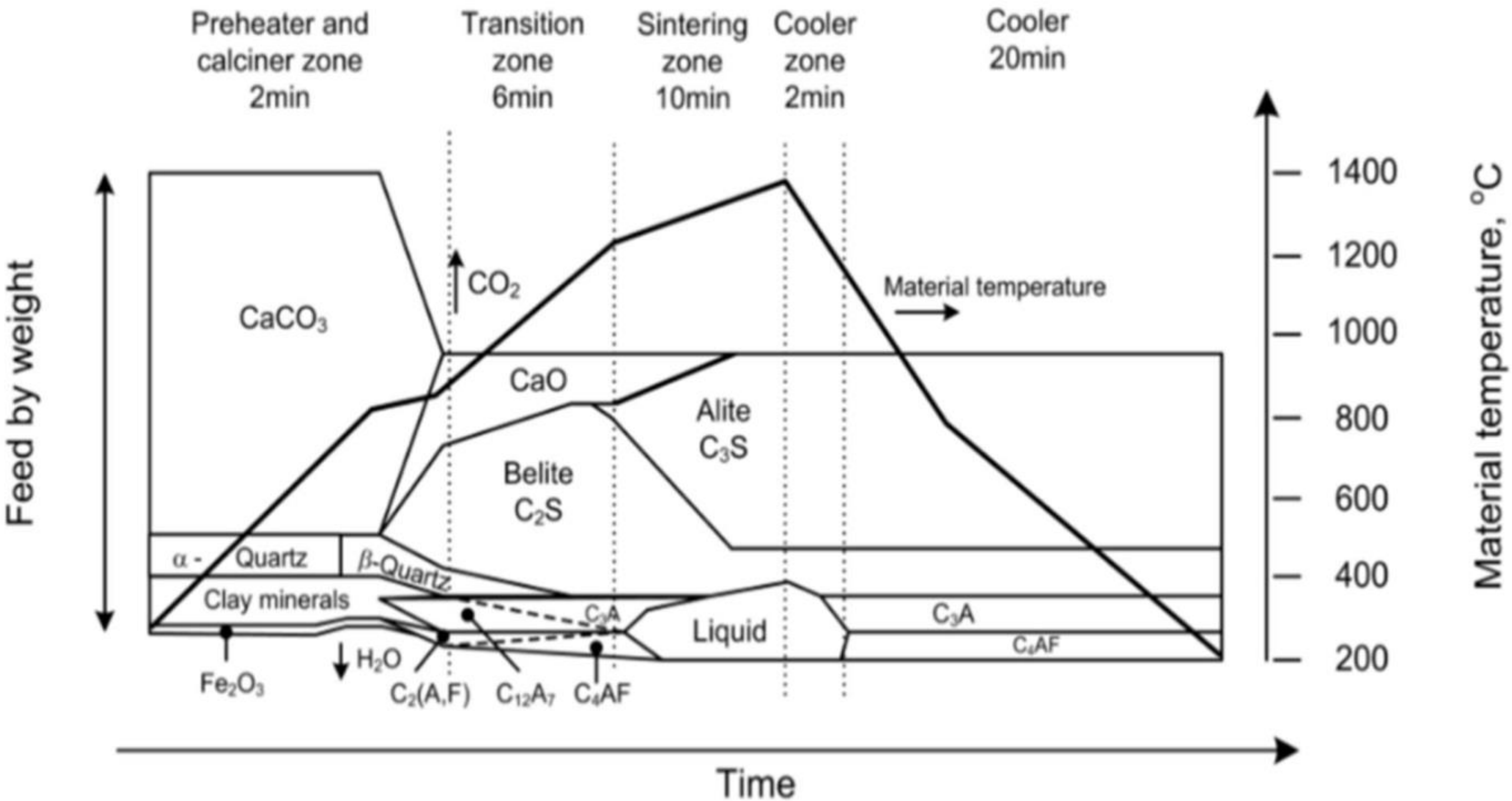
based on: K. Kogut, J. Górecki, P. Burmistrz, Opportunities for reducing mercury emissions in the cement industry, Journal of Cleaner Production, Vol.293, 2021, 126053

chemical conversion: limestone ($CaCO_3$) to burnt lime (CaO)

combustion



BACKGROUND

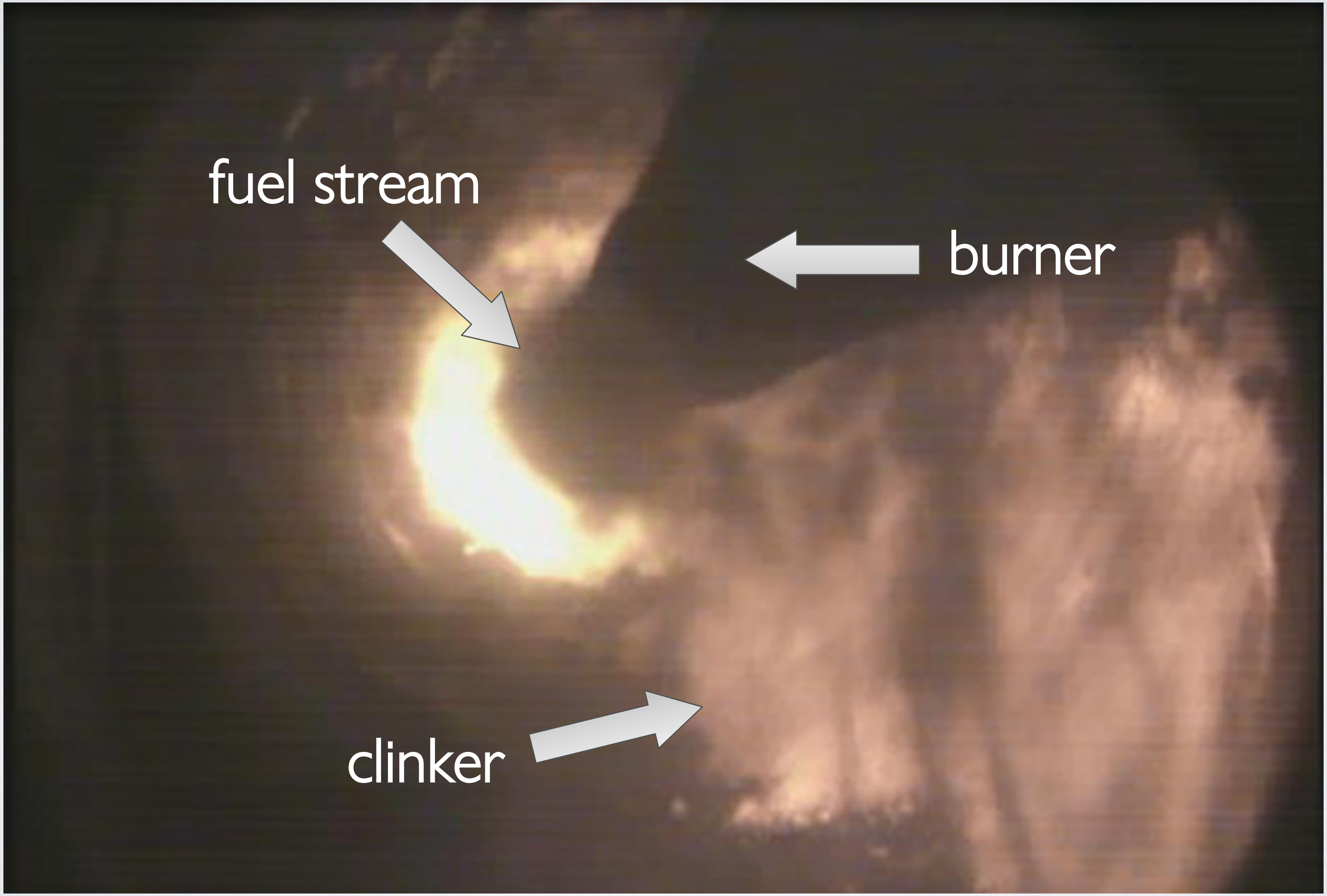


Preheater and calciner zone 2min
Transition zone 6min
Sintering zone 10min
Cooler zone 2min
Cooler 20min
Feed by weight
CaCO3
CO2
CaO
Belite C2S
Alite C3S
Material temperature
α - Quartz
β-Quartz
Clay minerals
C3A
Liquid
C3A
C4AF
H2O
Fe2O3
C2(A,F)
C12A7
C4AF
1400
1200
1000
800
600
400
200
Material temperature, °C
Time

BACKGROUND

courtesy of SECIL Maceira-Liz

BACKGROUND



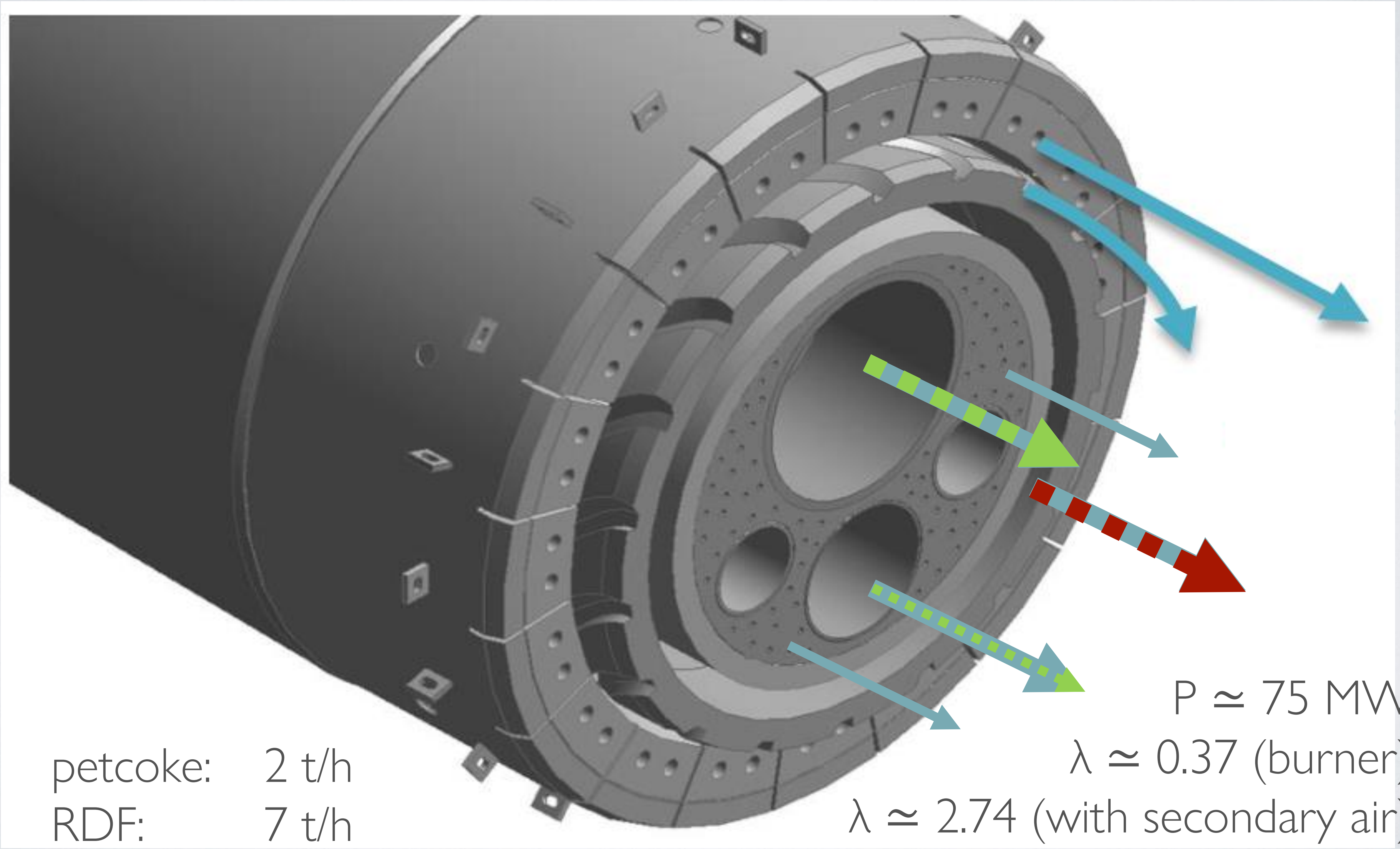
courtesy of SECIL Maceira-Liz

BACKGROUND

Given the process, what can be done?

- reduction of chimney heat loss / energy consumption:
  - clinker heat is recovered by the 'secondary air'
  - kiln flue gas heat is used in calciner and further
- **reduction of the fossil fuel (petcoke) consumption**:
  - biomass-based alternative solid fuel
  - refuse-derived fuels (circular economy aspect)

BACKGROUND



P ≃ 75 MW
λ ≃ 0.37 (burner)
λ ≃ 2.74 (with secondary air)
petcoke: 2 t/h
RDF: 7 t/h

OBJECTIVES

- to create a numerical CFD model of multifuel-combustion in the kiln furnace
- to evaluate the possibility of running the process on 100% of RDF in terms of the thermo-flow conditions in the kiln
- to assess the possibility of hydrogen introduction and its influence on the thermal conditions in the kiln

RDF fed to the burner

courtesy of SECIL Maceira-Liz

FUELS

Petcoke and RDF - widely different properties

- **particles shape and size distribution**
  (petcoke is fine and uniform - RDF is composed from various pieces of paper and cardboard pieces, plastics, foils, textiles and others)
- **calorific value and volatiles content**

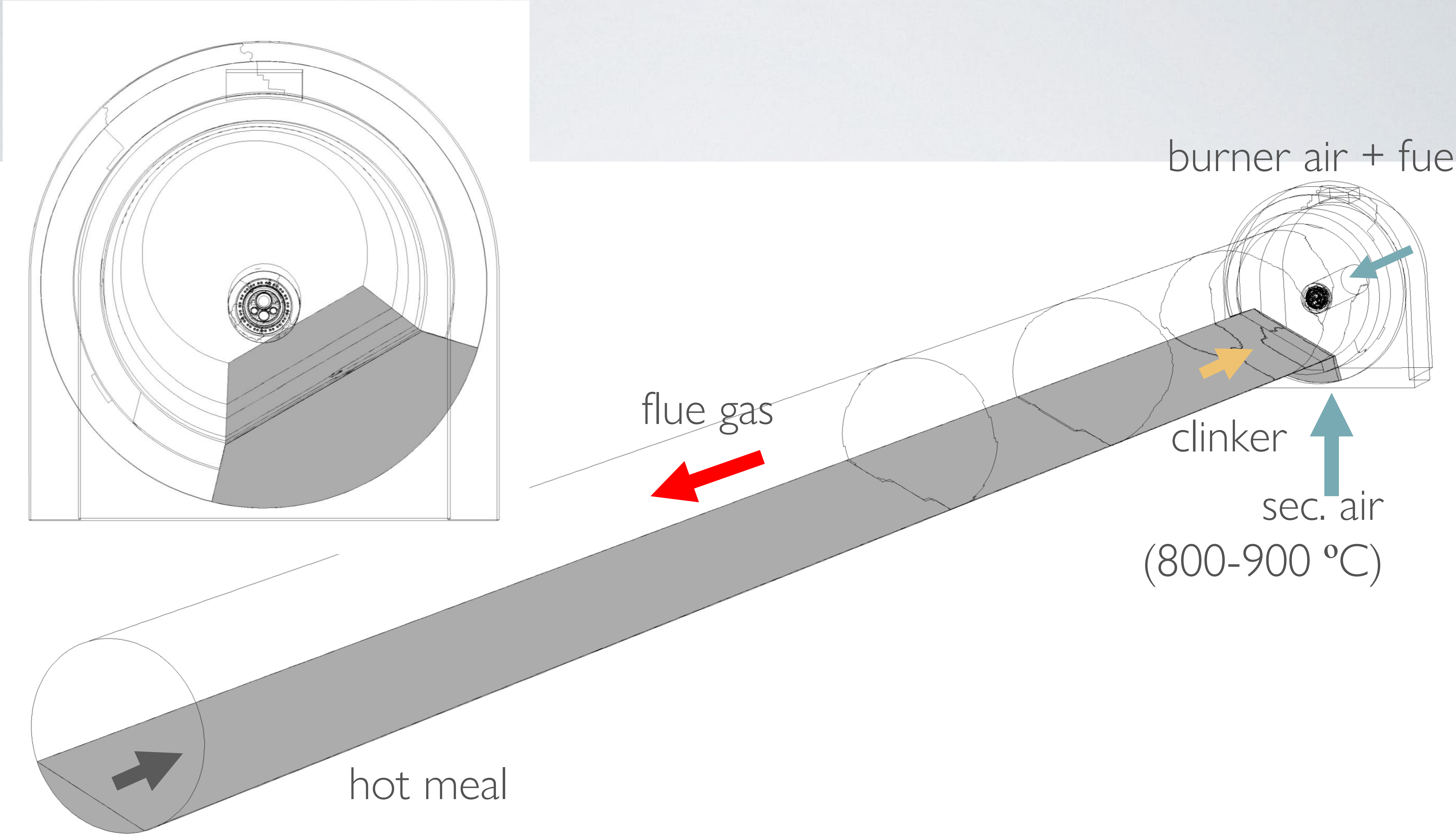
	petcoke	RDF	H_2
LHV	34 MJ/kg	~19-32 MJ/kg	120 MJ/kg
volalites	17%	60%	n.a.
d	7-70 µm	0.2-2 mm (up to cm)	n.a.

POWERING CASES

In terms of energy share in the fuel:

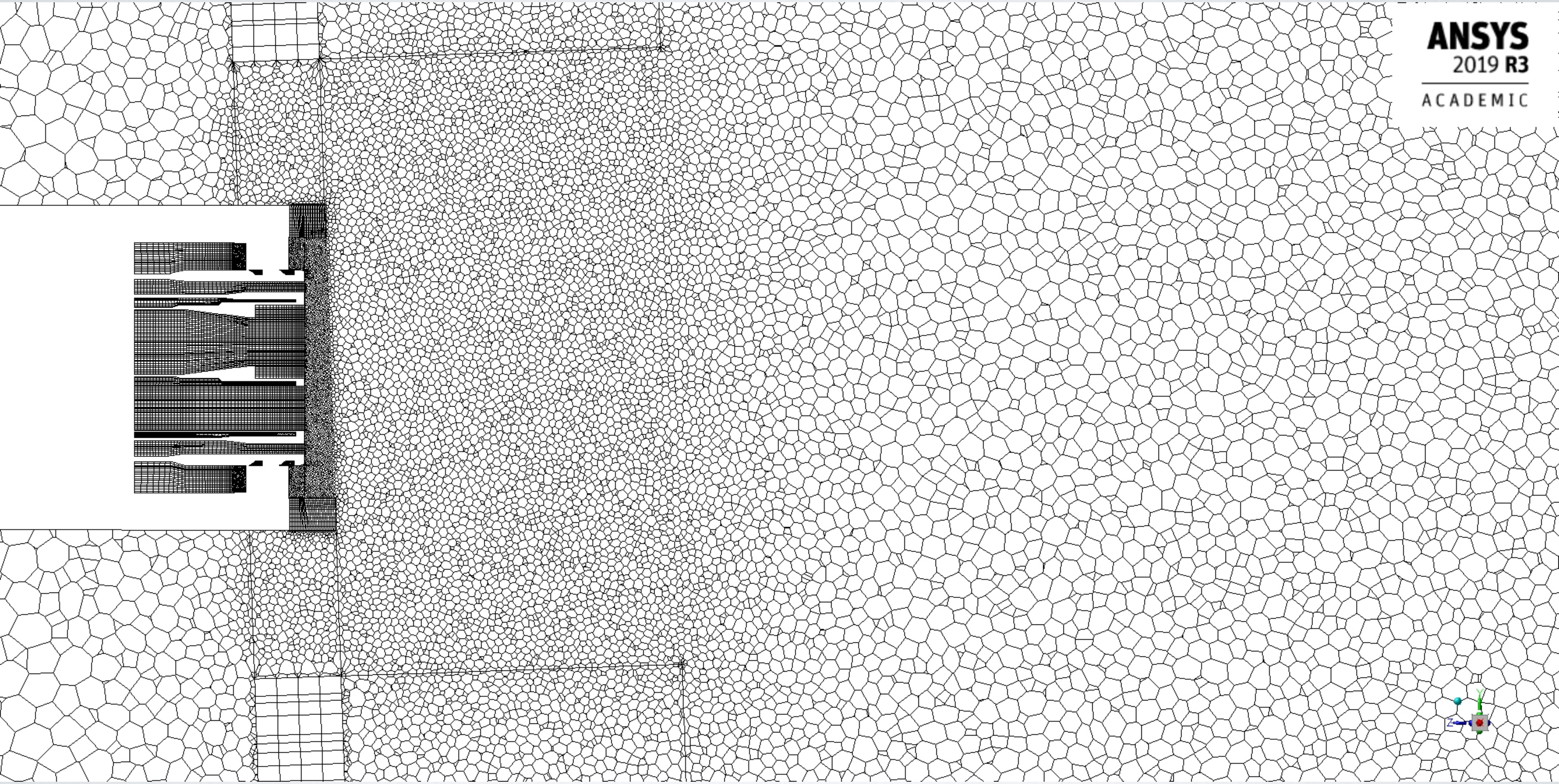
1. 100% petcoke
2. 25% petcoke, 75% RDF
3. 100% RDF (single inlet)
4. 100% RDF (double inlet)
5. 99% RDF, 1% H_2 (side)
6. 95% RDF, 5% H_2 (side)
7. 95% RDF, 5% H_2 (mixed with central air)

FURNACE MODEL



FURNACE MODEL

HEX+POLY, 6.21 Mcells



FURNACE MODEL

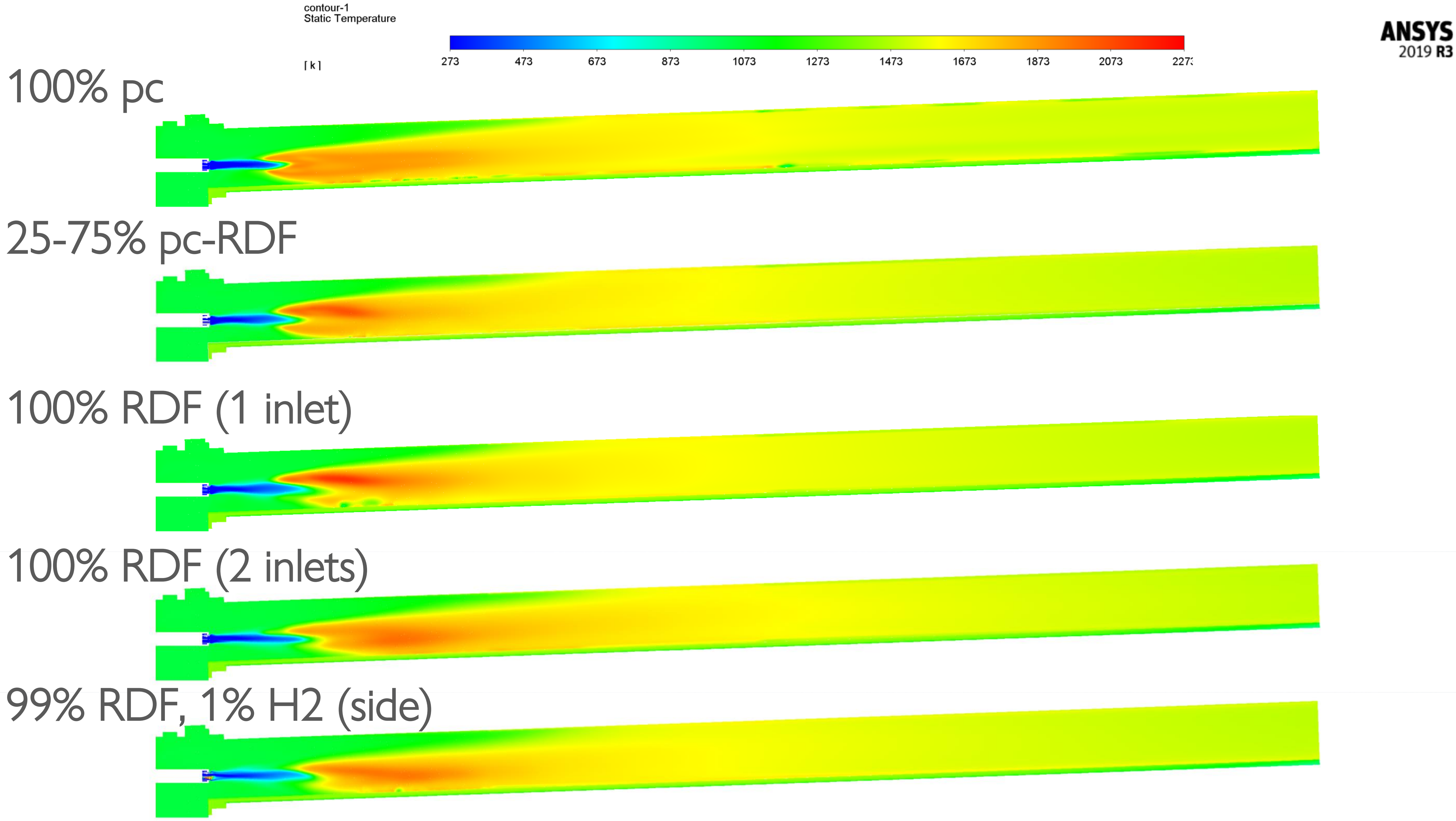
GEKO, DO+WSGGM, FR/ED

No	reaction	reaction heat, kJ/mol	reaction rate, kmol/(m³s)	reaction rate model[1]	A, [2]	n, -	E, kJ/mol
1	volpc + 2.28 O_2 → 1.24 CO + 3.69 H_2O + 0.066 N_2	-913	$A\ T^n \exp(-E/(RT))\ [volpc]^{0.2}\ [O_2]^{1.3}$	fr/ed	7.310×10^{9}	0	125.6
2	volrdf + 1.17 O_2 → 1.48 CO + 1.42 H_2O + 0.012 N_2	-655	$A\ T^n \exp(-E/(RT))\ [volrdf]^{0.2}\ [O_2]^{1.3}$	fr/ed	5.012×10^{11}	0	202.6
3	CO + 0.5 O_2 → CO_2	-283	$A\ T^n \exp(-E/(RT))\ [CO]\ [O_2]^{0.25}[H_2O]^{0.50}$	fr/ed	2.239×10^{12}	0	170.0
4	H_2 + 0.5 O_2 → H_2O	-242	$A\ T^n \exp(-E/(RT))\ [H_2][O_2]$	fr/ed	9.870×10^{8}	0	31.0
5	CO_2 + M → CO + 0.5 O_2 + M	283	$A\ T^n \exp(-E/(RT))\ [CO_2]\ [M]$[3]	fr	1.600×10^{26}	-3.72	363.5
6	meal → clinker	23.7	$A\ T^n \exp(-E/(RT))\ [H_2][O_2]$	fr	1.000×10^{37}	-9.91	130.0

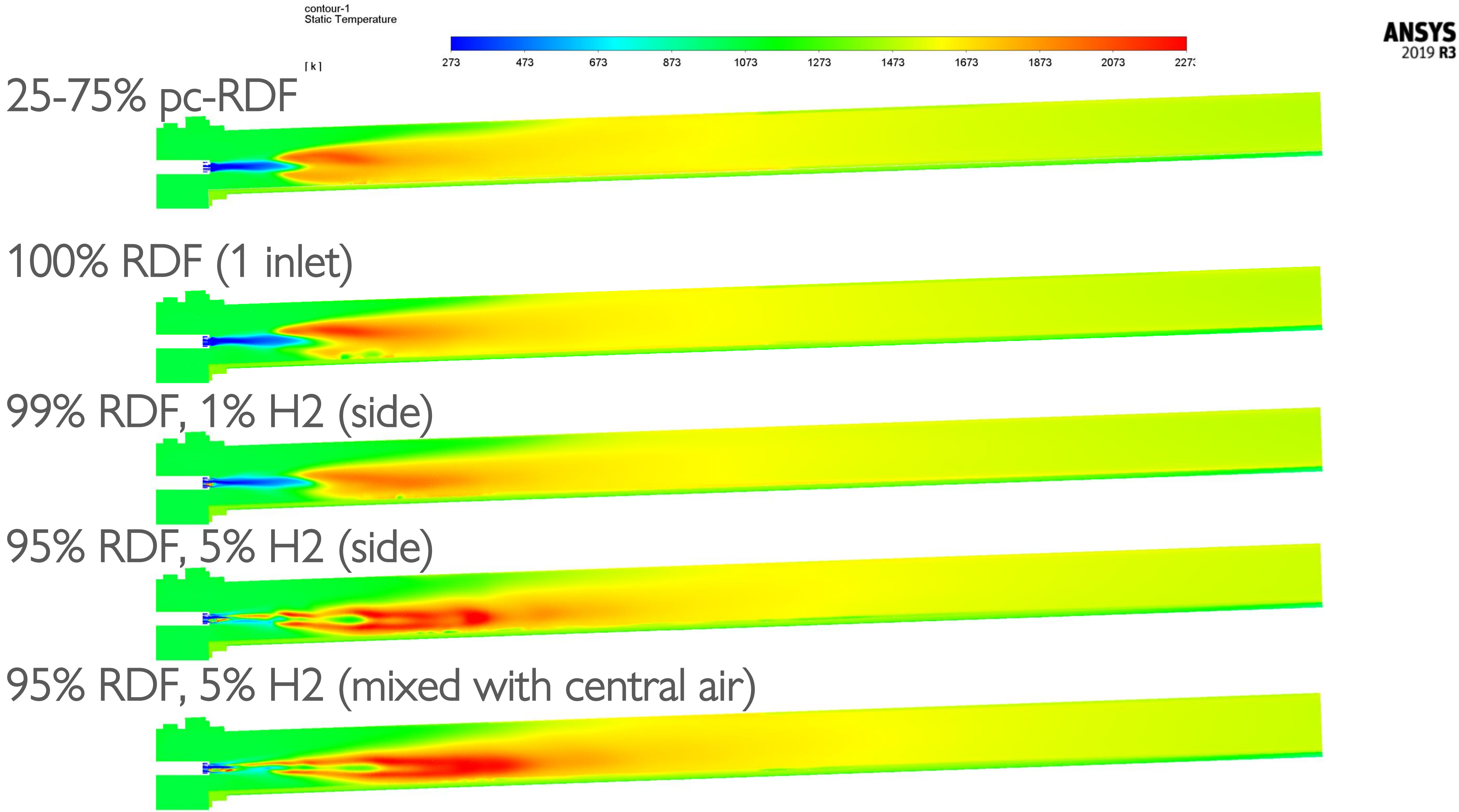
[1] Westbrook C.K., Dryer F.L., *Simplified reaction mechanisms for the oxidation of hydrocarbon fuels in flames*, Combustion Science and Technology 27, pp. 31-43, 1981

[2] Dryer F.L., Glassman I., *High-temperature oxidation of CO and CH_4*, 14th Symposium (int.) on Combustion, 1973

RESULTS


contour-1
Static Temperature
[k]
273
473
673
873
1073
1273
1473
1673
1873
2073
ANSYS
2019 R3
100% pc
25-75% pc-RDF
100% RDF (1 inlet)
100% RDF (2 inlets)
99% RDF, 1% H2 (side)

RESULTS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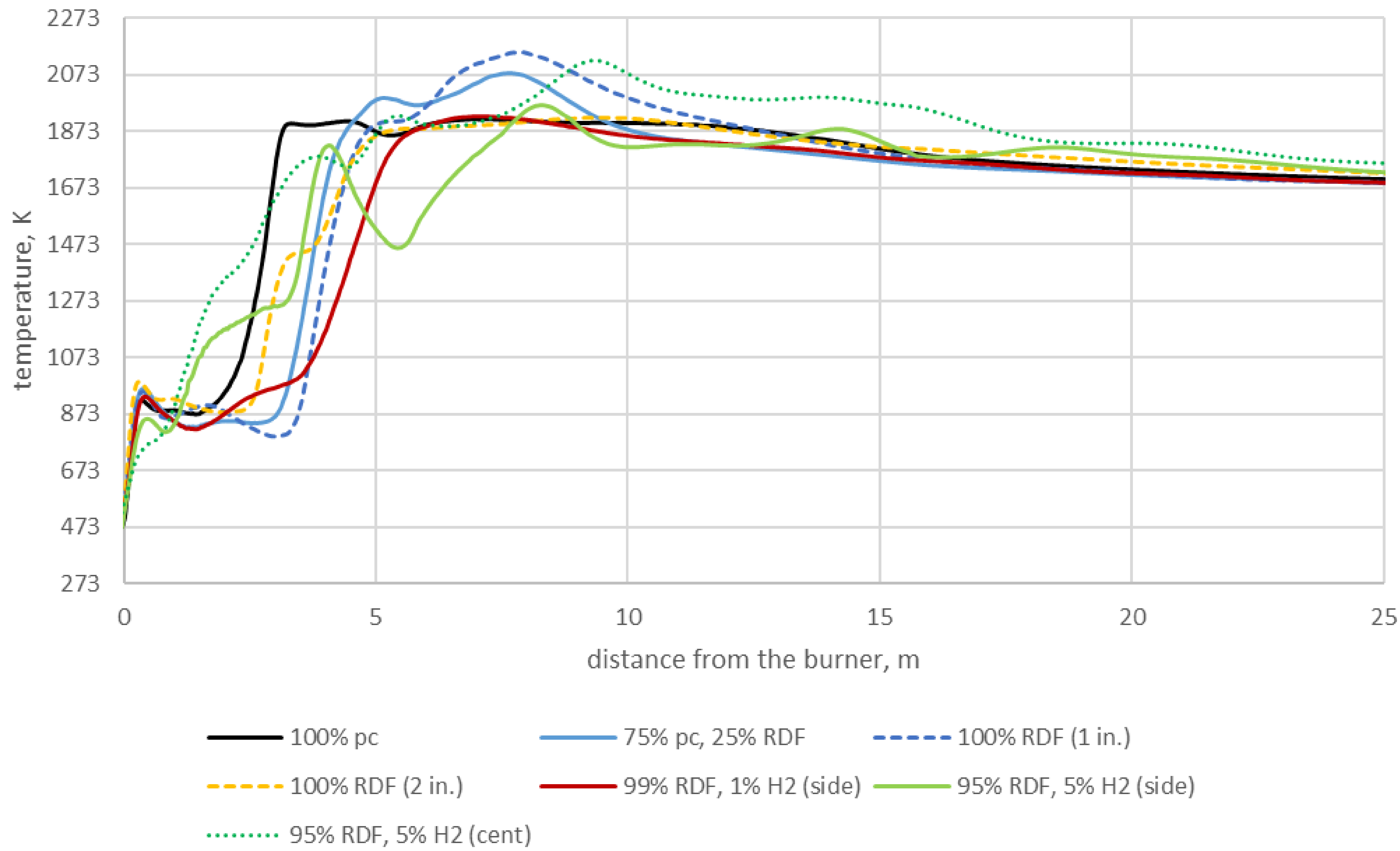

temperature, K
2273
2073
1873
1673
1473
1273
1073
873
673
473
273
0
5
10
15
20
25
distance from the burner, m
100% pc
75% pc, 25% RDF
100% RDF (1 in.)
100% RDF (2 in.)
99% RDF, 1% H2 (side)
95% RDF, 5% H2 (side)
95% RDF, 5% H2 (cent)

CONCLUSION

- high RDF share moves the flame forward, making it shorter and locally hotter
- 100% petcoke case T-profile indicating flame distance has not been recreated with other fuel mixtures, 75-25% almost has - futher studies necessary as H_2 shows some visible impact
- realistic lift-off of a flame (distance from a burner tip) has been achieved
- believable flame and klinker outlet temperatures (~1200 ºC) in a base cases have been obtained
- preliminary model of gas-klinker interaction and the klinker flow (forward+mixing) has been checked
- model is currently difficult to validate due to lack of measurements and extreme conditions of furnace operation (high temp., dust, kiln rotation)
- approach to model RDF as a set of particles of the averaged properties is not sufficient - model should include major groups of RDF
- to model co-firing of RDF with extensive amounts of H_2 implementation of H_2O decomposition reaction seems necessary

Thank you for your attention

Q&A

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