CLEANclinKER by calcium looping for low-CO_2 cement

CLEANKER

20-21 January 2020 – Geleen (The Netherlands)

8th High Temperature Solid Looping Cycles Network Meeting

Simulation of CLEANKER Demonstrator Reactors with Versatile Modelling Tools

Kari Myöhänen[1], Maurizio Spinelli[2]

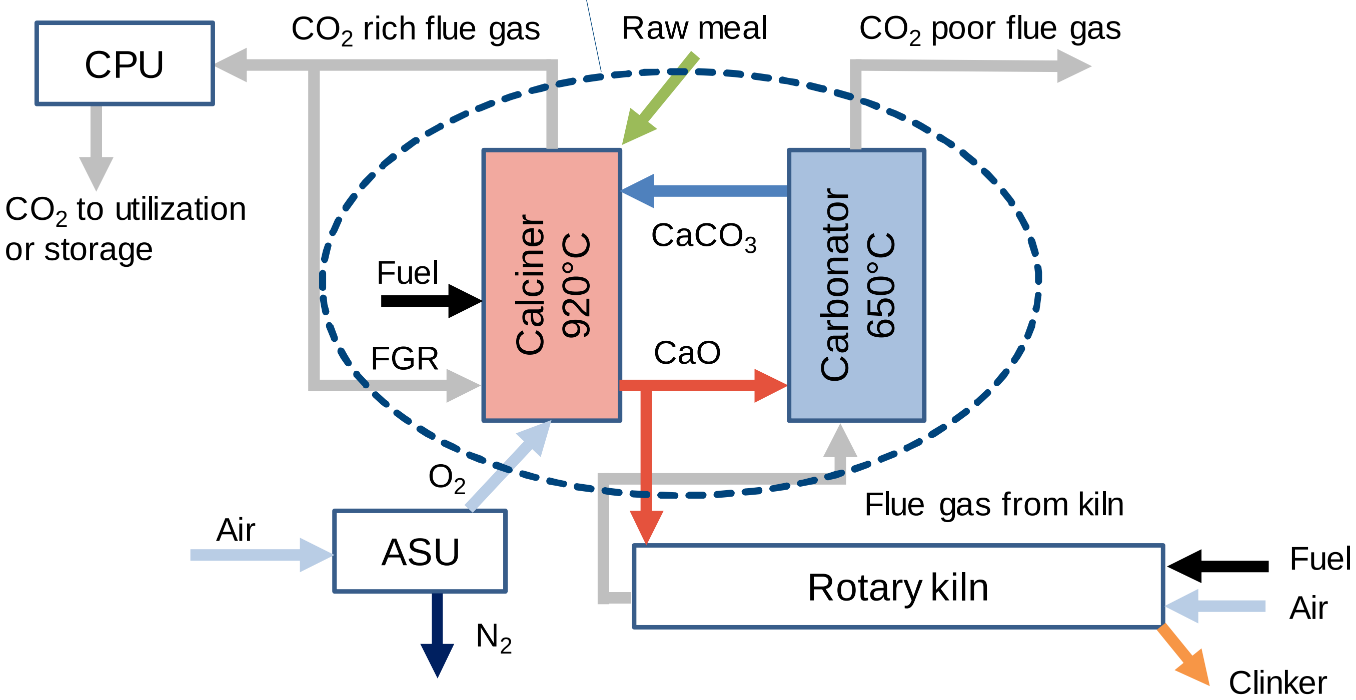
[1]LUT University, Finland, [2]LEAP, Italy

Introduction

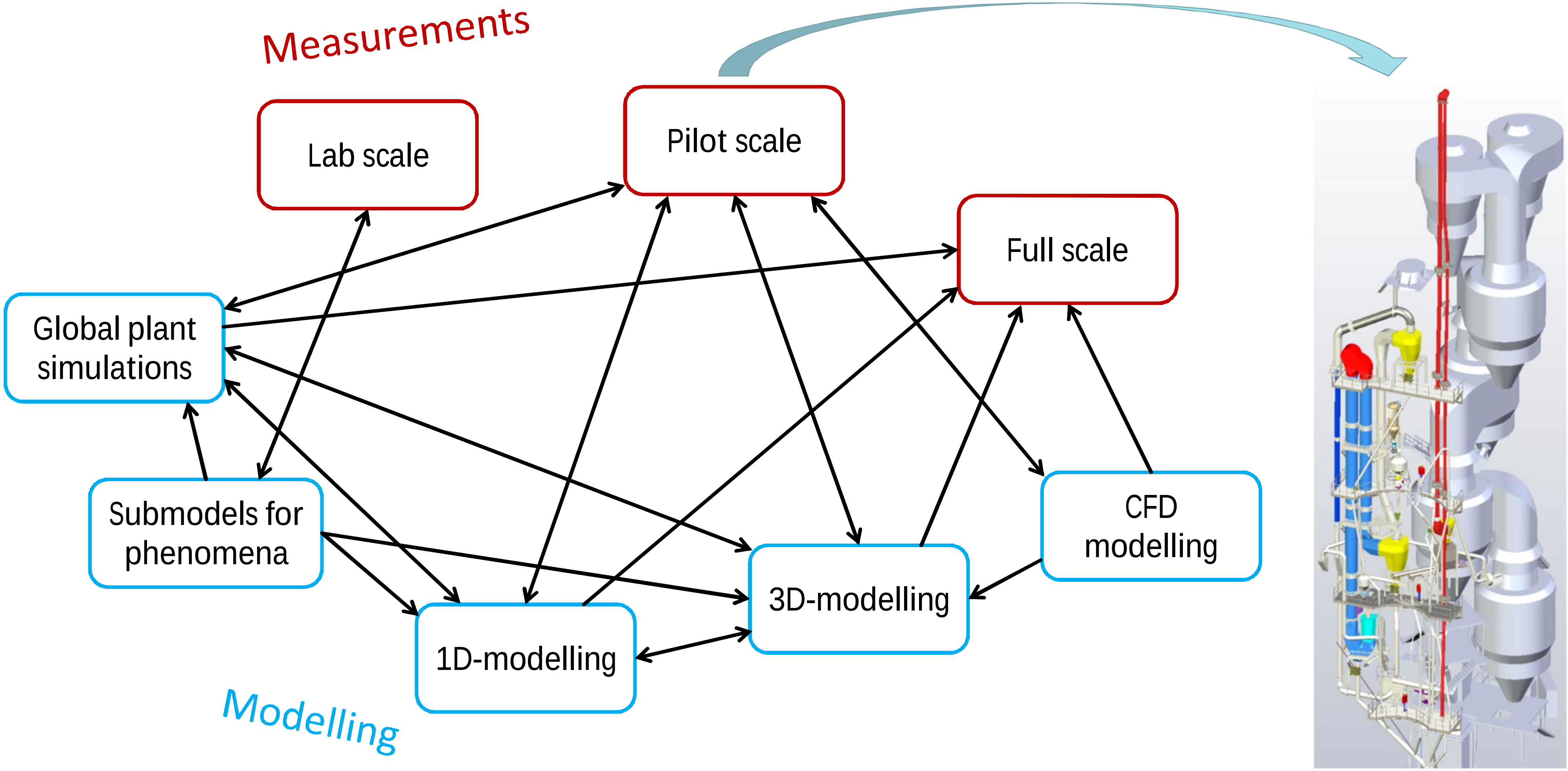
Contents of presentation

- Overview
- Global plant simulations
- 1D modelling
- 3D modelling
- CFD modelling
- Summary

Scope of simulations: calciner and carbonator reactors

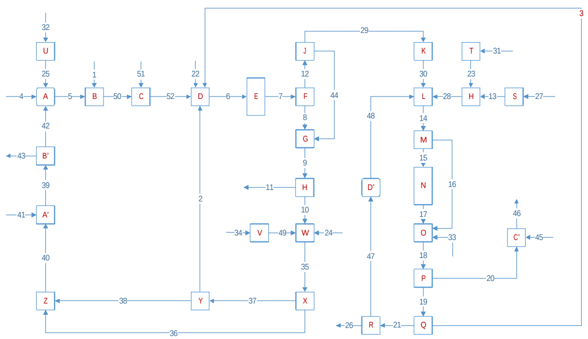


Overview: interlinks between measurements and modelling methods

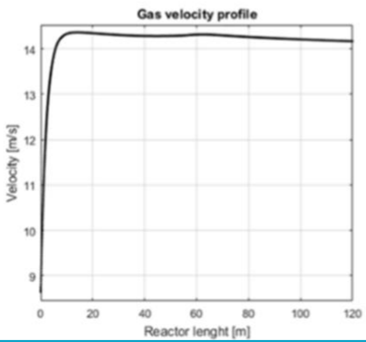


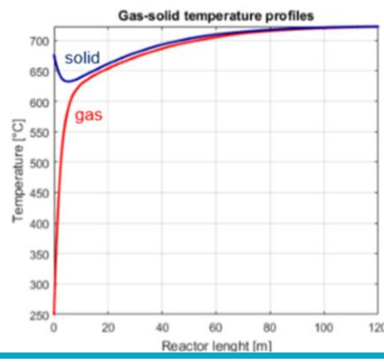
Global plant simulations

- GS simulation software has been used to calculate pilot plant mass & energy balances, to support the first design of the pilot plant

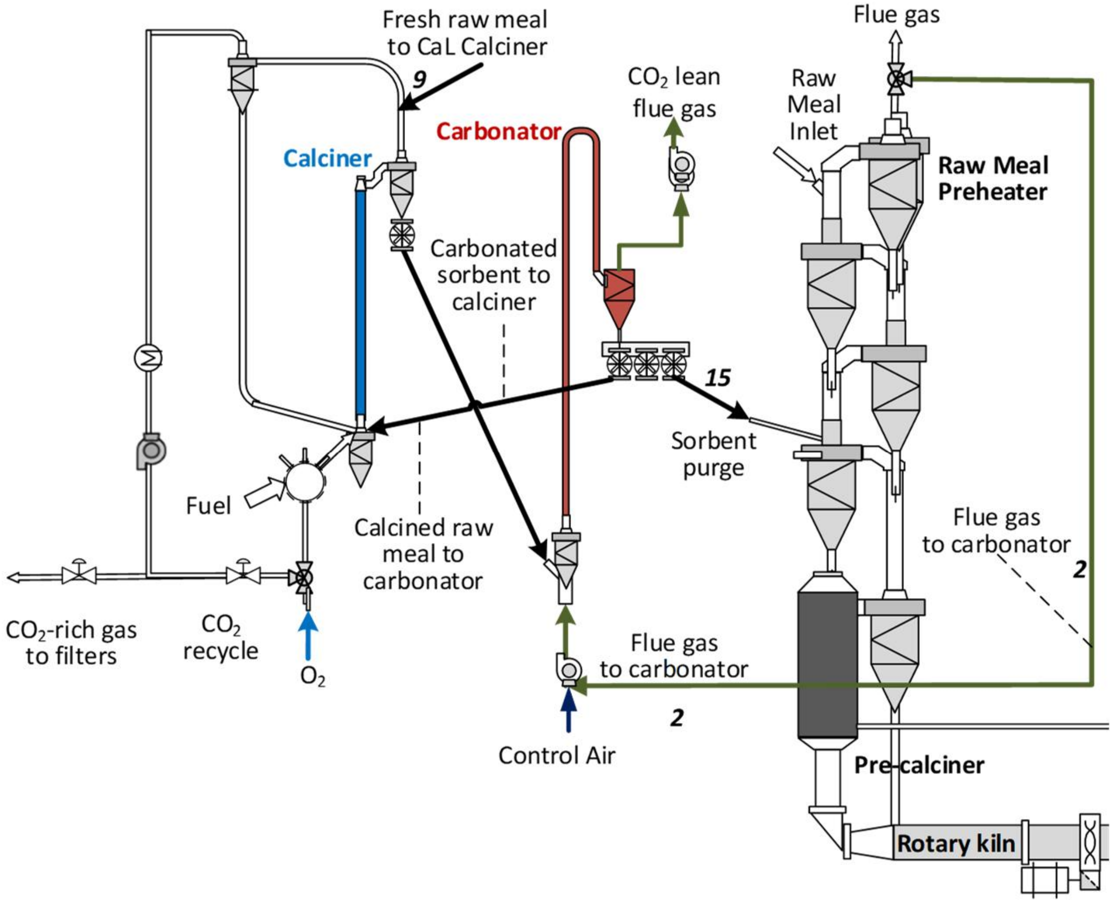


- EF Carbonator performances have been estimated by using a dedicated 1D model (implemented in Matlab®)





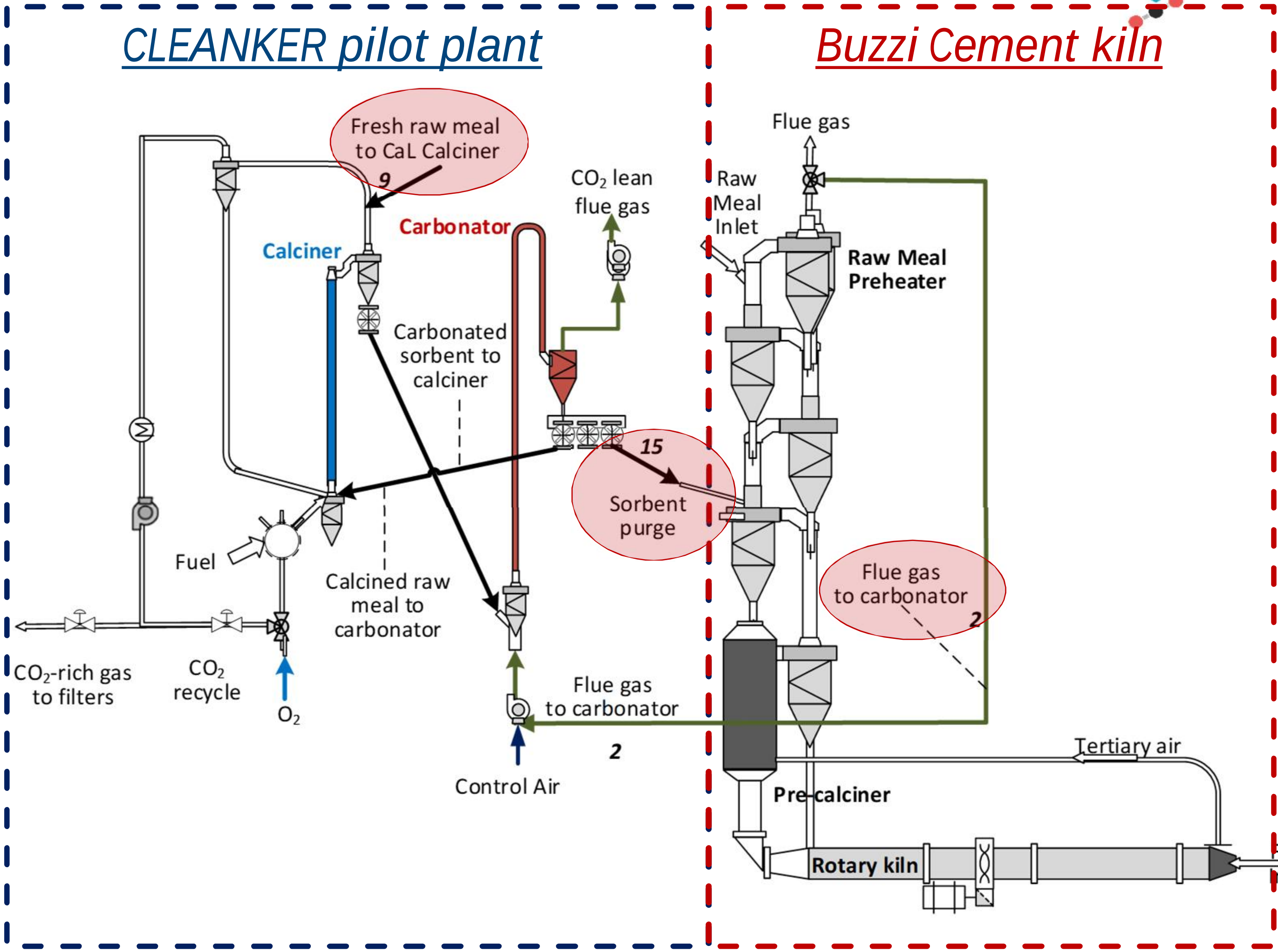
Pilot plant simplified flowsheet



Global plant simulations – process description and assumptions

The pilot plant is connected to the Vernasca kiln by means of the following streams:

- Flue gases for the carbonator are extracted from the last stage of the preheater at 30%CO_2 and about 300°C (#2). This stream is mixed with fresh air to achieve 20%CO_2 (making the flow representative of rotary kiln exhausts).
- A fraction of the fresh raw meal normally fed to the kiln is sent to the oxyfired calciner of the pilot to be used as CO_2 sorbent (#9);
- A fraction of the sorbent at carbonator outlet is purged form the pilot and sent to the first stage of the kiln preheater (#15).

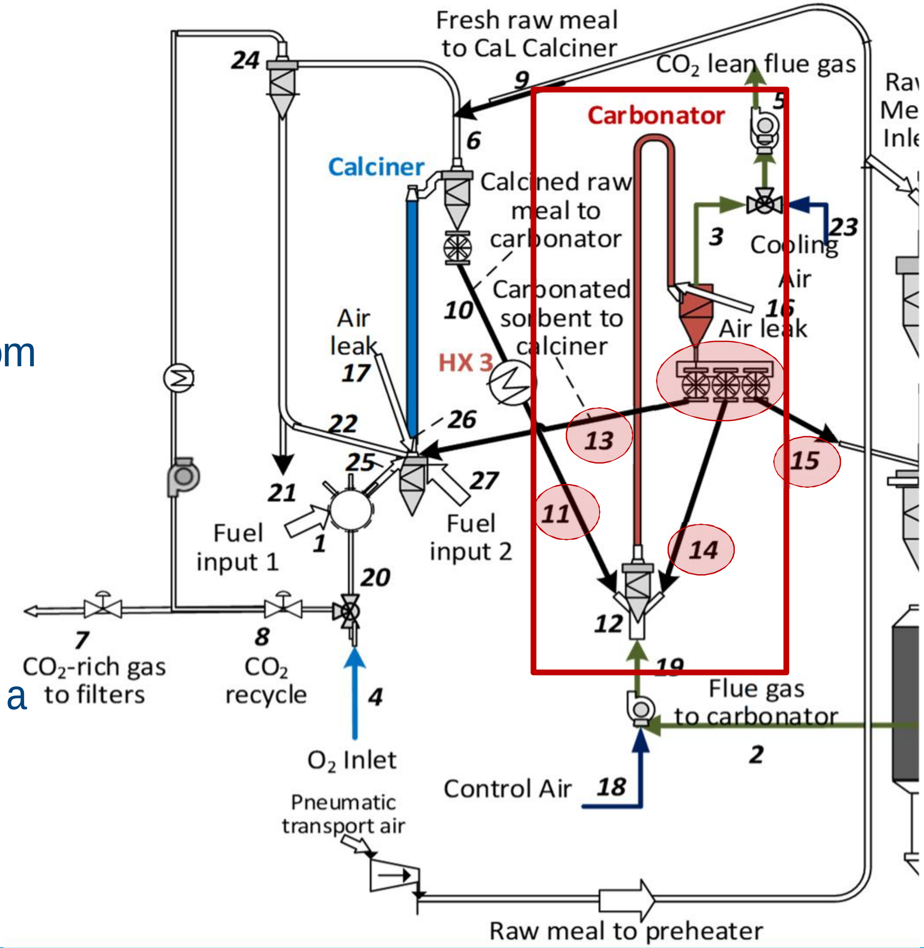


Global plant simulations – process description and assumptions

Carbonator section:

- The carbonator is an insulated, recirculating entrained flow reactor (L=120 m, D=0.25-0.35m) threating a gaseous stream of about 1000 Nm3, which defines the absolute size of the pilot;
- The carbonator is fed with the solid stream coming from the oxyfired calciner. The amount of solids sent to the carbonator can be tuned from 2.4 up to 8.9 t/h, depending on the operating condition.
- at carbonator outlet, solids are diverted by means of cooled screws among:
  - the oxy-fired calciner (#13);
  - the carbonator (#14, an internal recycle determined to achieve a sorbent conversion ΔX of 10%);.
  - the industrial kiln as purge of the pilot (#15).

CLEANKER pilot plant



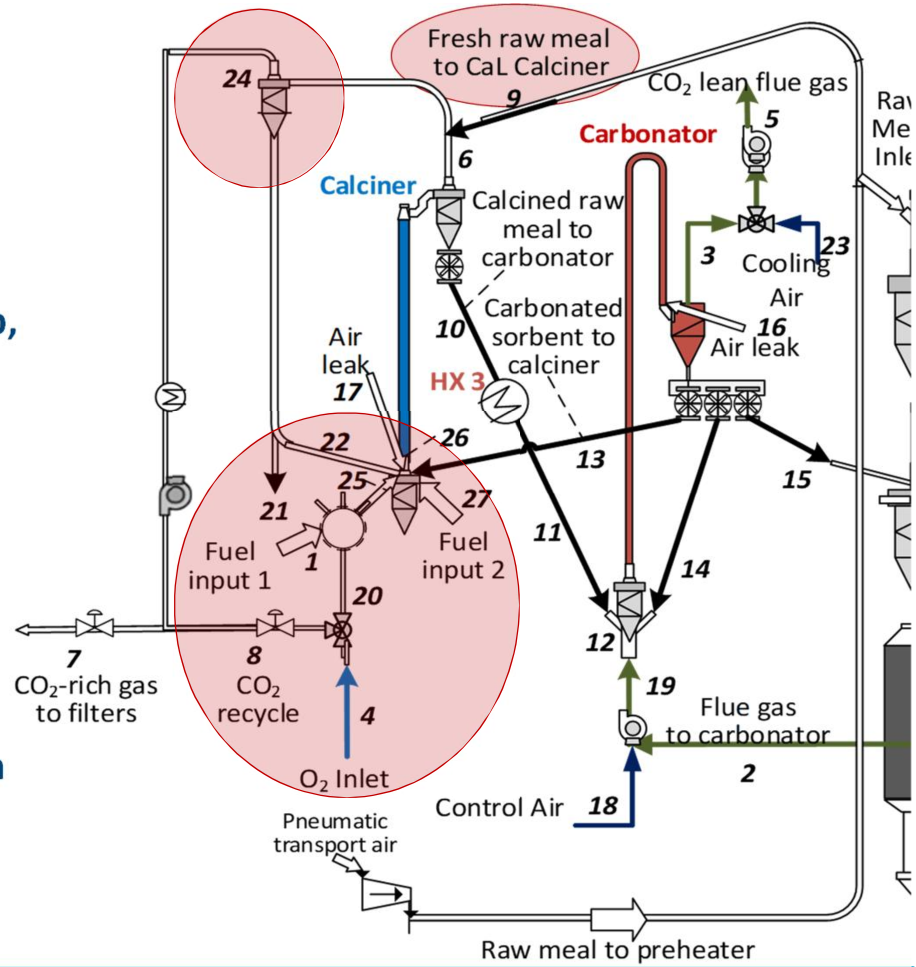
Calciner section:

- The amount of raw meal fed to the pilot (#9) is defined by keeping the same ratio between the flow rates of raw meal and rotary kiln off-gas of industrial cement kilns (2.8-4.3 kg/Nm3).

- The raw meal is preheated in a single stage riser-cyclone at calciner top, with the aim of :
  - reducing the fuel consumption and the raw meal residence time in the calciner;
  - cooling the CO_2 rich gas produced in the calciner and reducing the heat load of the downstream gas cooling pipe;

- Calcination is sustained by the multiple-stage oxycombustion of a heavy-oil fuel, set to reach 920°C at calciner outlet. The oxidant stream is a mixture of pure oxygen and recycled CO_2, set to have 24-35% oxygen at calciner inlet (depending on the configuration).

CLEANKER pilot plant



Co-funded by the Horizon 2020 Framework Programme of the European Union

Global plant simulations – sensitivity analysis

GS/Matlab simulations performed to predict the CO_2 capture efficiency and the consumables supply requirements (O_2, fuel) as a function of CaL parameters:

- The sorbent conversion capacity (Xmax, from 20 to 40%), which depends on the nature of the raw meal and on the extent of side reactions;
- The fresh raw meal to carbonator inlet gas ratio (2.8 - 4.3 kg/Nm3) , which is an important parameter for the performances of CaL system. This ratio increases with the pre-calcination degree of the reference cement plant: the higher the precalcination, the lower the fuel burned in the rotary kiln and the exhaust gases sent to the carbonator.

Alternative operating conditions simulated for promoting the flexibility of the pilot and of the experimental activity:

- stand alone operation of the carbonator;
- stand alone operation of the calciner;
- air-blown calcination case.

Assumptions

Calciner	
Outlet gas superficial velocity, m/s	~15
O_2 inlet, %vol,wet	30
O_2 at calciner outlet, %vol,wet	4
O_2 inlet temperature, °C	15
Calciner outlet temperature, °C	920
Calcination degree, %	90
Air ingress, Nm^3/h	200
Efficiency of cyclones, %	90

Carbonator	
Diameter, m	0.25
CO_2 at carbonator inlet, %vol,wet	20
Gas superficial velocity, m/s	~15
Gas/sorbent inlet adiabatic mixing temperature, °C	600
Air ingress, Nm^3/h	100
Efficiency of cyclones, %	90
CaO recarbonation (ΔX), %	~10

Co-funded by the Horizon 2020 Framework Programme of the European Union

Global plant simulations – results

Effects of the CaL variables ➔ (i) Xmax and (ii) Raw meal/kiln gas ratio:

- At constant Raw meal/kiln gas ratio and high CO_2 capture rates, an increase of X_{max} (from 20 to 40%) allows :

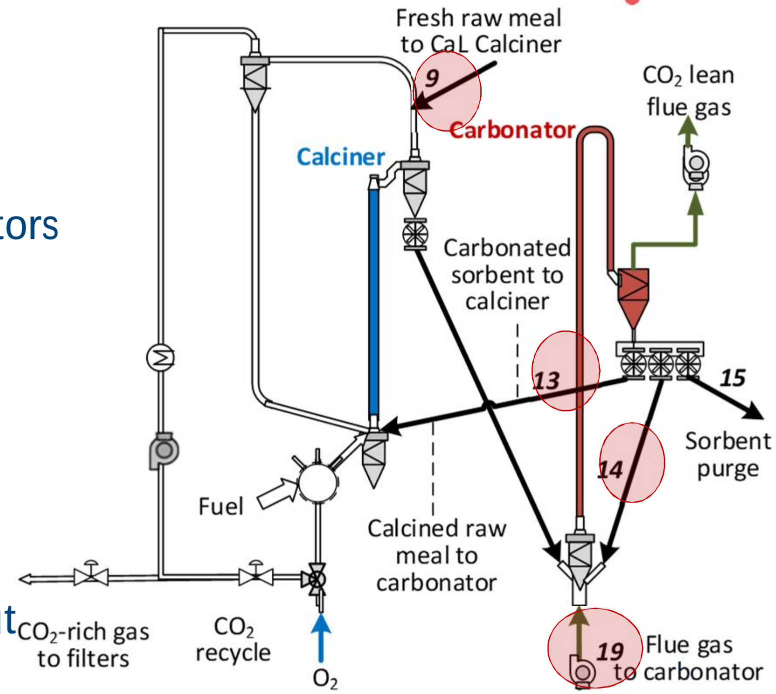
  1- reducing the amount of sorbent circulating between the two CaL reactors (#13, -50%) or

  2- reducing the amount of sorbent internally recirculated in the carbonator (#14, -50%)

⇩

Option 1 is the best one in terms of energy consumption: fuel and oxygen consumption decrease respectively by 15% and 27% going from Xmax=20 to 40%.

On the other hand, option 2 decreases CO_2 capture rate in the carbonator (-5%) but the overall capture is still >90%.



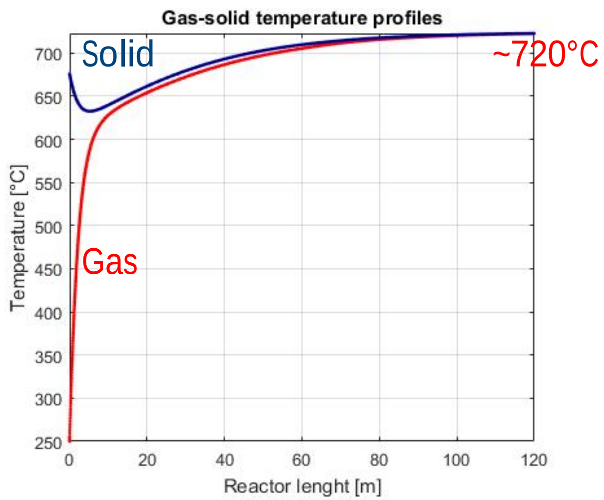
- At constant X_{Max} an increase of Raw meal/kiln gas ratio (from 2.8 to 4.3 kg/Nm3) determines an increase of the overall carbon capture rate (>95%) but involves also an increase of fuel and O_2 consumption (respectively +26% and +30%), required for calcining a higher amount of fresh sorbent.

Global plant simulations – results (carbonator)

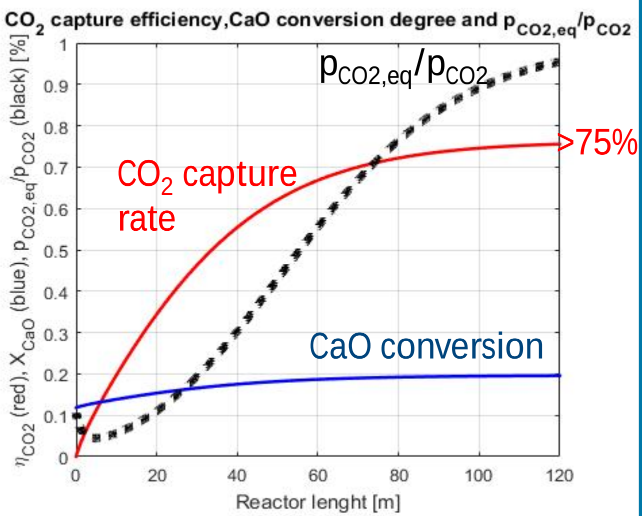
For all the configurations proposed, the carbonator has been simulated using a 1D Matlab model developed in the framework of the Cemcap project.

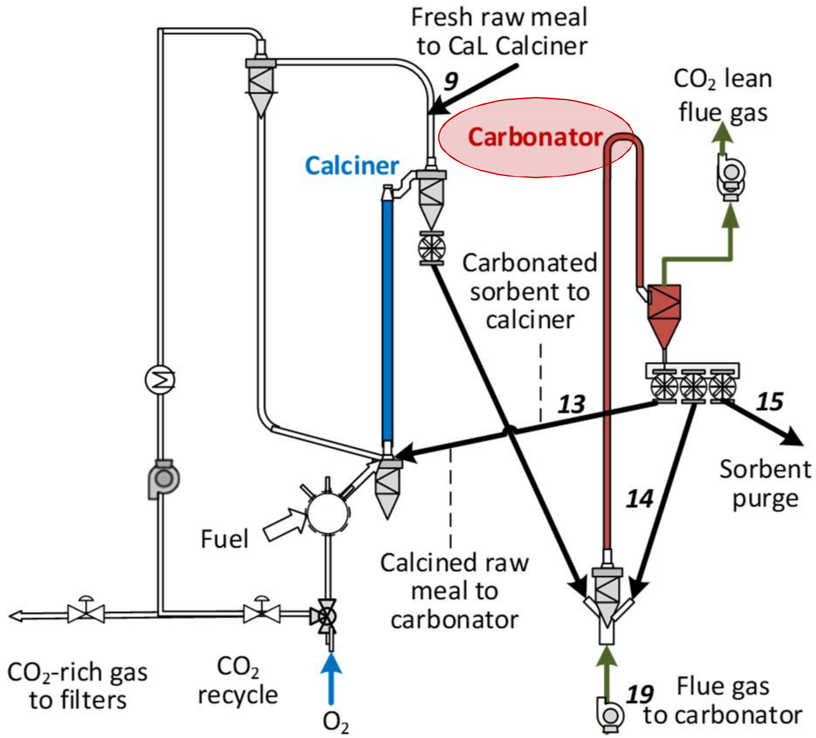
Results for a case with Xmax=40%, Raw meal/kiln gas ratio=2.8 kg/Nm3:

Gas/Solid temperature profile



CO_2 capture rate and CaO conversion



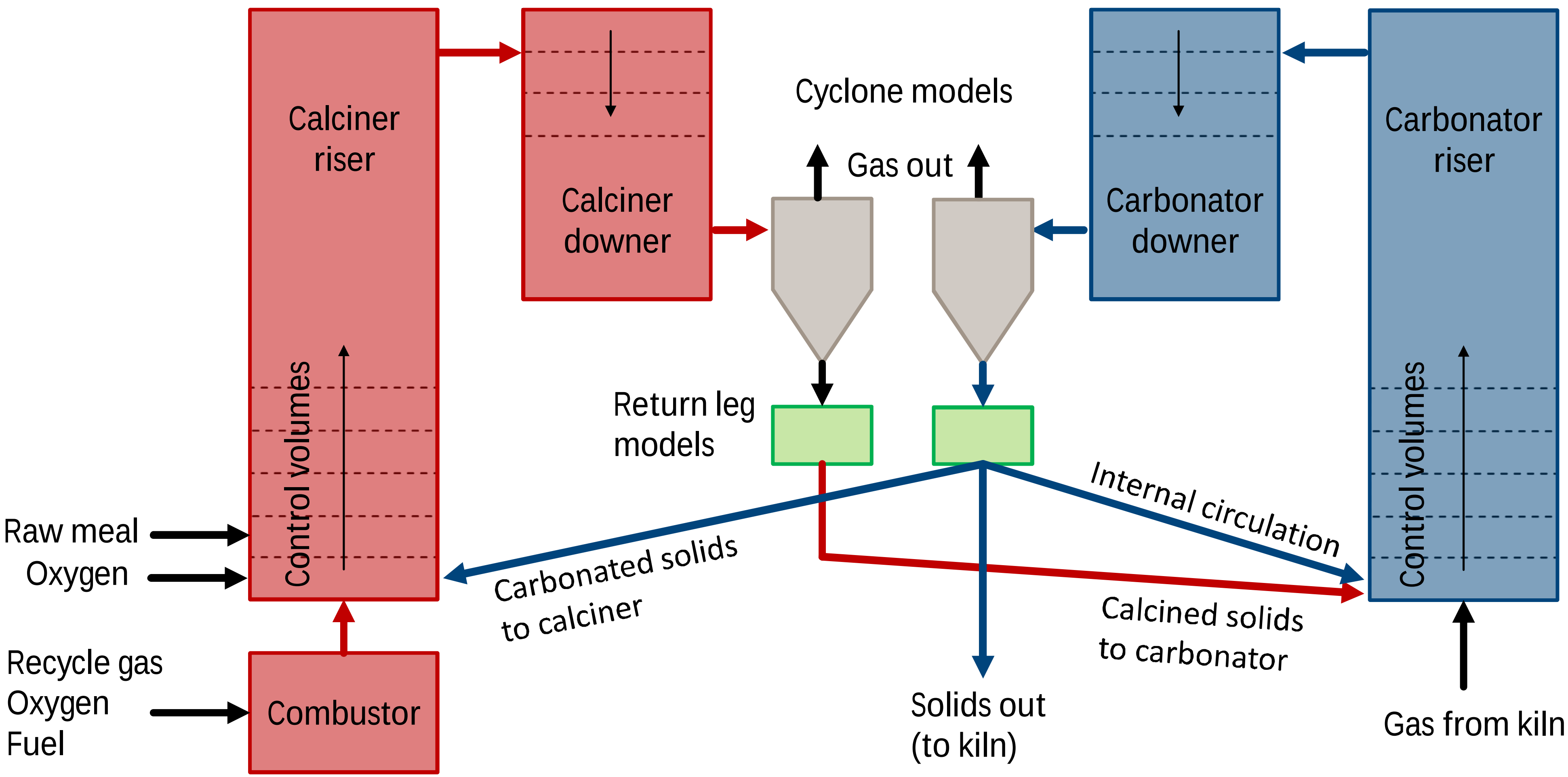


Work in progress:

Development of a similar EF calciner model, including a simplified model for combustion and the kinetics of calcination and other side reaction (e.g. silicates formation ➔ belite). Both carbonator and calciner models will be calibrated using experimental results of the CLEANKER pilot, and will be a useful instrument for the design of the full scale CaL plant.

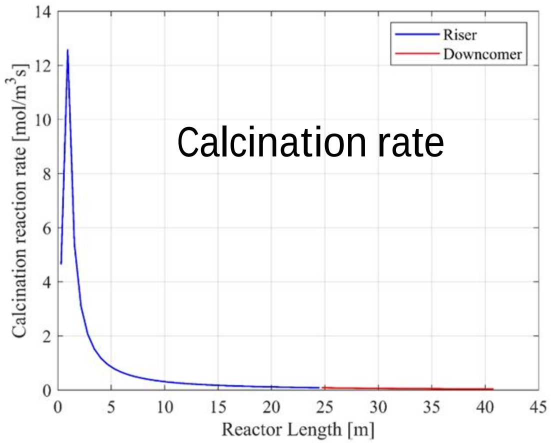
Co-funded by the Horizon 2020 Framework Programme of the European Union

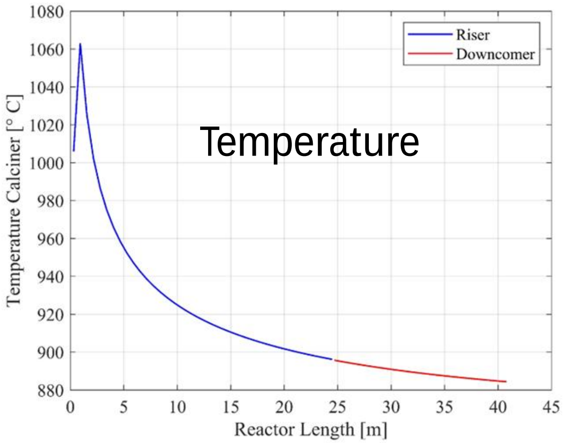
1D model by LUT

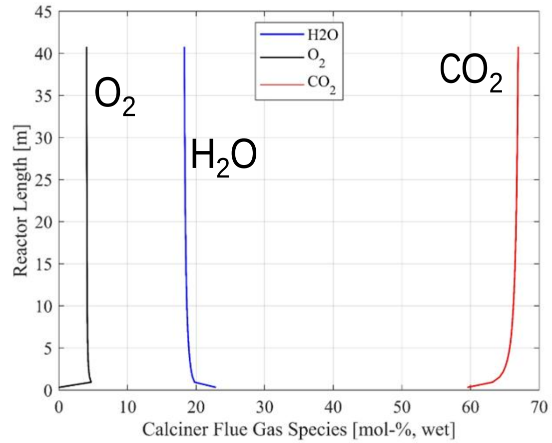


Results from 1D model (Case C)

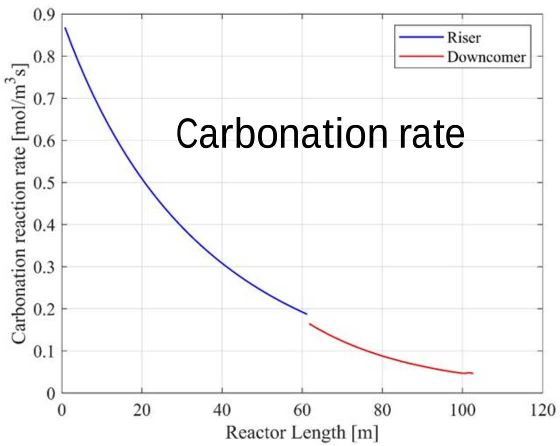
Calciner

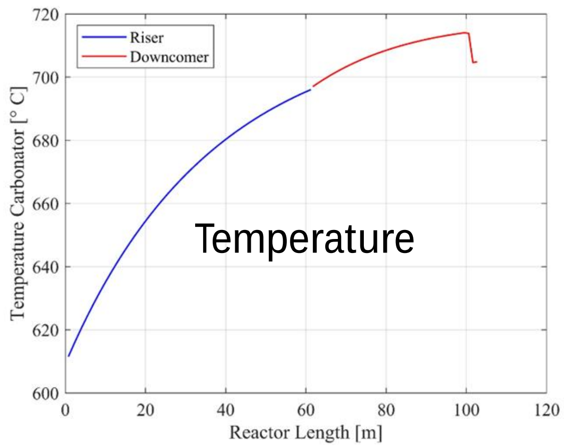


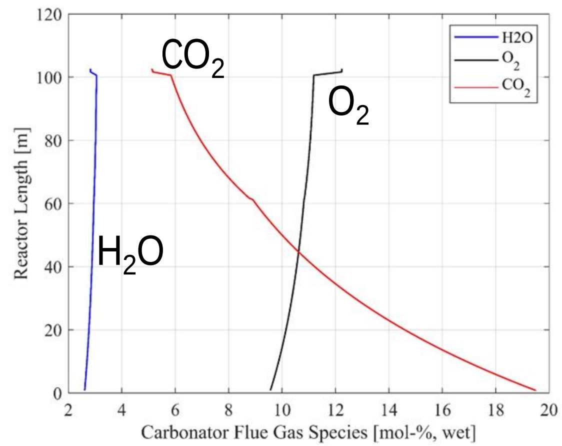




Carbonator



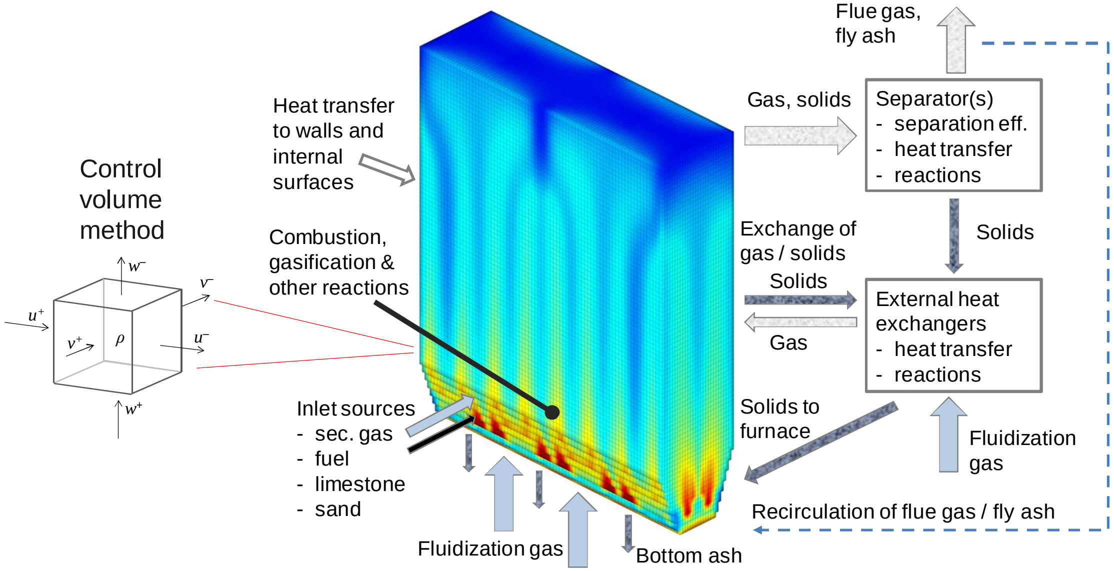


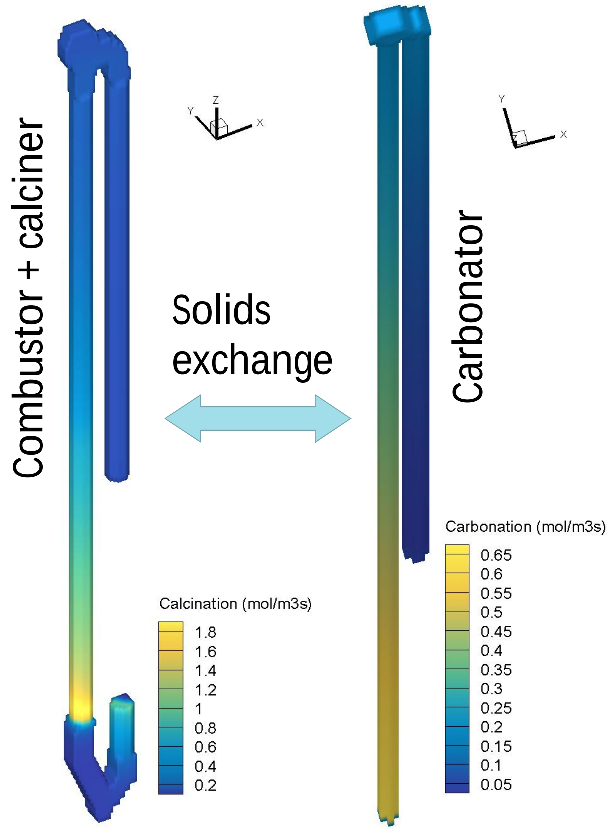


Co-funded by the Horizon 2020
Framework Programme of the European Union

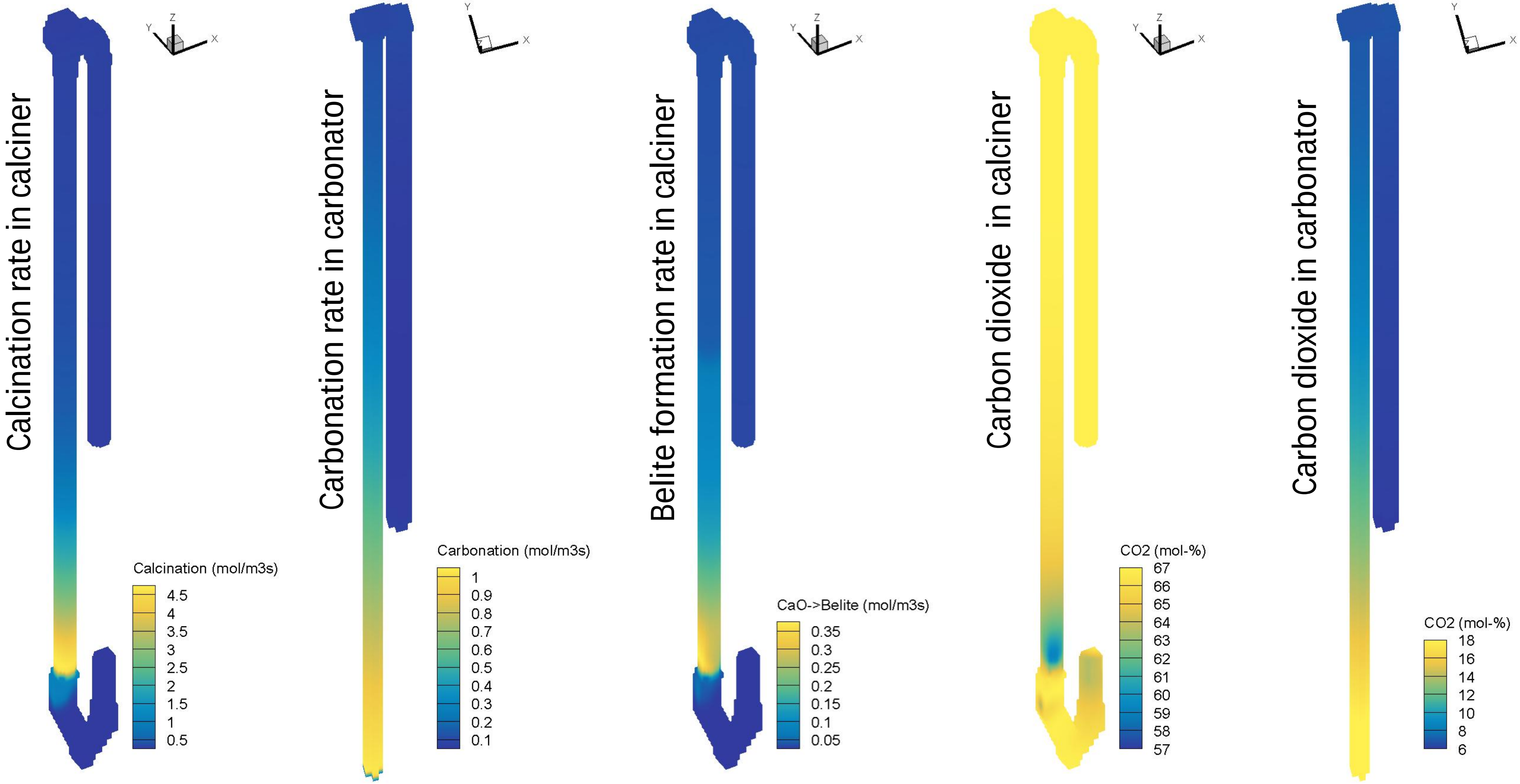
3D model by LUT

- Originally for CFB combustion -------------------------------> modified to handle coupled entrained flow reactors





3D model results (Case C)



Co-funded by the Horizon 2020 Framework Programme of the European Union

Comparison of main results with different models (Case C)

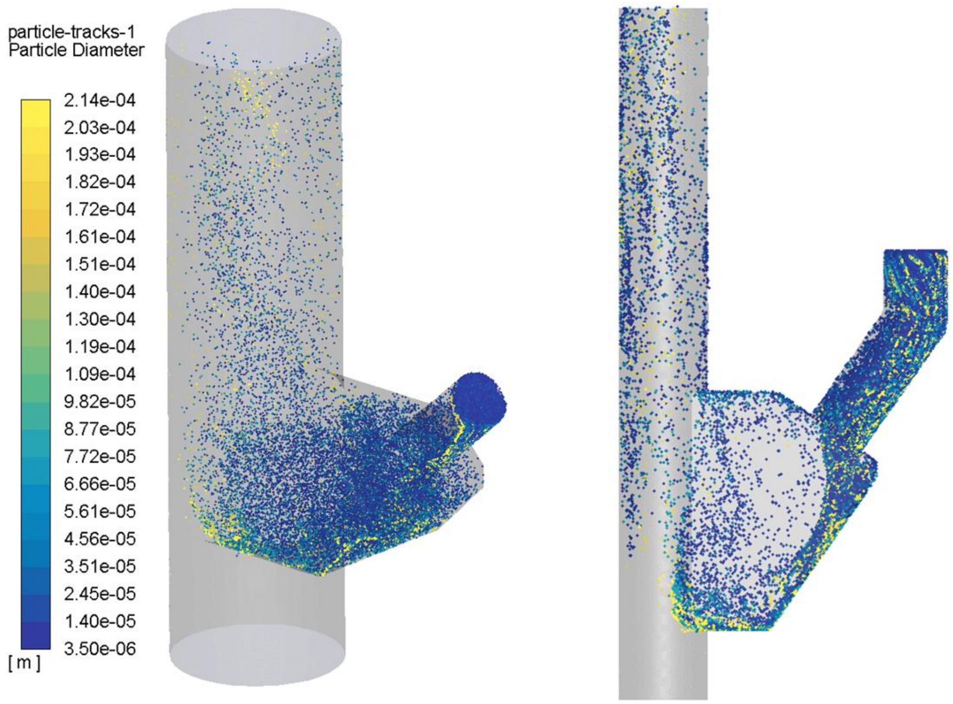
	0D	1D	3D
Gas flow after calciner (kg/s)	1.89	1.90	1.92
Temperature (°C)	920	884	909
O_2 (vol-%)	4.0	4.0	3.5
CO_2 (vol-%)	66.9	66.9	67.4
Calcination degree (%)	89.7	86.4	89.8
Gas flow after carbonator (kg/s)	0.33	0.33	0.33
Temperature (°C)	711	705	712
O_2 (vol-%)	12.3	12.2	12.2
CO_2 (vol-%)	5.1	5.1	5.4
CO_2 capture efficiency (%)	75.6	75.6	74.2

CFD (Fluent) modelling of specific equipment

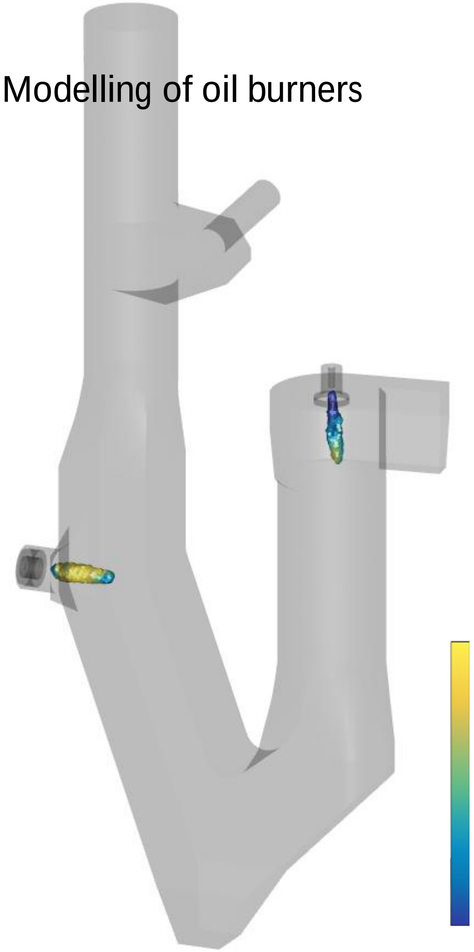
Modelling of particle flows in splash boxes

Calciner

Carbonator



Modelling of oil burners



Isosurface of complete evaporation colored by reaction rate

Summary and conclusions

- Different simulation tools have been applied to study the CLEANKER process and support the planning of the pilot tests.
  - Global plant simulations.
  - 1D and 3D modelling.
  - CFD modelling.
- At this stage, the model parameters are based on earlier experience and bench scale studies.
- The measurement data of the CLEANKER pilot will be applied to validate the models and adjust the parameters.
- The validated models can then simulate a large scale process and support the design of a commercial CLEANKER application.

Co-funded by the Horizon 2020 Framework Programme of the European Union

Acknowledgments

This project has received funding from the European Union's Horizon 2020 research and innovation programme under Grant Agreement n. 764816

This work is supported by the China Government (National Natural Science Foundation of China) under contract No.91434124 and No.51376105

www.cleanker.eu

Twitter: @CLEANKER_H2020

LinkedIn: www.linkedin.com/company/14834346