CLEAN clinKER by calcium looping for low-CO_2 cement

CLEANKER

20-21 January 2020 – Geleen (The Netherlands)
8th High Temperature Solid Looping Cycles Network Meeting

CLEANKER Overview

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Summary

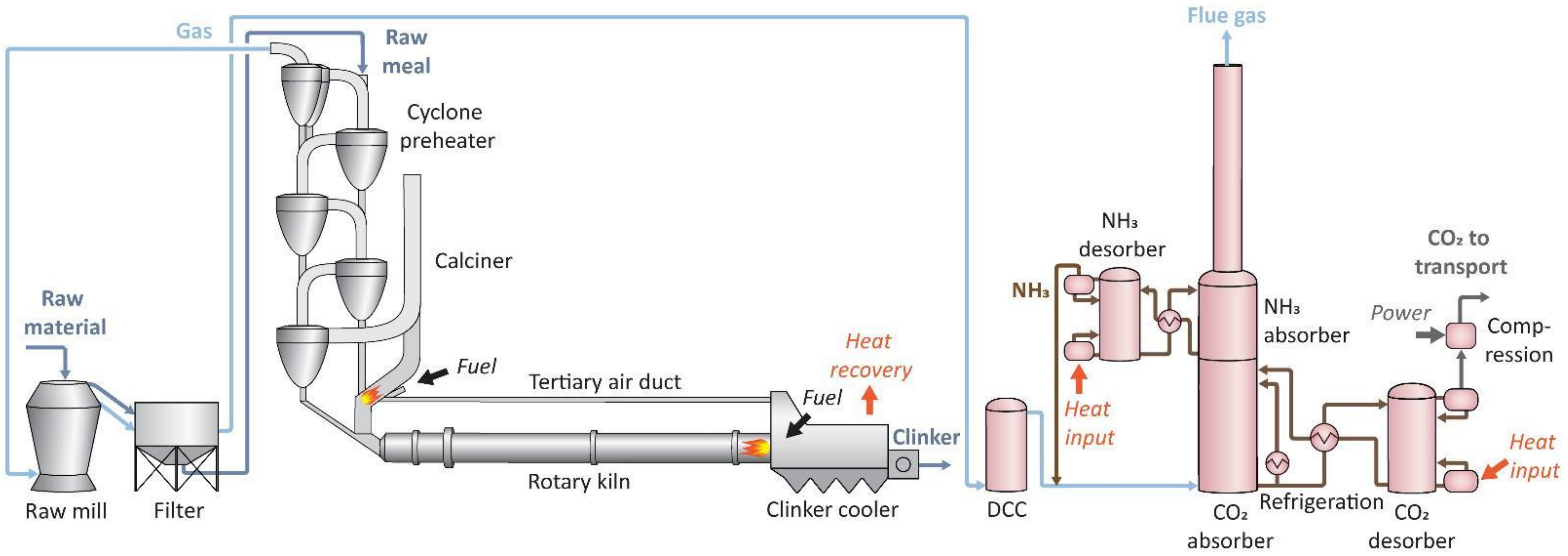
- **Main technologies for CO_2 capture in cement plants:**
  - Post-combustion solvent systems
  - Oxyfuel
  - Externally heated calcination
  - Calcium looping

- **CLEANKER project**
  - Project objectives
  - The consortium
  - CaL integrated configuration
  - CLEANKER demo system
  - CLEANKER project timeline
  - CLEANKER targets

Main technologies for CO_2 capture in cement plants

Post-combustion capture by solvents

- **Most mature technology for full-scale applications. Large scale units operating on power plant flue gases.**
- **Extensive experience for application in power plants**



Main technologies for CO_2 capture in cement plants

Post-combustion capture by solvents

- Most mature process for industrial applications. Large scale units operating on power plant flue gases (corresponding to full-scale cement kiln gas).
- With MEA, deep SO_2 removal needed to avoid solvent degradation
  - gas desulfurization required.
- Some emissions of amines and NH_3 expected.
- High thermal power needed for solvent regeneration: ~2-4 MJ/kgCO2
  - in a 120 t/h clinker plant generating 850 kgCO_2/tclinker, 80-105 MWth at about 120°C are needed for capturing 90% of the CO_2.
  - Dedicated steam generation unit needed.

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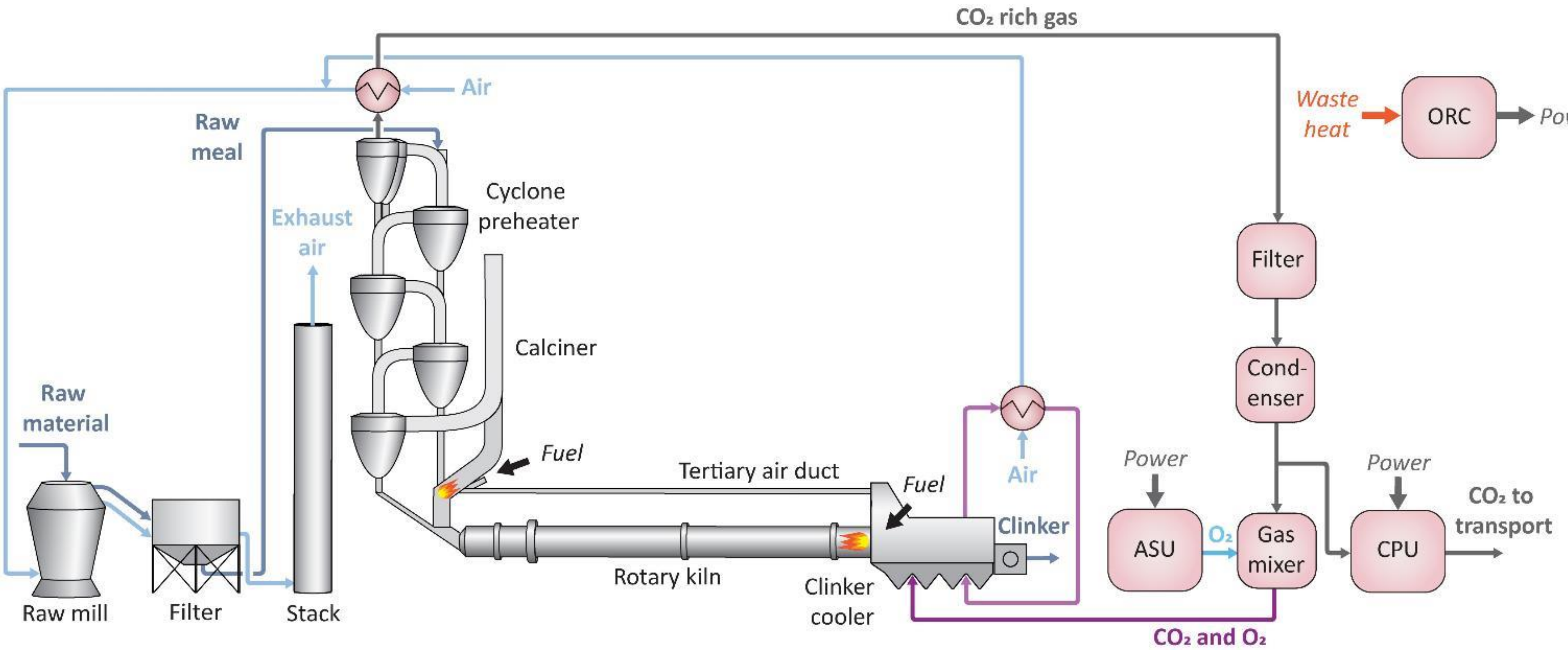
Main technologies for CO_2 capture in cement plants

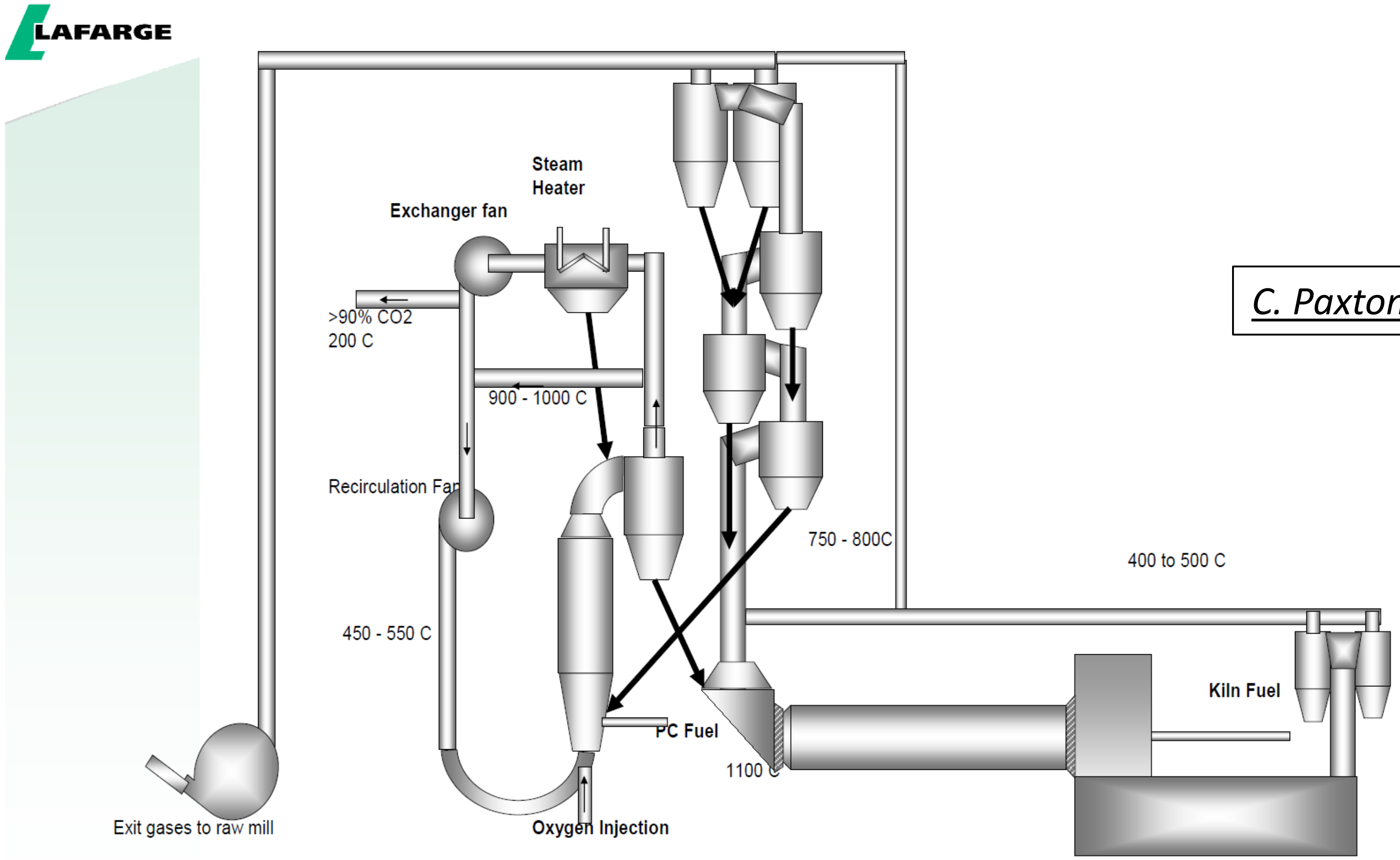
Oxyfuel combustion



Main technologies for CO_2 capture in cement plants

Oxyfuel combustion

- Partial oxyfuel: oxyfuel pre-calciner with air-fired rotary kiln and air-cooled clinker cooler



C. Paxton, M. Weichinger, 2008. Patent WO2008059378 A2.

Main technologies for CO_2 capture in cement plants

Oxyfuel combustion

- <u>Partial oxyfuel</u>
  - Maximum CO_2 capture efficiency limited at 60-70%
  - No modifications of the rotary kiln operation and of the clinker cooler
  - Not affected by false air ingress in the rotary kiln and clinker cooler

- <u>Full oxyfuel (oxyfuel pre-calciner + oxyfuel rotary kiln):</u>
  - Maximum CO_2 capture efficiency > 90% possible
  - Tight sealing needed in the rotary kiln and clinker cooler to keep very low air infiltration and avoid CO_2 dilution

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Main technologies for CO_2 capture in cement plants

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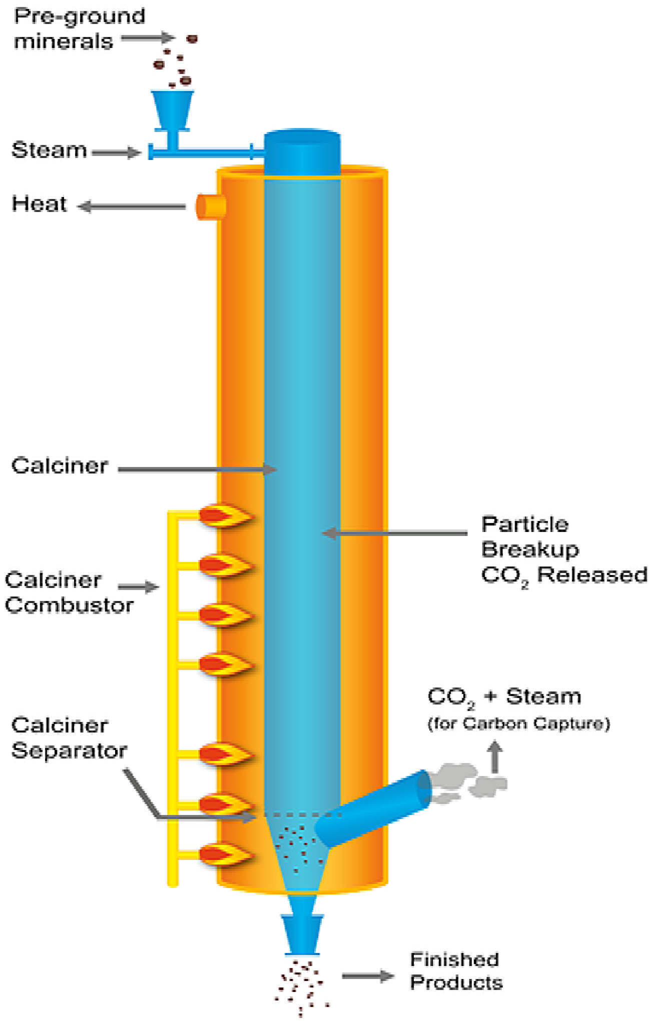
Externally heated calcination



Leilac

www.project-leilac.eu/

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Main technologies for CO_2 capture in cement plants

Externally heated calcination

- High purity CO_2 produced ✓
- No ASU, no chemicals ✓
- Challenging scalability: very high heat transfer surface needed in full-scale cement kilns ✗
- Limited capture efficiency: only CO_2 from limestone calcination is captured ✗
  - Hybridization needed to achieve high capture efficiency
- Calcination restricted to clean fuels to avoid fouling of heat transfer surface ✗

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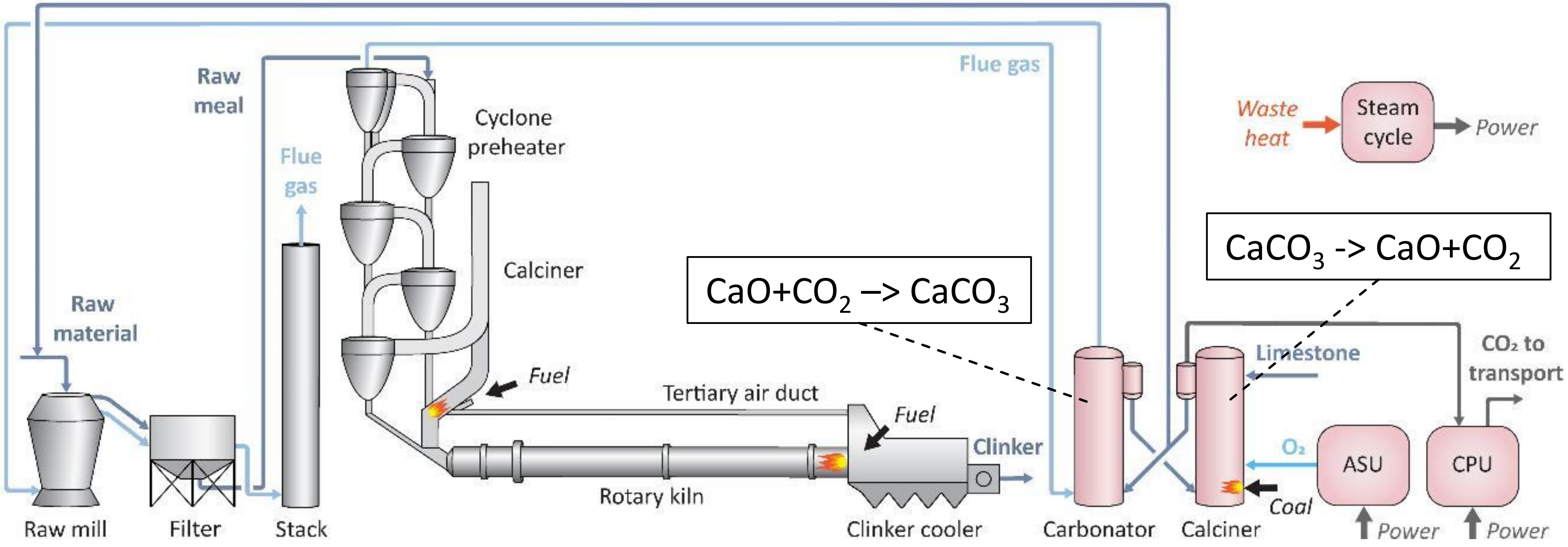
Main technologies for CO_2 capture in cement plants

Calcium Looping

- <u>Tail-end Calcium looping:</u>
  - Post-combustion capture configuration -> highly suitable for retrofit
  - 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



Arias et al., 2017. *Ind. Eng. Chem. Res.*, 56, 2634–2640;

Hornberger et al., 2017. Energy Procedia, 114, 6171–6174;

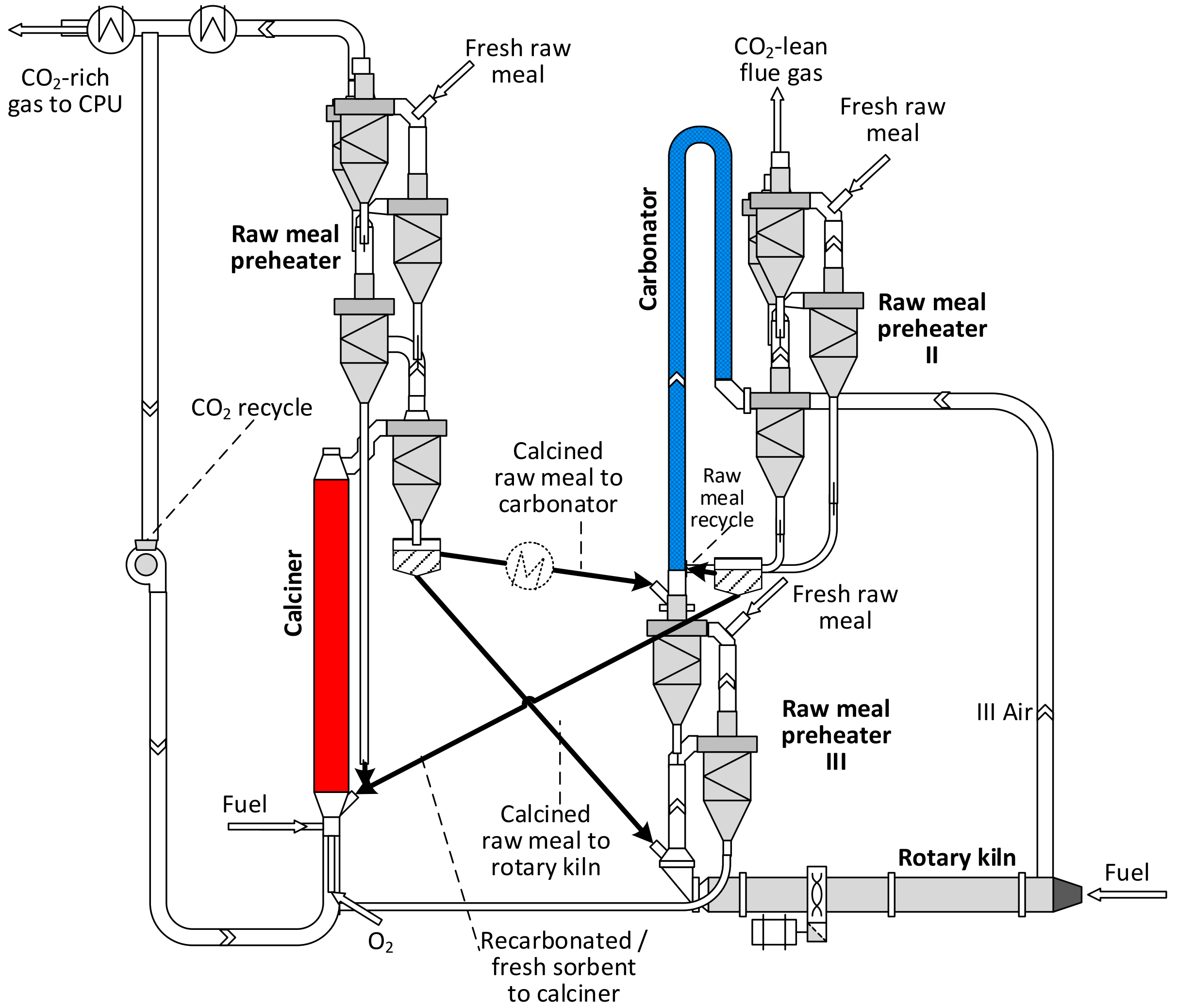
De Lena et al., 2017. Int. J. Greenh Gas Control, 67, 71-92.

CEMCAP

Main technologies for CO_2 capture in cement plants

Calcium Looping

- **Integrated CaL:**
  - CaL carbonator highly integrated within the preheater, captures CO_2 from rotary kiln gas
  - CaL calciner coincides with the cement kiln pre-calciner -> no double calcination, lower fuel consumption
  - Calcined raw meal as CO_2 sorbent in the carbonator instead of high purity limestone
  - Sorbent has small particle size (d_{50}=10-20 µm) -> entrained flow reactors



Alonso et al., 2018. Energy & Fuels, 31, 13955–13962.
Turrado et al., 2018. Ind Eng Chem Res, 57, 13372-13380.
De Lena et al., 2019. Int J Greenh Gas Control, 82, 244-260.

Main technologies for CO_2 capture in cement plants

Calcium looping

- <u>Tail-end configuration:</u>
  - Low uncertainty in the feasibility of the process (very similar to application in power plants)
  - Very high CO_2 capture can be achieved
  - Double calcination leads to high fuel consumptions

- <u>Integrated CaL configuration:</u>
  - 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 verification

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Key Performance Indicators

- **Equivalent primary energy consumption:**

$$q_{eq}\left[\frac{MJ}{t_{clinker}}\right] = q + P_{el} / \eta_{ref,el}$$

Direct fuel consumption

Indirect fuel consumption
Average European grid: $\eta_{ref,el}$ = 45.9%

- **Equivalent CO_2 emissions:**

$$e_{CO2,eq}\left[\frac{kg_{CO2}}{t_{clinker}}\right] = e_{CO2} + P_{el} \cdot e_{ref,el}$$

Direct emissions

Indirect emissions
Average European grid: $e_{ref,el}$=262 kg/MWh

Qualitative technology comparison

	Post-combustion solvents	Oxyfuel	Calcium looping	Externally heated calcination
Direct CO_2 emissions	⇩⇩ 💧	⇩⇩	⇩⇩	⇩
Direct fuel consumption	⇧ 💧	=	⇧	?
Electricity consumption	⇧	⇧⇧	=	⇧
Indirect fuel consumption and CO_2 emissions	⇧	⇧	=	⇧ ← *Increase rate depends on electric grid mix*
Capital costs	⇧	⇧	⇧⇧	?

💧 *Need of steam generation may increase emissions and fuel consumption in the cement kiln battery limit*

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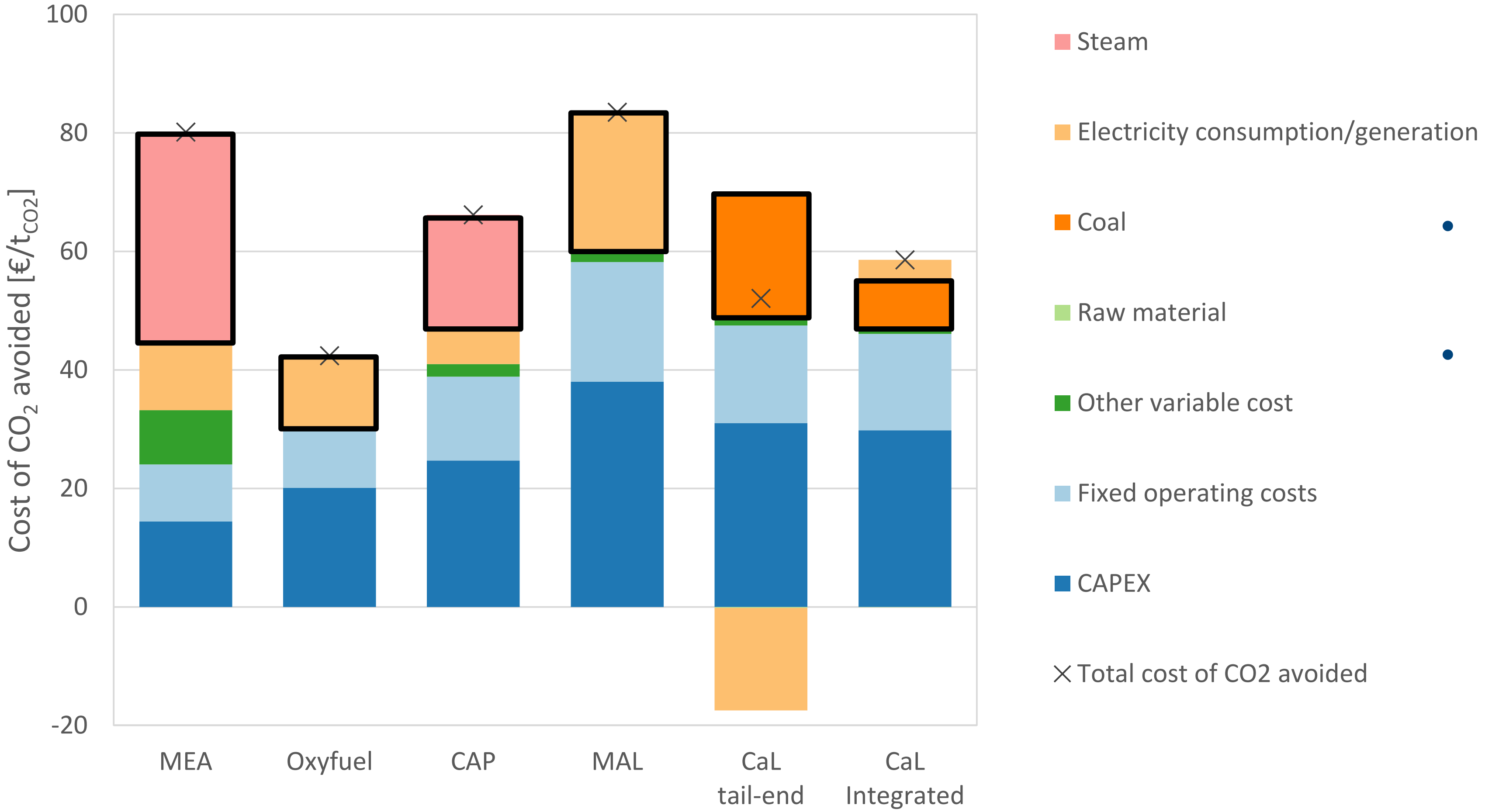
Technology comparison

CEMCAP Benchmarking: cost of CO_2 avoided



- Investment costs: 40-50% of cost share in all the technologies
- Operating costs of CO_2 avoided mainly related to:
  - Increased electric absorption for oxyfuel and membrane separation
  - Steam demand for post-combustion solvent-based separation
  - Increased fuel consumption for CaL

Gardarsdottir et al, 2019. Energies 2019, 12, 542.

CEMCAP

Main technologies for CO_2 capture in cement plants

- For cement plants, different CO_2 capture technologies can compete. The optimal technology may be site dependent, as CO_2 avoidance cost depends on: (i) cost of fuel and availability of alternative fuels; (ii) cost of utilities; (iii) needed purity of CO_2; (iv) financial framework, advantaging technologies with partial CO_2 capture and lower investment costs; (v)….?
- Calcium looping is one of the (best) players on the ground!
- … but for the integrated CaL process, pilot scale demonstration and more accurate scale-up study is needed to answer some research questions

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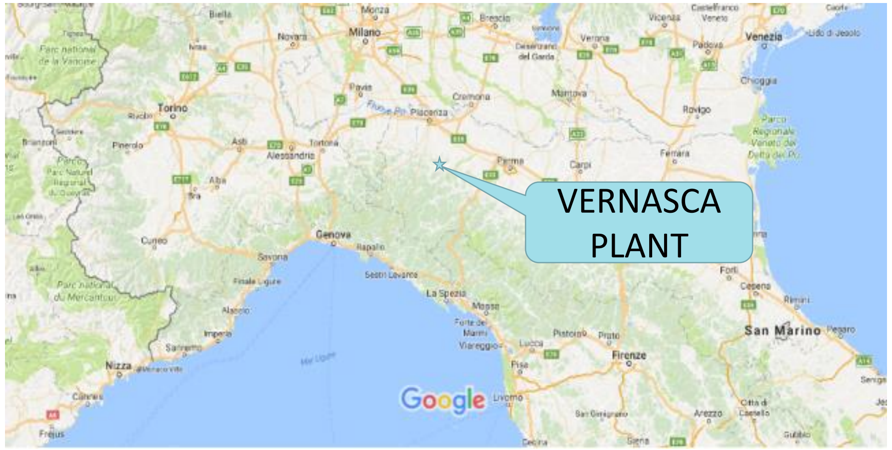
Project objectives

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 1.300.000 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.**

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CLEANKER project

The consortium

Starting date: October 1st 2017

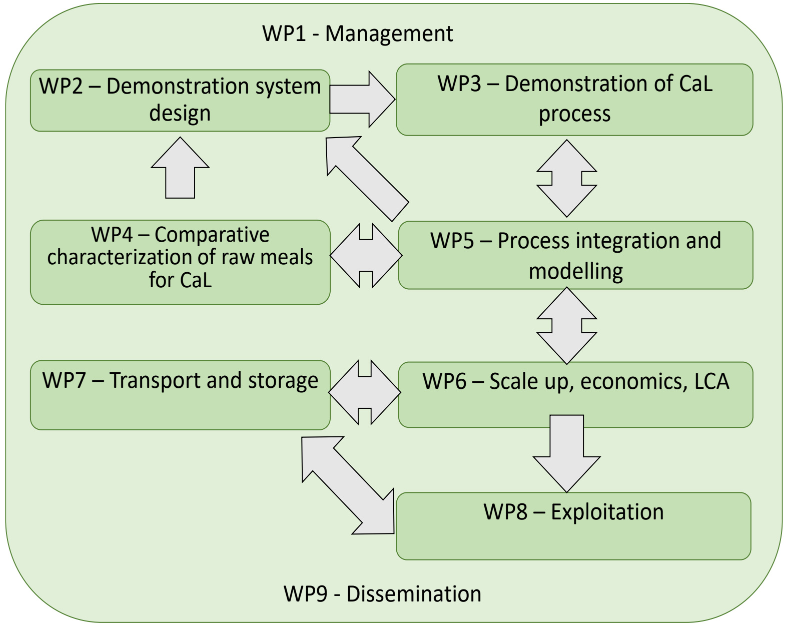
Duration: 4 years

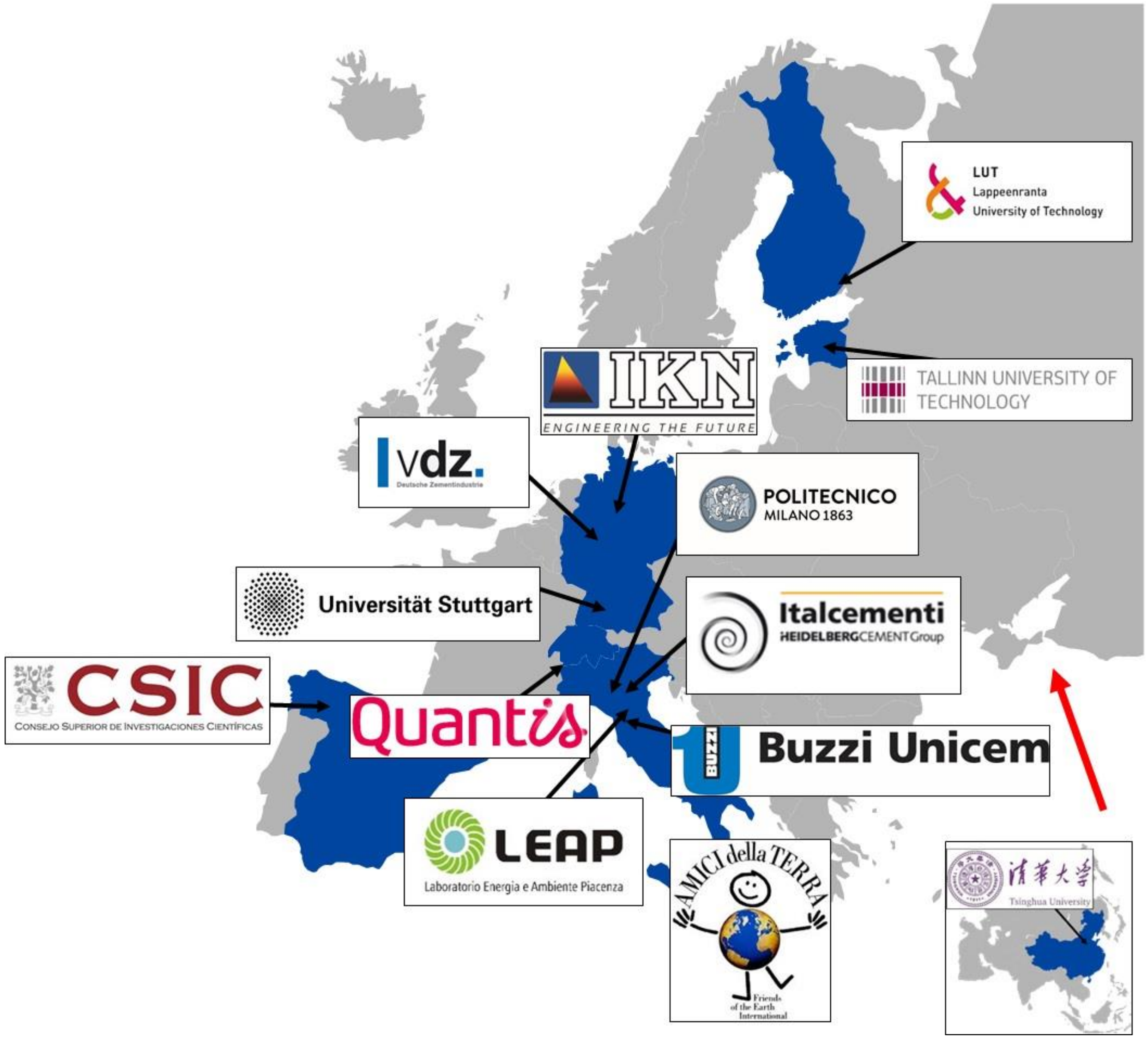
Total budget: € 9.237.851,25

UE co-financing: € 8.972.201,25

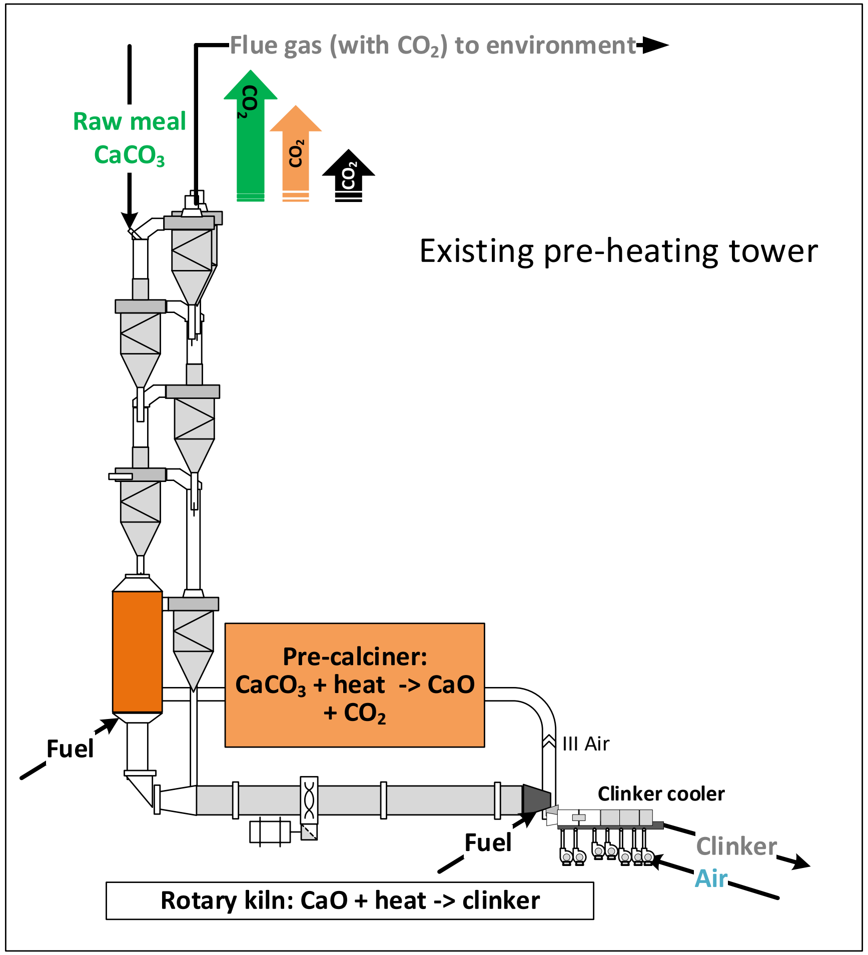
Chinese governement founding: 265.650 €

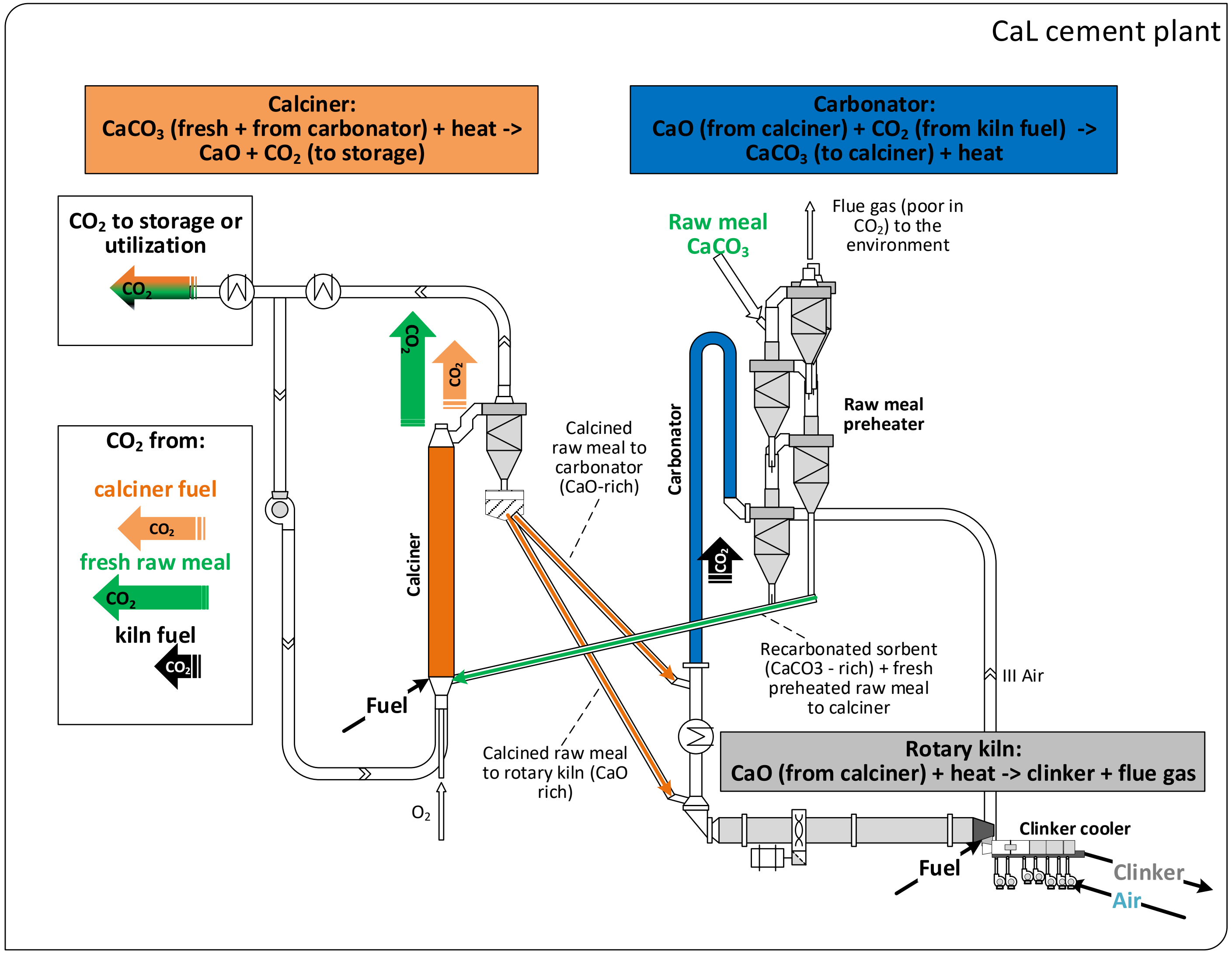
Partner: 13 from 5 EU member states + Switzerland and China





CaL integrated configuration





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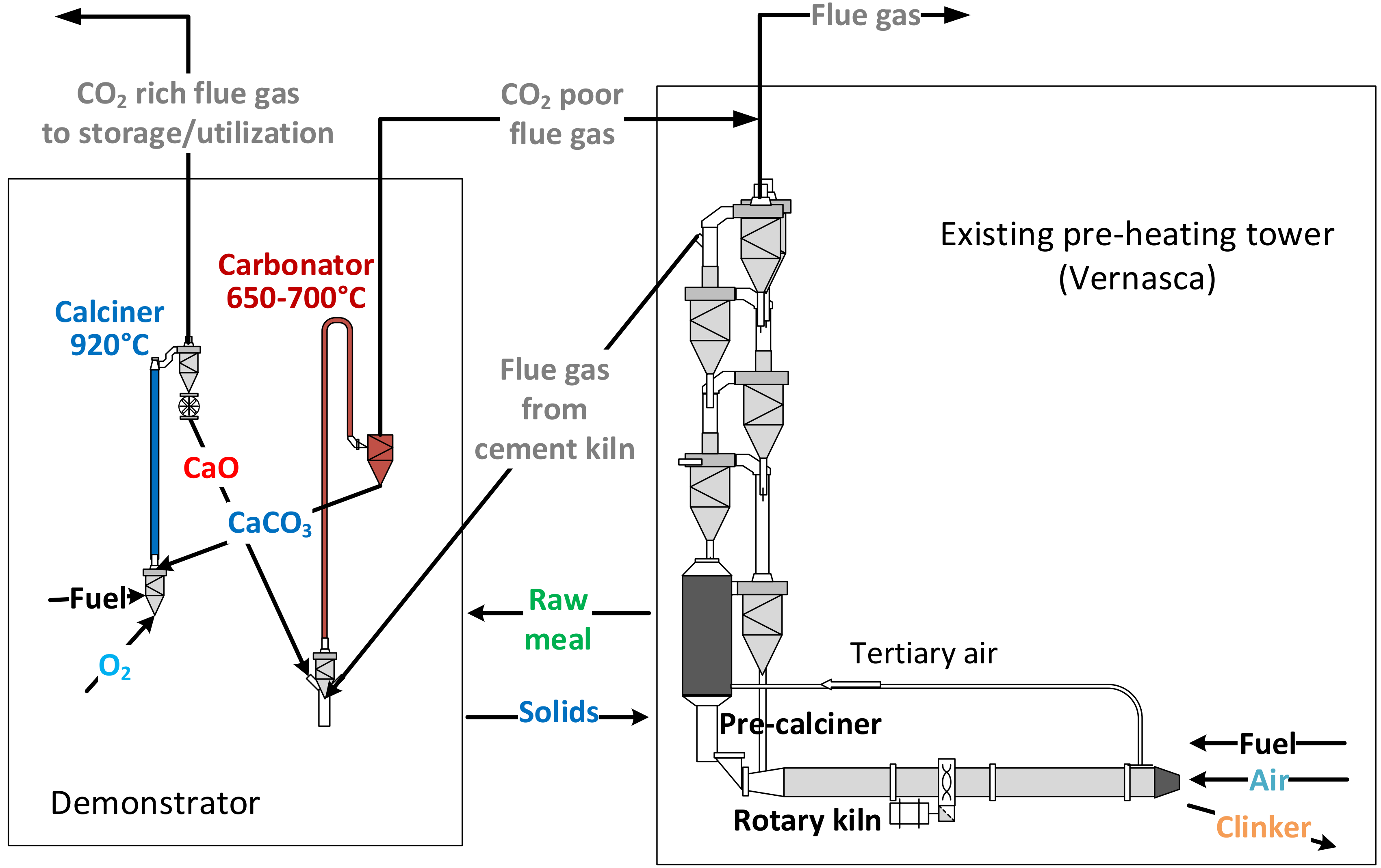
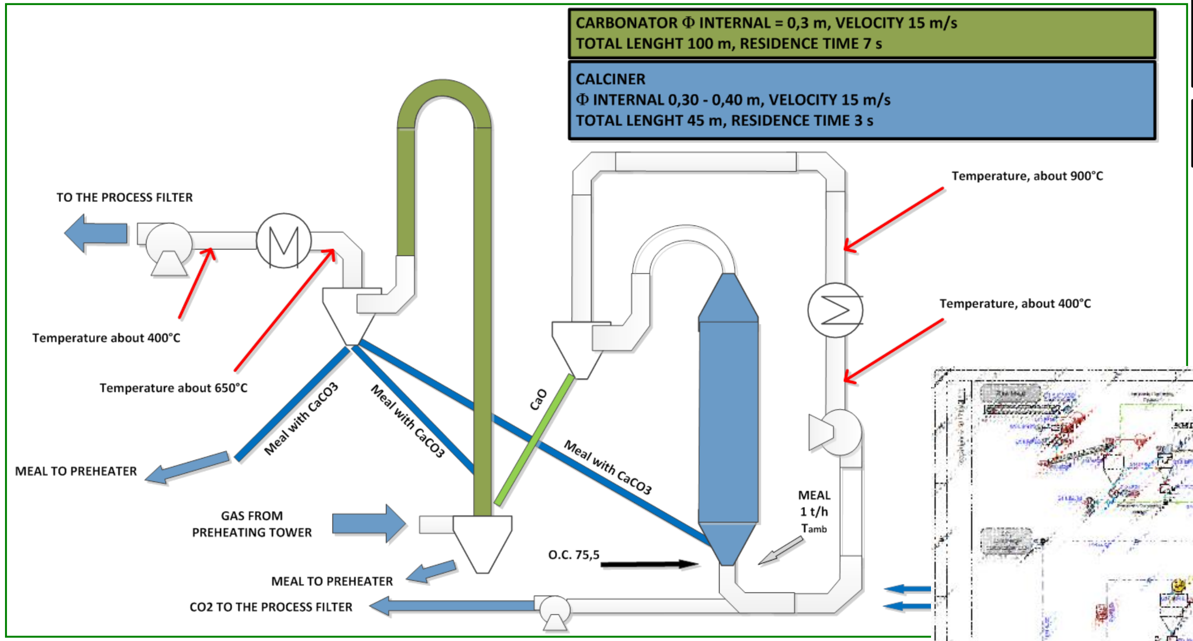
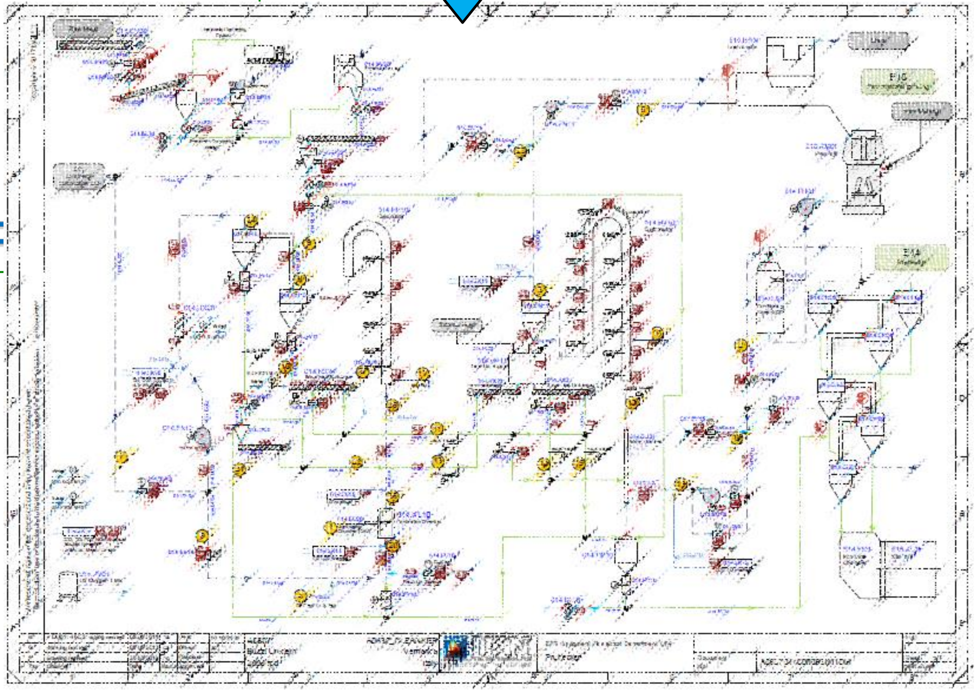
CLEANKER demo system



CLEANKER demo system

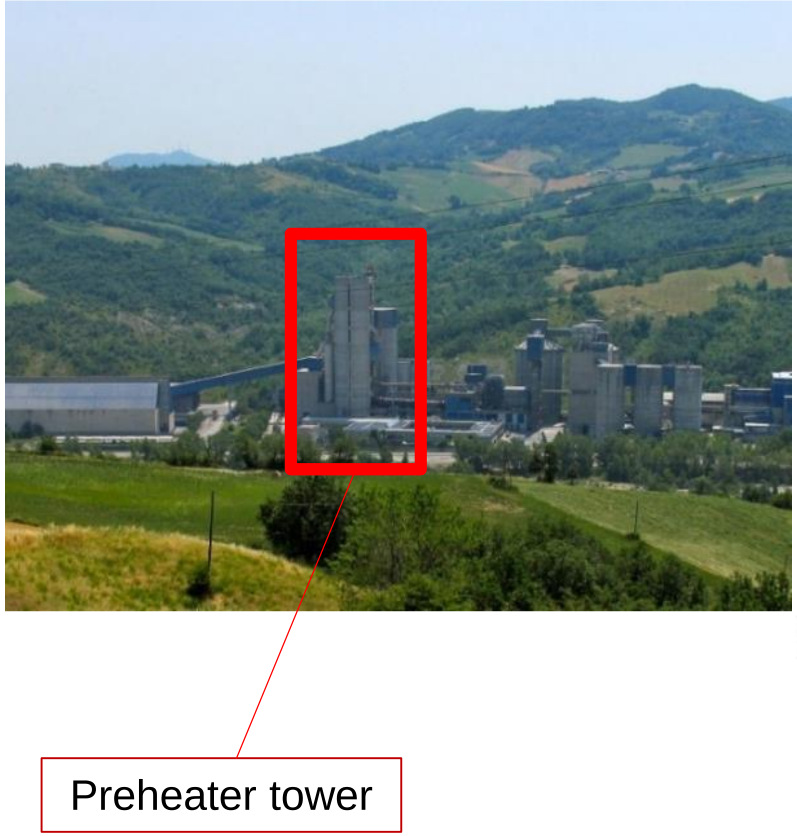


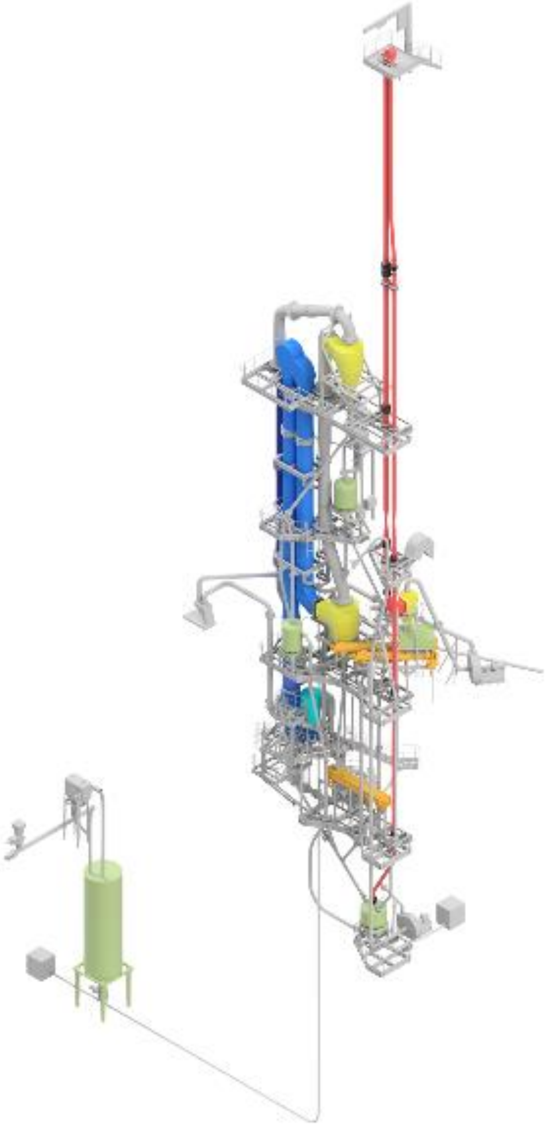
BASIC FLOWSHEET FOR THE APPLICATION

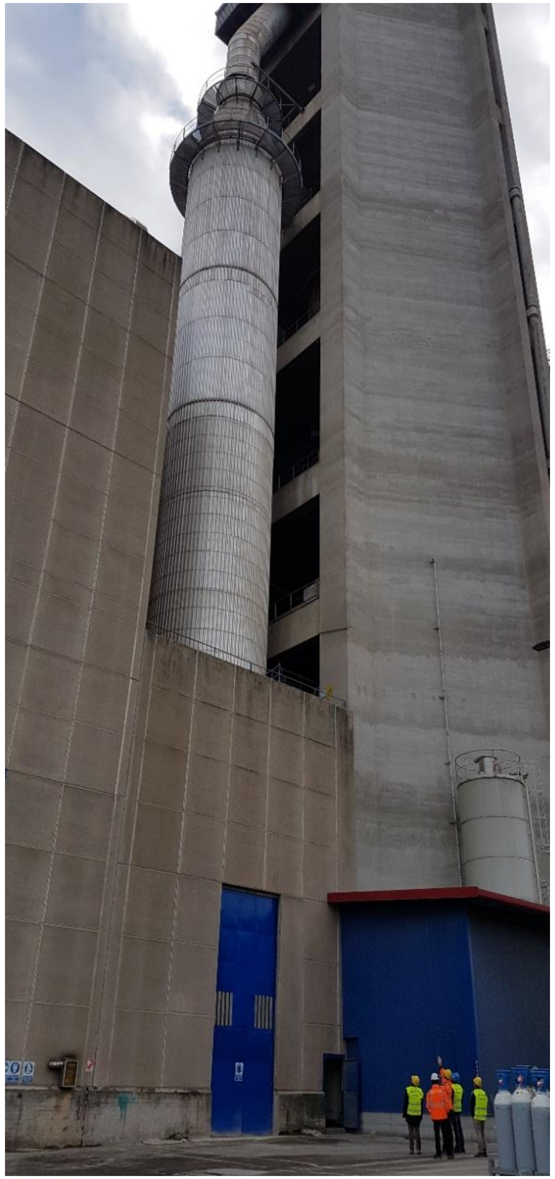


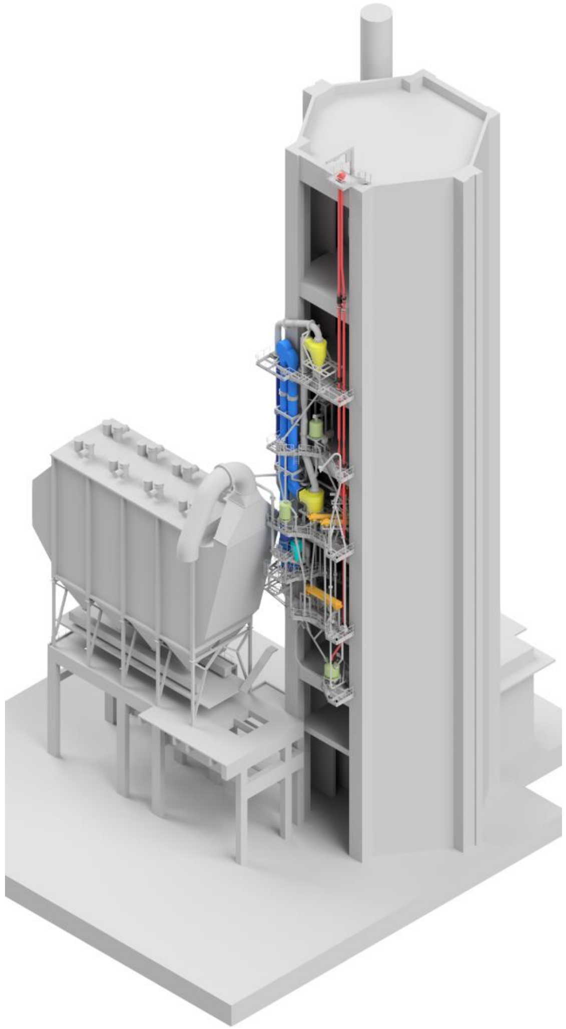
FINAL FLOWSHEET OF THE TEST RIG

CLEANKER demo system









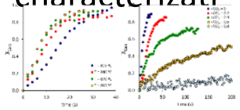
CLEANKER project

CLEANKER timeline

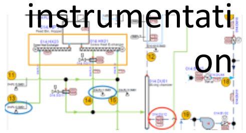
1st October 2017

17-18 October 2017
Kick-off meeting (Piacenza)

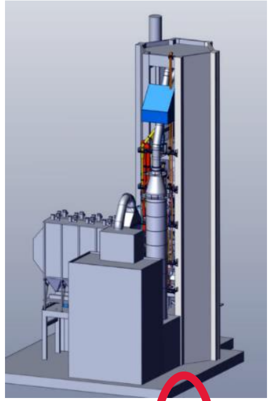
July 2018
Raw meal characterizati



June 2018
Measuring points and instrumentati on



July 2018
Final Plant layout



2017 — 2018 — 2019 — 2020 — 2021

March 2019
Main items fabrication

April 2020
Inspection

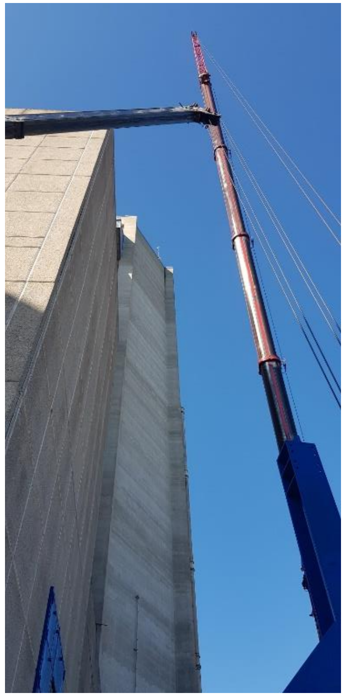
March 2020
Erection

May2020
Running tests and data

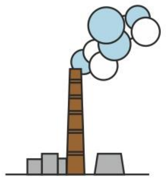
April 2021
Casting concrete results and full economic [...] f cement with CaL

September 2021
Final conclusions

30th September 2021



CLEANKER targets

Objective	Key indexes	Target
CO_2 **emissions** 	• CO_2 capture efficiency • CO_2 specific emissions	• Cement plant CO_2 capture efficiency >90% • Negative direct CO_2 emissions by biomass co-firing (Bio-CCS) • Reduction of total CO_2 specific emissions (kg_{CO2} per ton of cement) >85%
Energy efficiency 	• Fuel consumption • Electricity consumption • Specific primary energy consumption for CO_2 avoided (SPECCA*)	• increase of total fuel consumption with respect to state of the art plants <40% • increase of electric consumption with respect to state of the art plants <20% • SPECCA* < 2 MJ_{LHV} per kg of CO_2 avoided • SPECCA* at least 10% lower than that of benchmark full oxyfuel cement plants
Economics 	• Cost of cement • Cost of CO_2 avoided	• Increase of cement cost < 25 €/$_{tcement}$ • Cost of CO_2 avoided <30 €/t_{CO2}

**SPECCA = Specific primary energy consumption for CO_2 avoided*

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