Options for calcium looping for CO_2 capture in the cement industry

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2nd ECRA/Cemcap workshop:

Carbon Capture Technologies in the Cement Industry

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CEMCAP

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WP12 participants

Institute of Power Plant and Combustion technology, University of Stuttgart

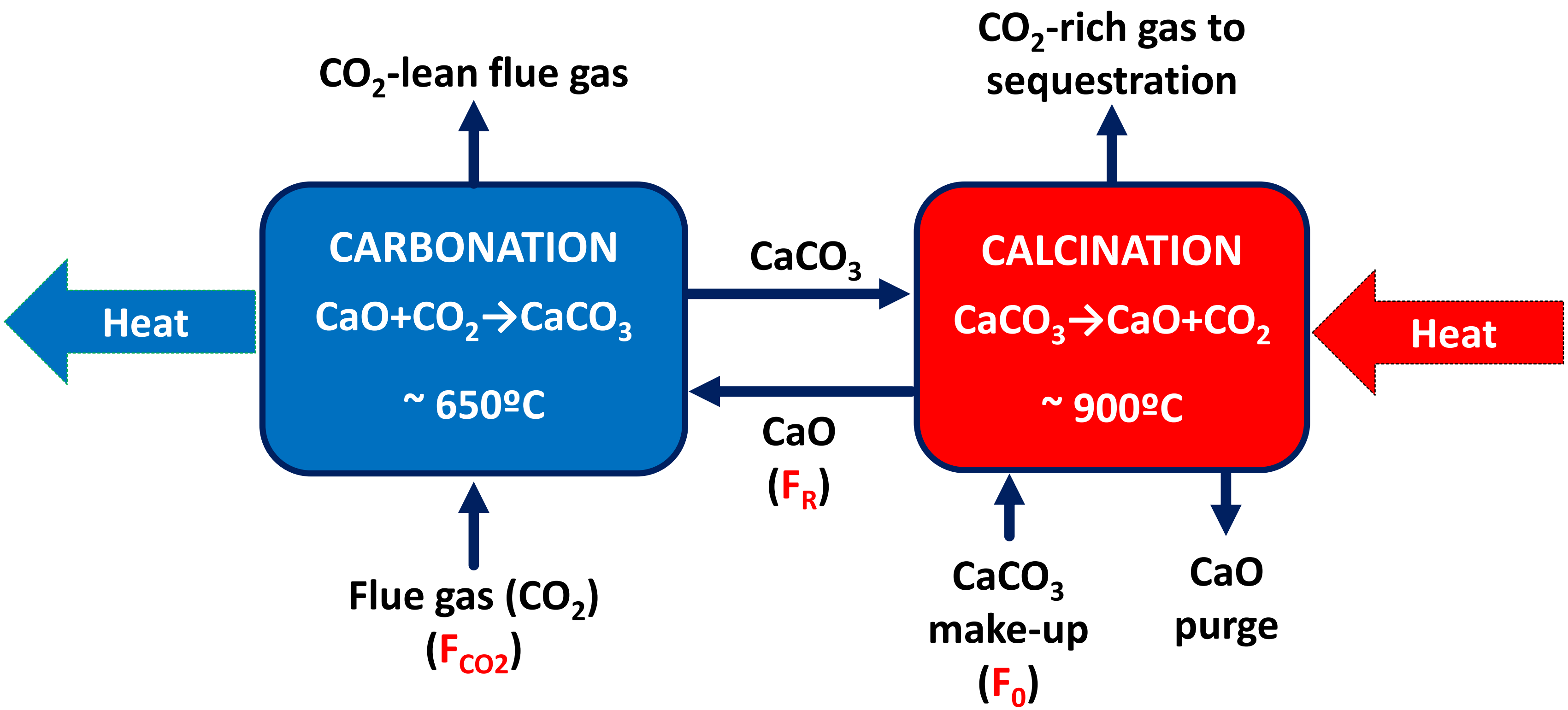
Spanish research council, INCAR-CSIC

Politecnico di Milano, Department of Energy

IKN,

Italcementi

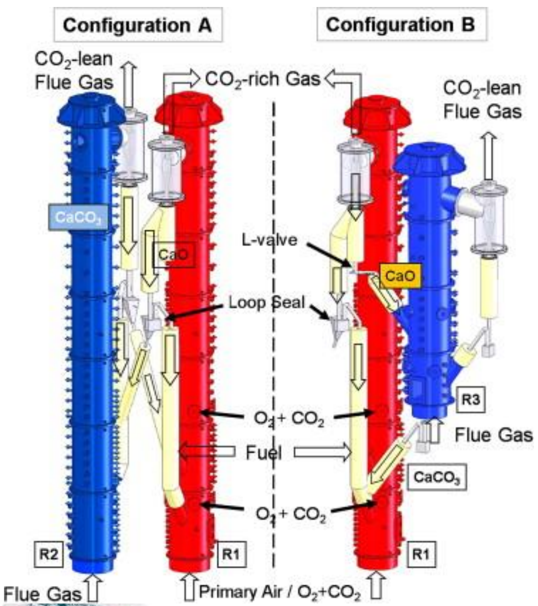
Calcium Looping process fundamentals



Calcium Looping for CO_2 capture: history

- Originally proposed by Shimizu et al., 1999. A twin fluid-bed reactor for removal of CO_2. Chem. Eng. Res. Des., 77.
- Continuously developed since 1998, mainly for application in power plants
- Several fluidized bed pilot facilities - demonstrated up to 1.7 MW

200 kW pilot at IFK, U. Stuttgart



1 MW pilot at TU Darmstadt

1.7 MW pilot at La Pereda (ES)

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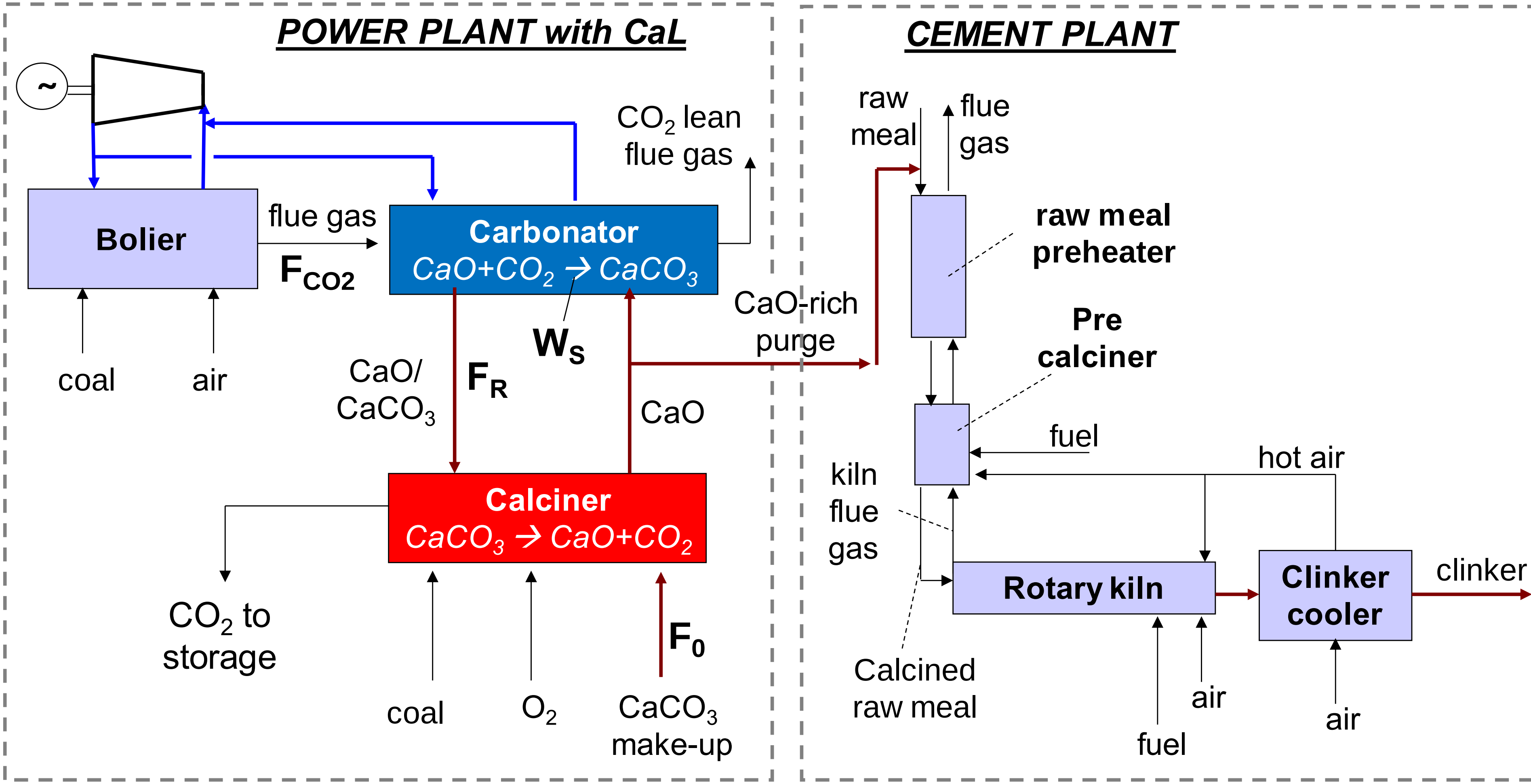
Calcium looping for cement plants

1. Cement plant-power plant coupling: CaO-rich spent sorbent from a CaL power plant as feed for the cement plant, as substitute of $CaCO_3$

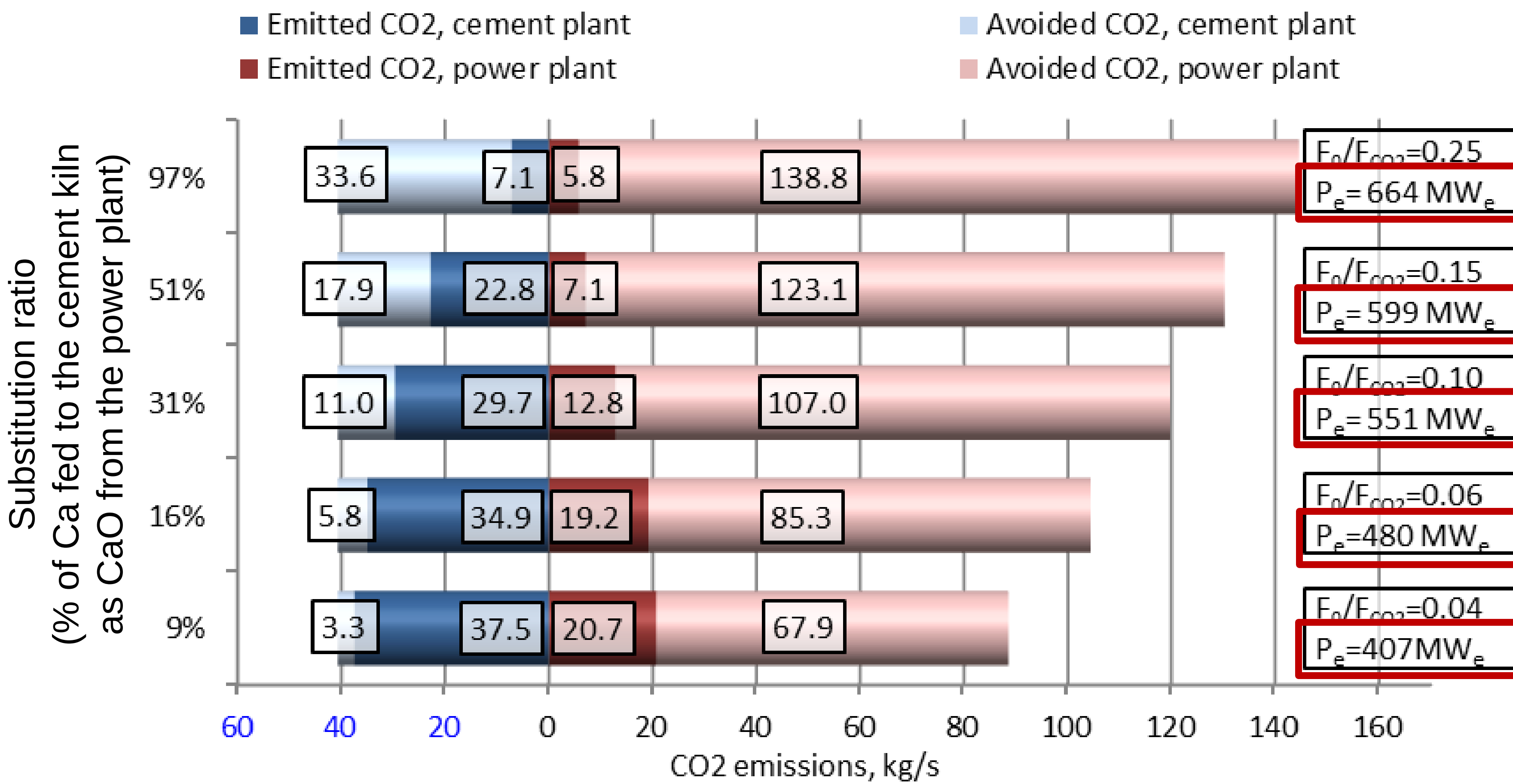
2. Post-combustion "tail end" configuration: CaL process is integrated in the cement plant with a conventional post-combustion capture configuration

3. Highly integrated CaL configuration: the CaL process is integrated within the cement production process by sharing the same oxyfuel calciner

Cement plant-power plant coupling

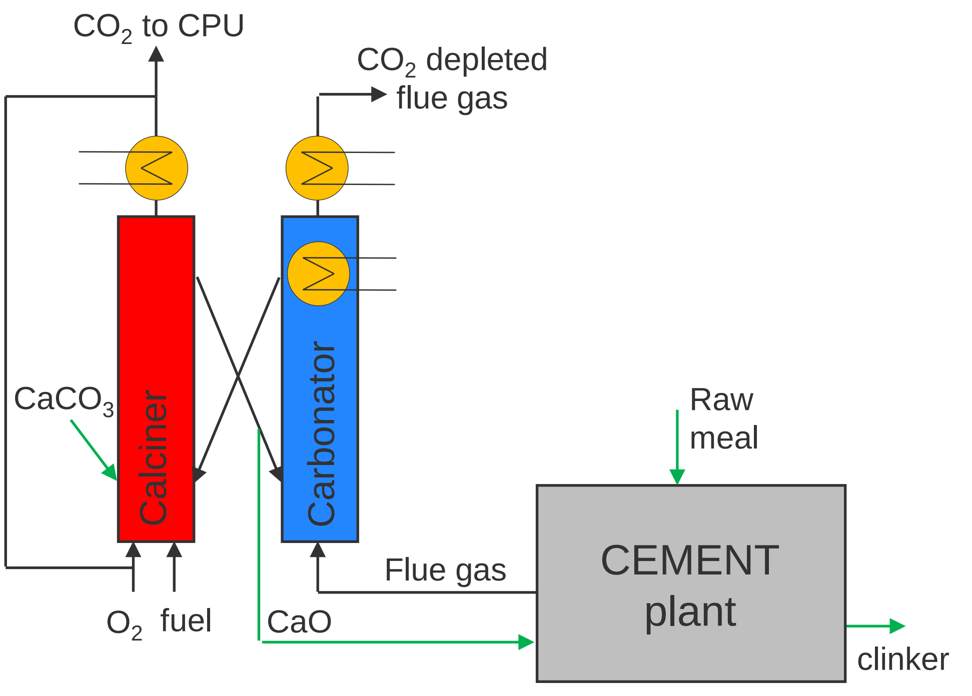


Cement plant-power plant coupling



Romano M.C. et al., 2013. The calcium looping process for low CO_2 emission cement and power. *Energy Procedia, 37, 7091-7099*.

Calcium Looping CO_2 capture: Tail-end CaL configuration



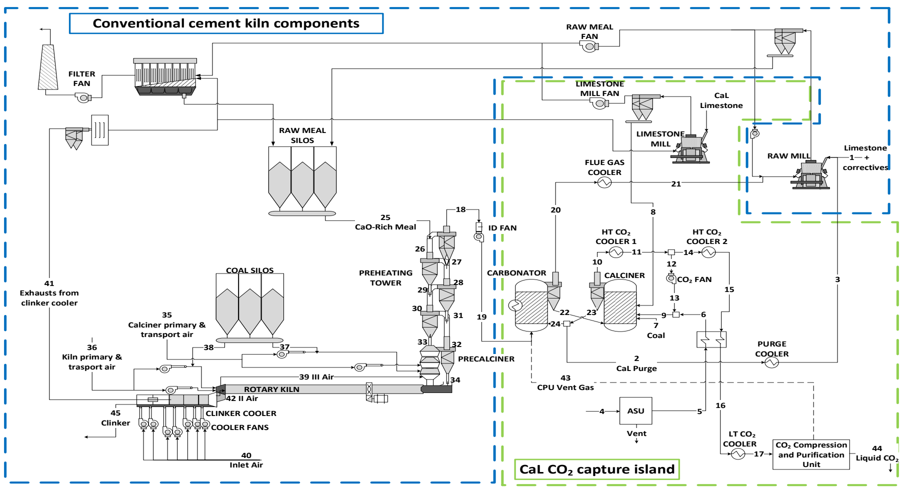
General features of the process:

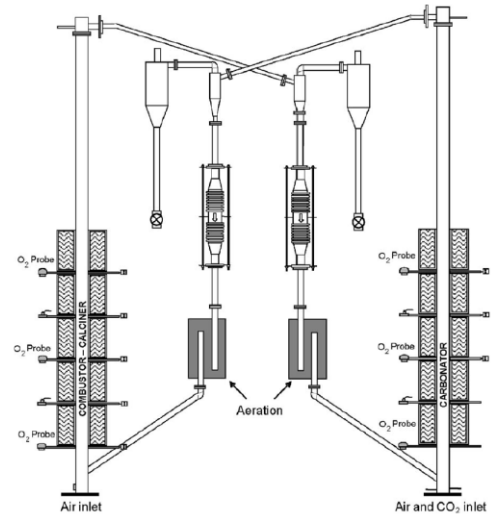
- Carbonator removes CO_2 from cement plant flue gas → Easy integration in existing cement
- Limestone partly calcined in Calcium Looping calciner → CaO-rich purge from CaL calciner used as feed for the cement kiln
- High fuel consumption (double calcination for the mineral CO_2 captured)
- Heat from fuel consumption recovered in efficient (~35% efficiency) steam cycle for power generation
- CFB CaL reactors: d_{50}=100-250 µm, vs. particle size for clinker production d_{50}=10-20 µm → CaL purge milled in the raw mill at low temperature

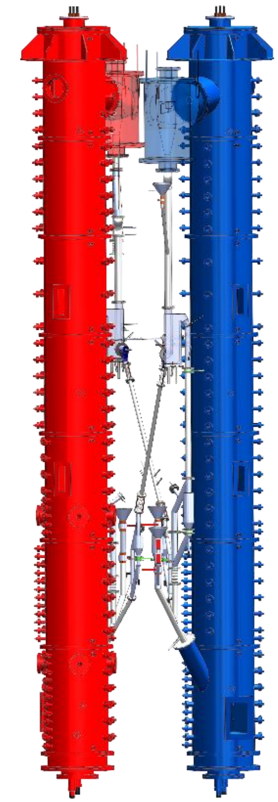
Calcium Looping CO_2 capture: Tail-end CaL configuration

Conducted Work:

- Parameter screening at 30 kW scale at CSIC (TRL5)
- Demonstration at semi-industrial scale (200 kW_{th}) at IFK (TRL6)
- Process simulation and integration







Arias et al., 2017. CO_2 Capture by CaL at Relevant Conditions for Cement Plants: Experimental Testing in a 30 kW Pilot Plant. *Ind. Eng. Chem. Res.*, 56, 2634–2640.

Hornberger et al., 2017. CaL for CO_2 Capture in Cement Plants – Pilot Scale Test. *Energy Procedia*, 114, 6171–6174.

Spinelli et al., 2017. Integration of CaL systems for CO_2 capture in cement plants. *Energy Procedia, 114, 6206-6214.*

De Lena et al. Process integration of tail-end CaL for CO_2 capture in cement plants. *Int J Greenh Gas Control. In press.*

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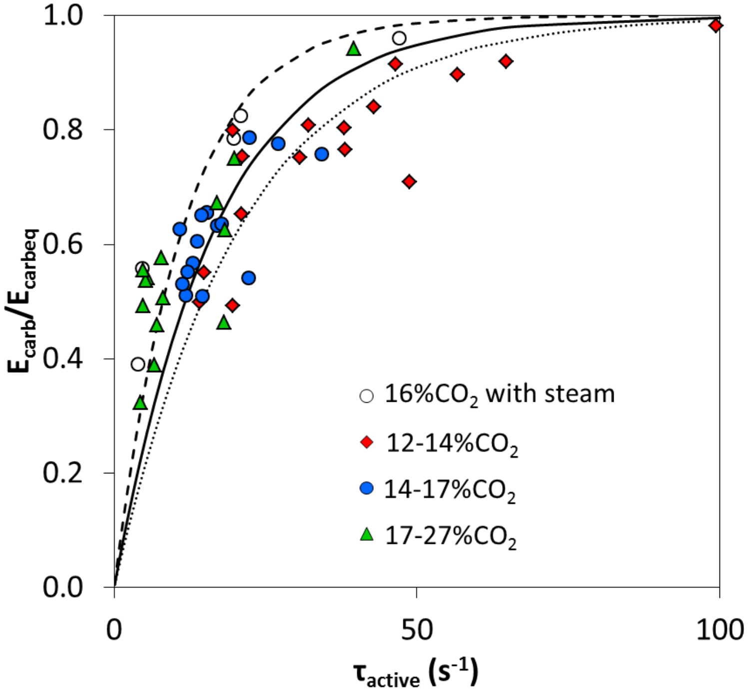
Calcium Looping CO_2 capture: Tail-end CaL configuration

Active space time design rule:

- $\tau_{active} = \frac{N_{CaO}}{\dot{N}_{CO_2}} f_a \, X_{ave}$
- $\tau_{active} > 50 \frac{1}{s}$ for 90 % CO_2 capture

Amount of active sorbent in the bed

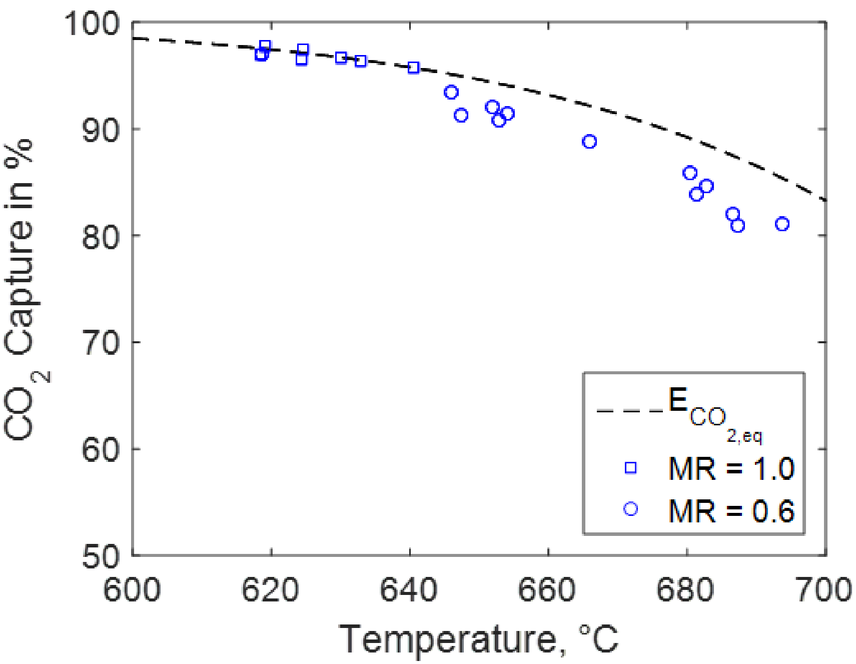


N_{CaO}: molar amount of CaO in Carbonator
$\dot{N}_{CO_2}$: molar flow of CO_2 entering the Carbonator
f_a: sorbent fraction reacting in fast reaction regime
X_{ave}: average sorbent CO_2 carrying capacity

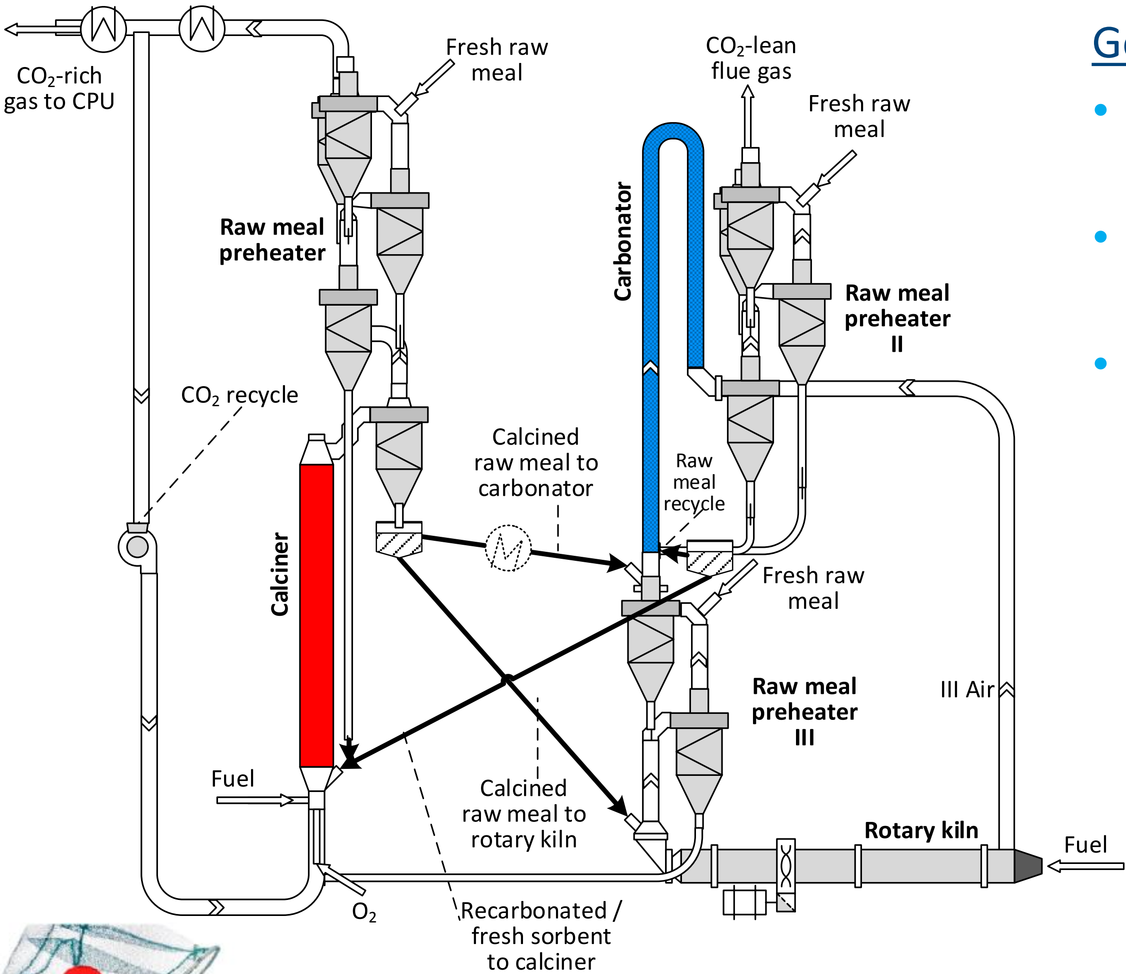
Calcium Looping CO_2 capture: Tail-end CaL configuration

<u>Demonstration at semi-industrial scale:</u>

- High CO_2 capture up to 98 % demonstrated
- Favorable CaL operation conditions
  - reduced recycle train
  - high sorbent activity
- High CO_2 capture at carbonator inlet may cause problems of entrainment due to reduction of fluidization gas (~ -25 %)



Calcium Looping CO_2 capture: highly integrated configuration



General information:

- CaL calciner coincides with the cement kiln pre-calciner
- Calcined raw meal as CO_2 sorbent in the carbonator
- Sorbent has small particle size (d_{50}=10-20 µm) → entrained flow reactors

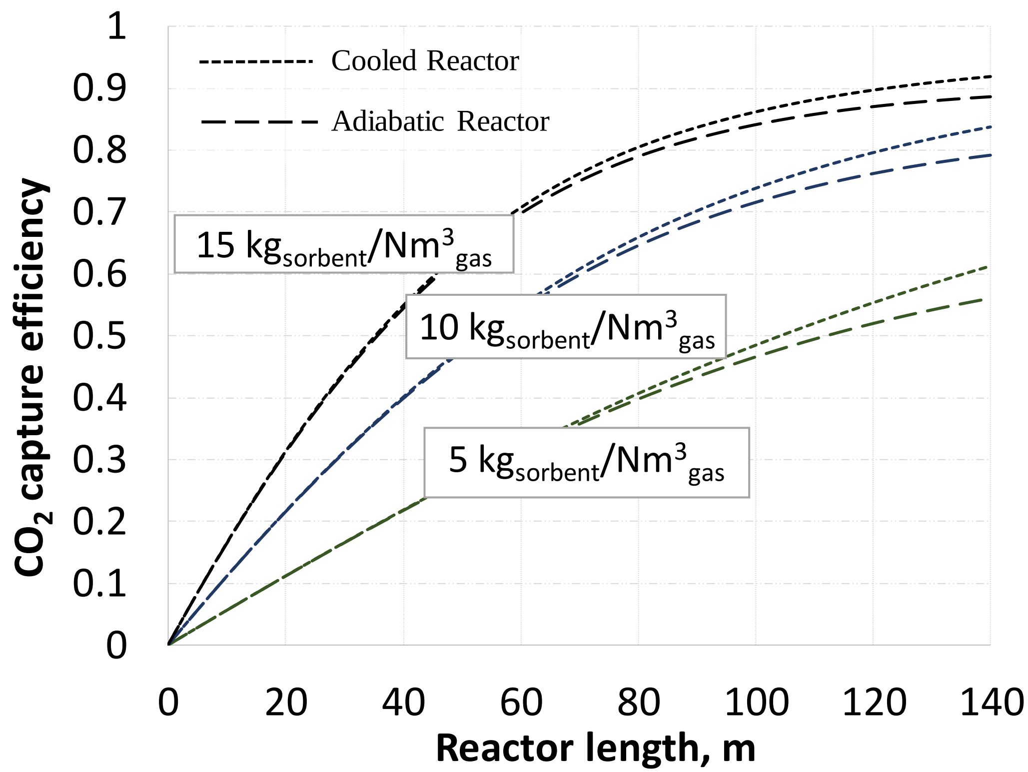
Marchi M.I., et al., 2012. Procedimento migliorato per la produzione di clinker di cemento e relativo apparato. *Patents MI2012 A00382 and MI2012 A00382.*

Romano et al., 2014. The calcium looping process for low CO_2 emission cement plants. *Energy Procedia, 61, 500-503.*

Calcium Looping CO_2 capture: highly integrated configuration

Conducted Work:

- TGA – sorbent characterization
- (Re)carbonation experiment in EF conditions
- EF oxyfuel calcination experiments
- Simulation of entrained flow Calcium Looping
- Preliminary process integration study



Tail end vs. highly integrated configuration: preliminary H&M balance

	Cement plant w/o capture	Tail-end CaL	integrated CaL
F_0/F_{CO2}	--	0.16	4.1
F_{Ca}/F_{CO2}	--	4.8	4.0
Carbonator CO_2 capture efficiency [%]	--	88.8	80.0
Total fuel consumption [MJ_{LHV}/t_{clk}]	3223	8672	4740
Rotary kiln burner fuel consumption [MJ_{LHV}/t_{clk}]	1224	1210	1180
Pre-calciner fuel consumption [MJ_{LHV}/t_{clk}]	1999	1542	3560
CaL calciner fuel consumption [MJ_{LHV}/t_{clk}]	--	5920	
Net electricity production [kWh_{el}/t_{clk}]	**-132**	**159**	**-164**
Direct CO_2 emissions [kg_{CO2}/t_{clk}]	863.1	143.2	71.4
Indirect CO_2 emissions [kg_{CO2}/t_{clk}]	105.2	-123.5	128.7
Equivalent CO_2 emissions [kg_{CO2}/t_{clk}]	968.3	19.7	200.1
Equivalent CO_2 avoided [%]	--	98.0	79.3
SPECCA [MJ_{LHV}/kg_{CO2}]	--	3.26	2.32

Spinelli M. et al., 2017. Integration of Ca-Looping systems for CO_2 capture in cement plants. *Energy Procedia, 114, 6206-6214.*

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The CLEANKER project

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[d] Buzzi Unicem

Calcium Looping for cement industry decarbonization

CLEANKER

Summary

- Project objectives
- The demo plant
- The consortium
- Work packages

Primary project objectives

Calcium Looping for cement industry decarbonization
CLEANKER

The ultimate objective of CLEANKER is advancing the integrated Calcium-looping process for CO_2 capture in cement plants.

This fundamental objective will be achieved by pursuing the following primary targets:

- **Demonstrate the integrated CaL process at TRL 7, in a new demo system connected to the operating cement burning line of the Vernasca 900.000 ton/y cement plant, operated by BUZZI in Italy.**
- **Demonstrate the technical-economic feasibility of the integrated CaL process in retrofitted large scale cement plants through process modelling and scale-up study.**
- **Demonstrate the storage of the CO_2 captured from the CaL demo system, through mineralization of inorganic material in a pilot reactor of 100 litres to be built in Vernasca, next to the CaL demo system.**

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

Vernasca plant location

Primary project objectives

- TRL 1 – basic principles observed
- TRL 2 – technology concept formulated
- TRL 3 – experimental proof of concept
- TRL 4 – technology validated in lab
- TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 7 – system prototype demonstration in operational environment
- TRL 8 – system complete and qualified
- TRL 9 – actual system proven in operational environ
manufacturing in the case of key enabling technologies; or in space)

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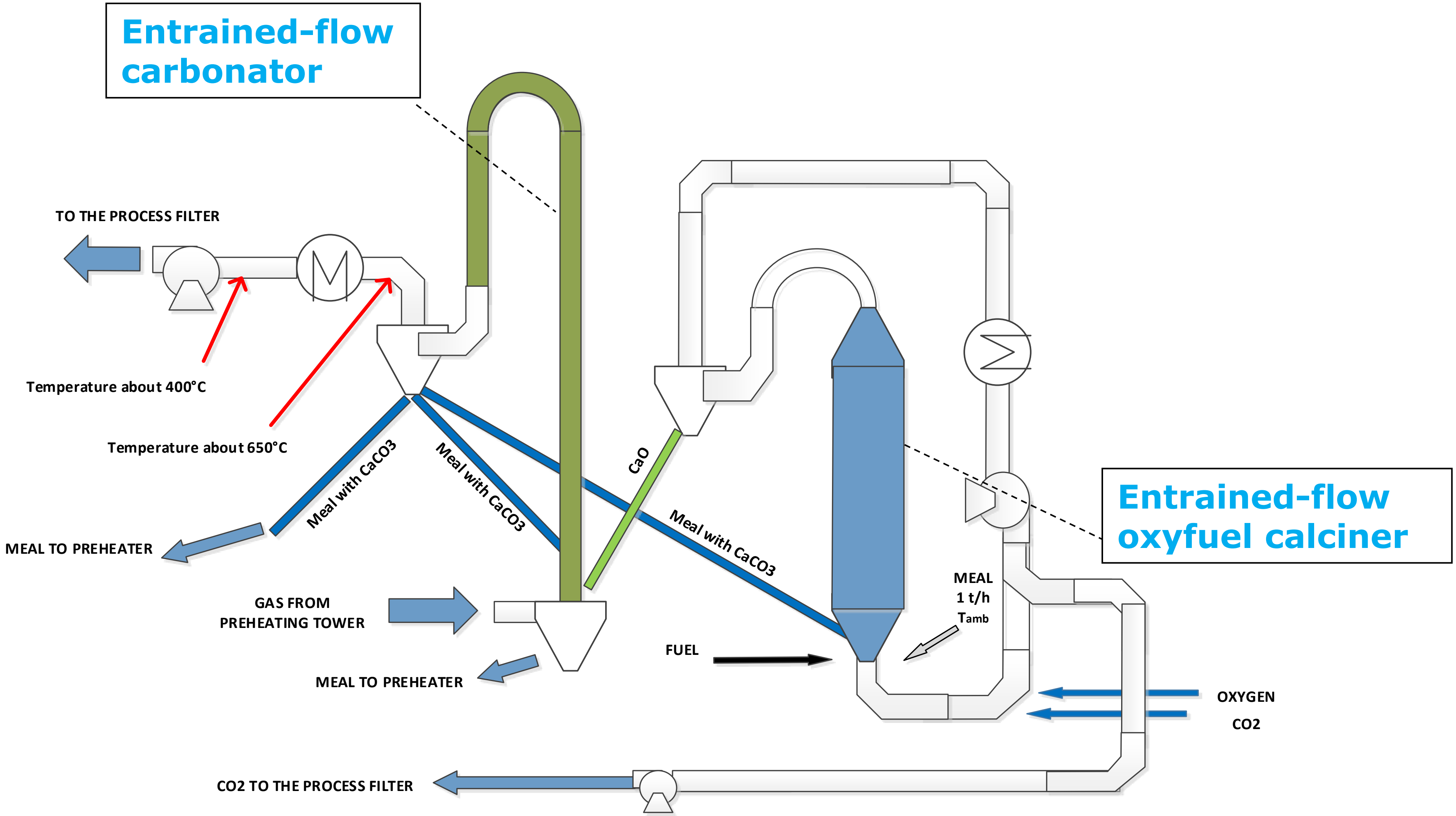
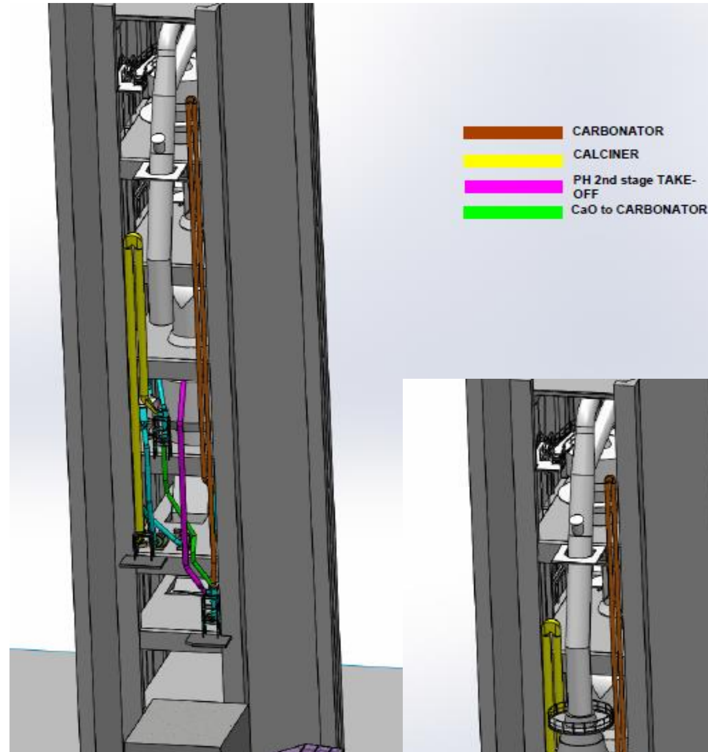
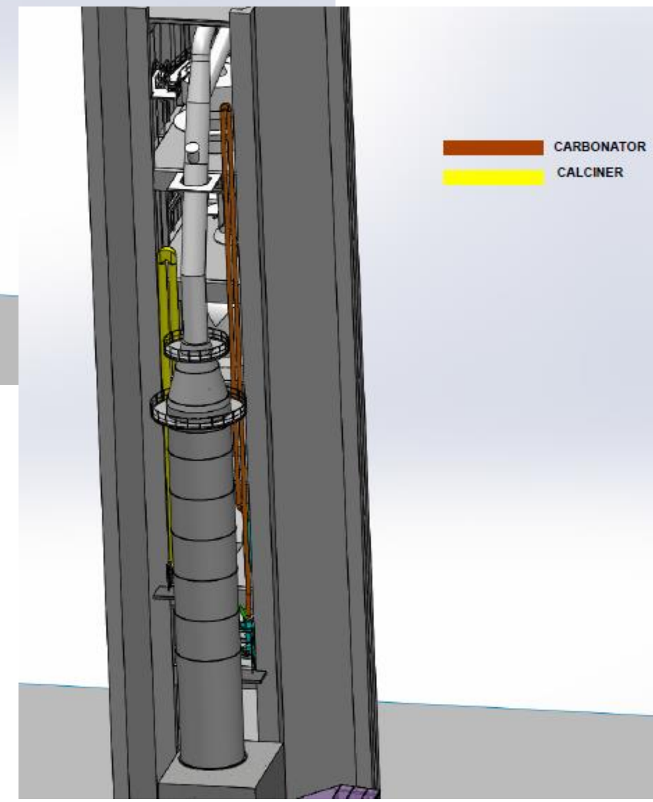
Indicative configuration of the CLEANKER pilot

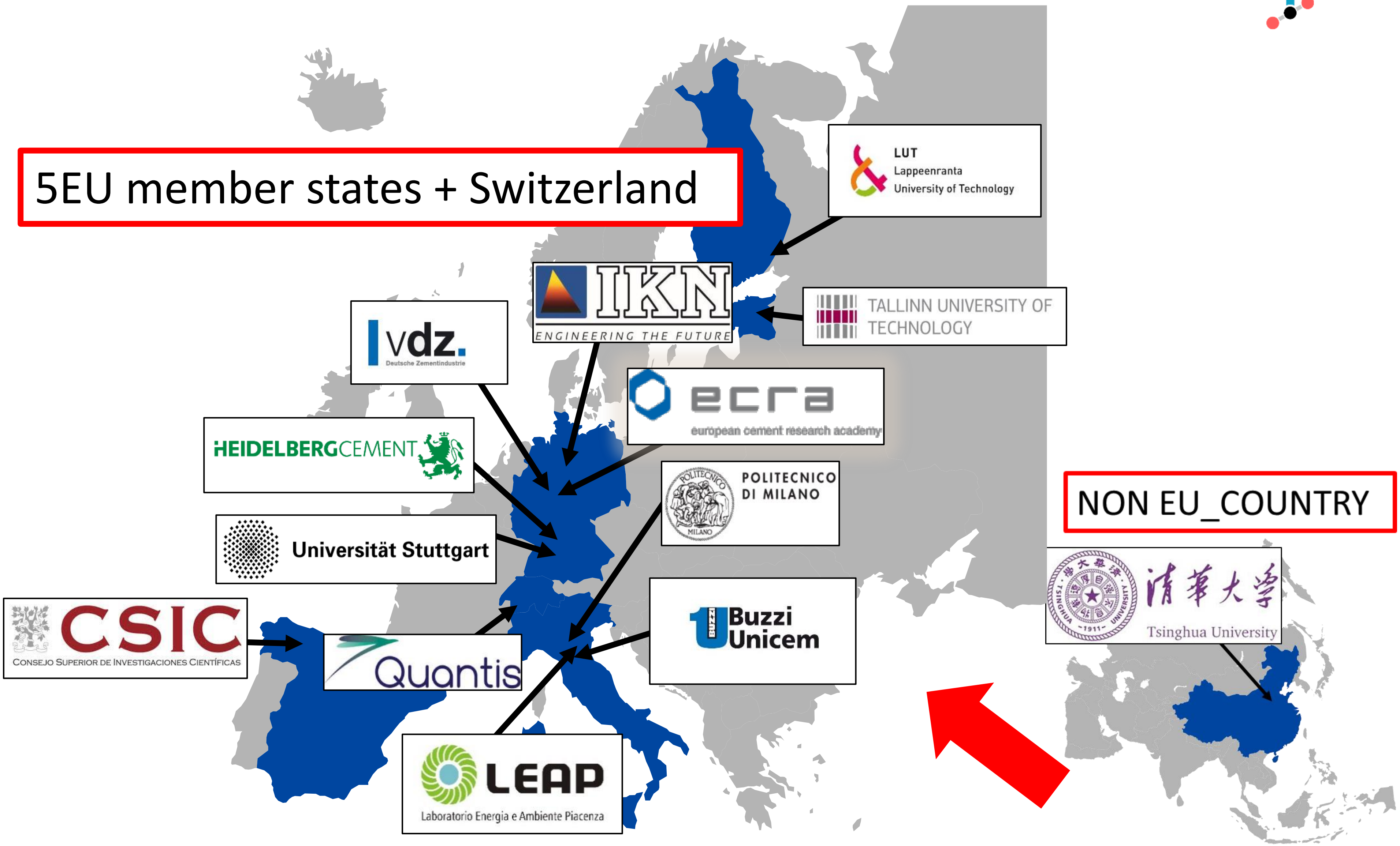


Vernasca kiln preheater and rendering of CaL pilot

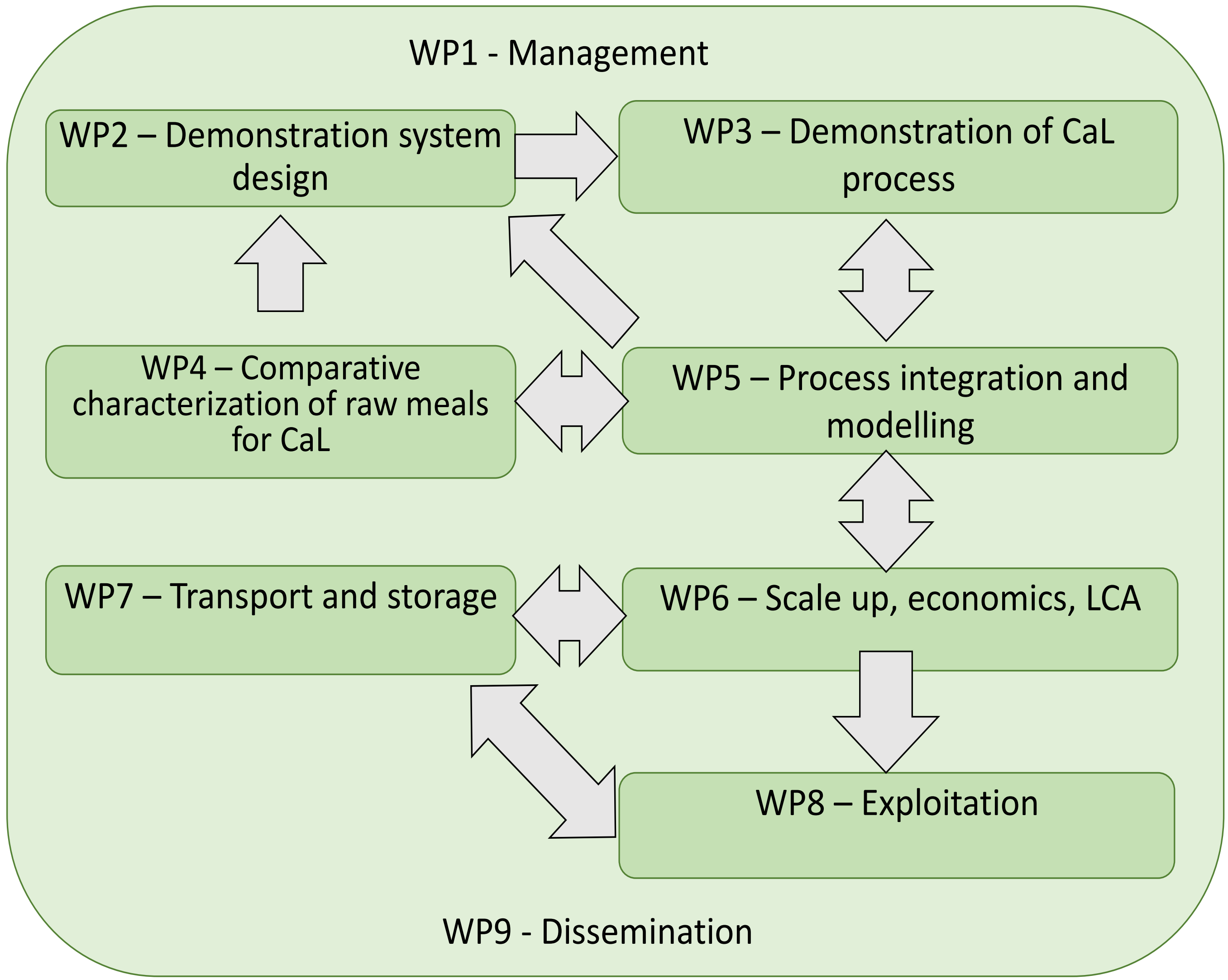




The consortium



Work packages



Conclusions and Outlook

Ca-LOOPING PROCESS INTEGRATION OPTIONS:

1. Cement plant-power plant coupling:
   - Excellent expected performance
   - Easily retrofittable with low cost
   - Logistic problem: a very large power plant has to be built next to the cement plant
2. Post-combustion capture configuration:
   - Low uncertainty in the feasibility of the process (very similar to application in power plants)
   - Very high CO_2 capture expected
   - Two calciners are present in the system, leading to high fuel consumptions
3. Integrated CaL configuration:
   - High CO_2 capture efficiency without modifying rotary kiln operation (no need of kiln oxyfiring).
   - Higher thermal efficiency and lower fuel consumptions expected (compared to option 2)
   - New carbonator design and fluid-dynamic regime: fluid-dynamics, heat management and sorbent performance need validation

Thank you for your attention!

Acknowledgement

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