Integration of Ca-Looping systems for CO_2 capture in cement plants

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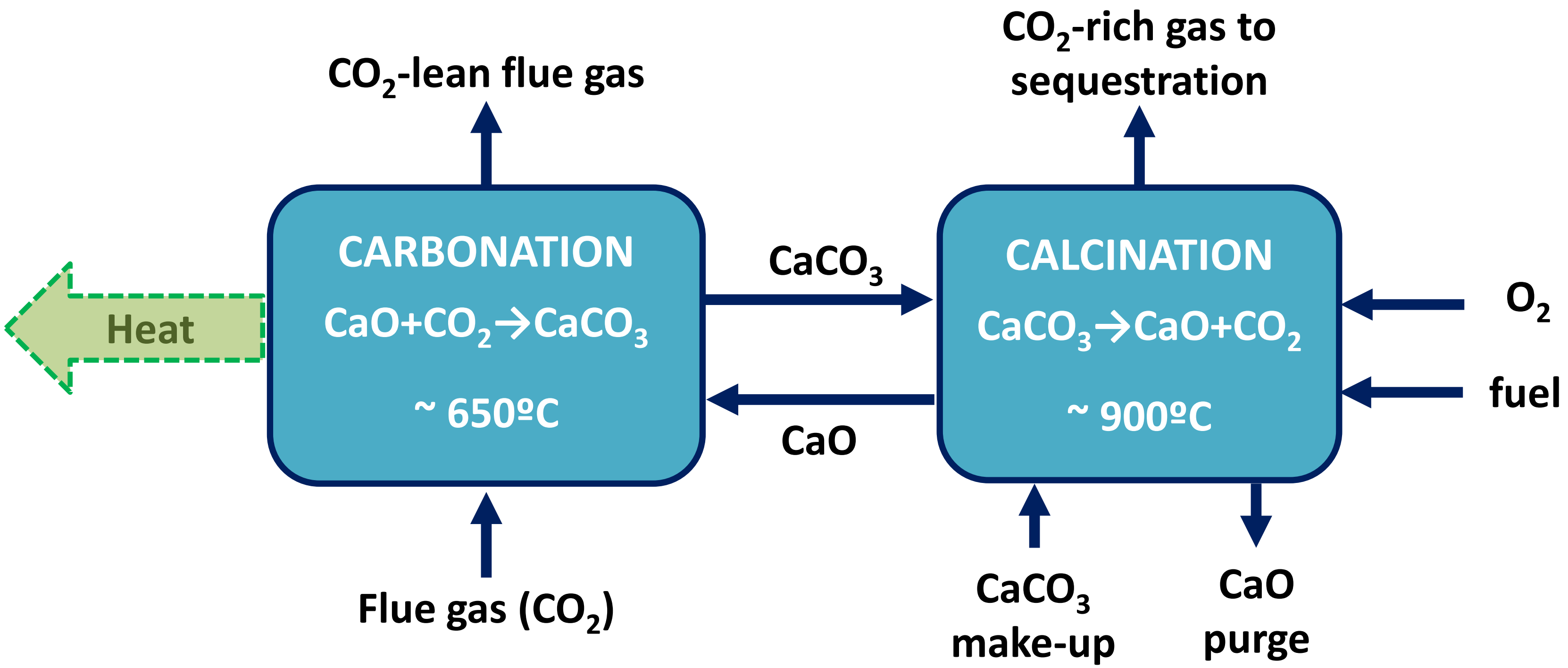
SUMMARY

- Why Calcium-looping in cement plants
- Integration options of Calcium-looping in Cement plants
    - Tail-end CaL configuration
    - Integrated CaL configuration
- Key performance indicators
- Results
- Conclusions

WHY CALCIUM-LOOPING

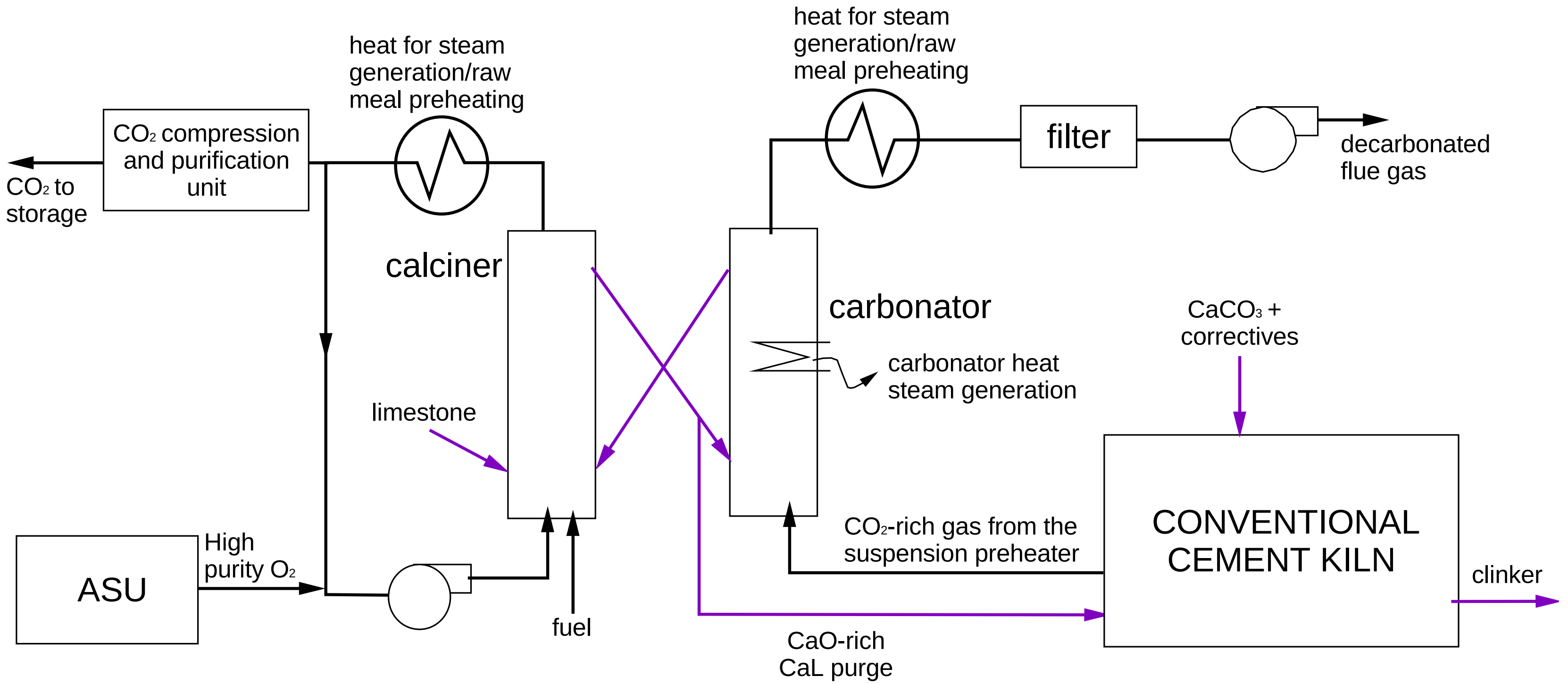


- Sorbent originates from $CaCO_3$ which is a raw material for clinker production
- CaO purge can be used in clinker production

TAIL-END CaL CONFIGURATION

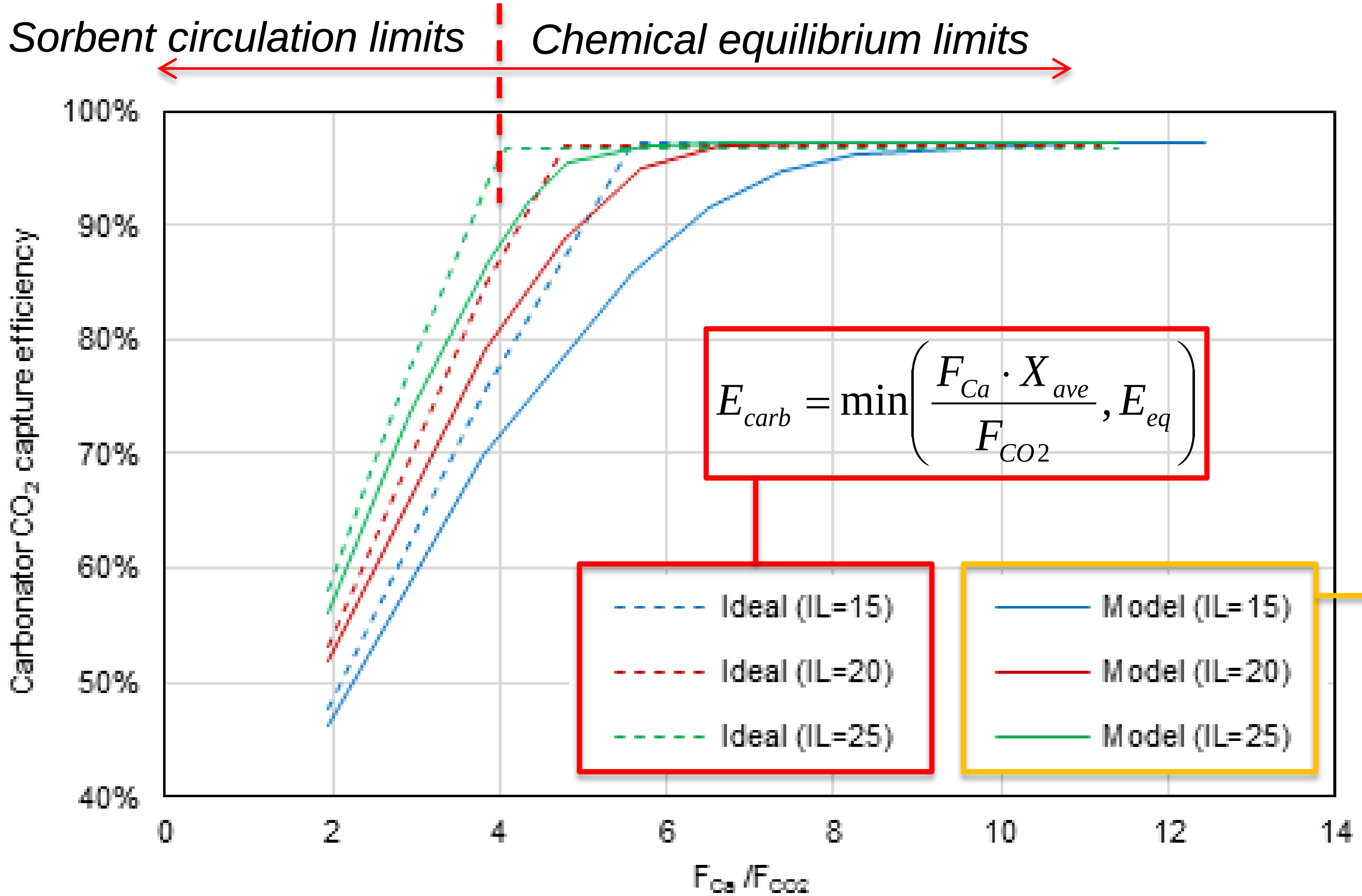
- Carbonator removes CO_2 from cement plant flue gas → highly suitable for retrofit
- CaO-rich purge from CaL calciner used as feed for the cement kiln
- CFB CaL reactors: d_{50}=100-250 μm
  Particle size for clinker production d_{50}=10-20 μm

  → CaL purge milled in the raw mill at low temperature



TAIL-END CaL CONFIGURATION – CAPTURE EFFICIENCY

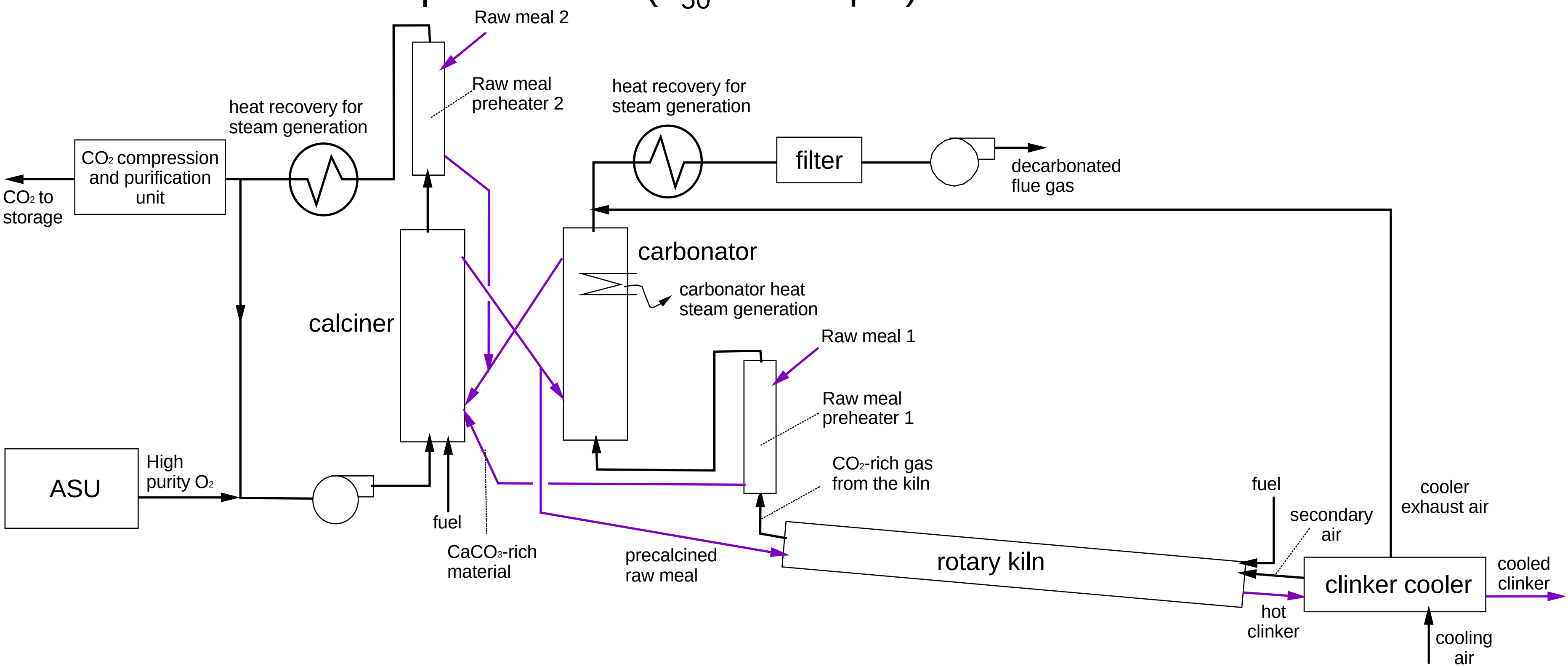
Definition of <u>integration level (IL)</u>: % of CaO entering the cement kiln with the CaO-rich purge of the CaL unit with respect to the total Calcium input



Romano, 2012. Chem Eng Sci, 69:257–69.

INTEGRATED CaL CONFIGURATION

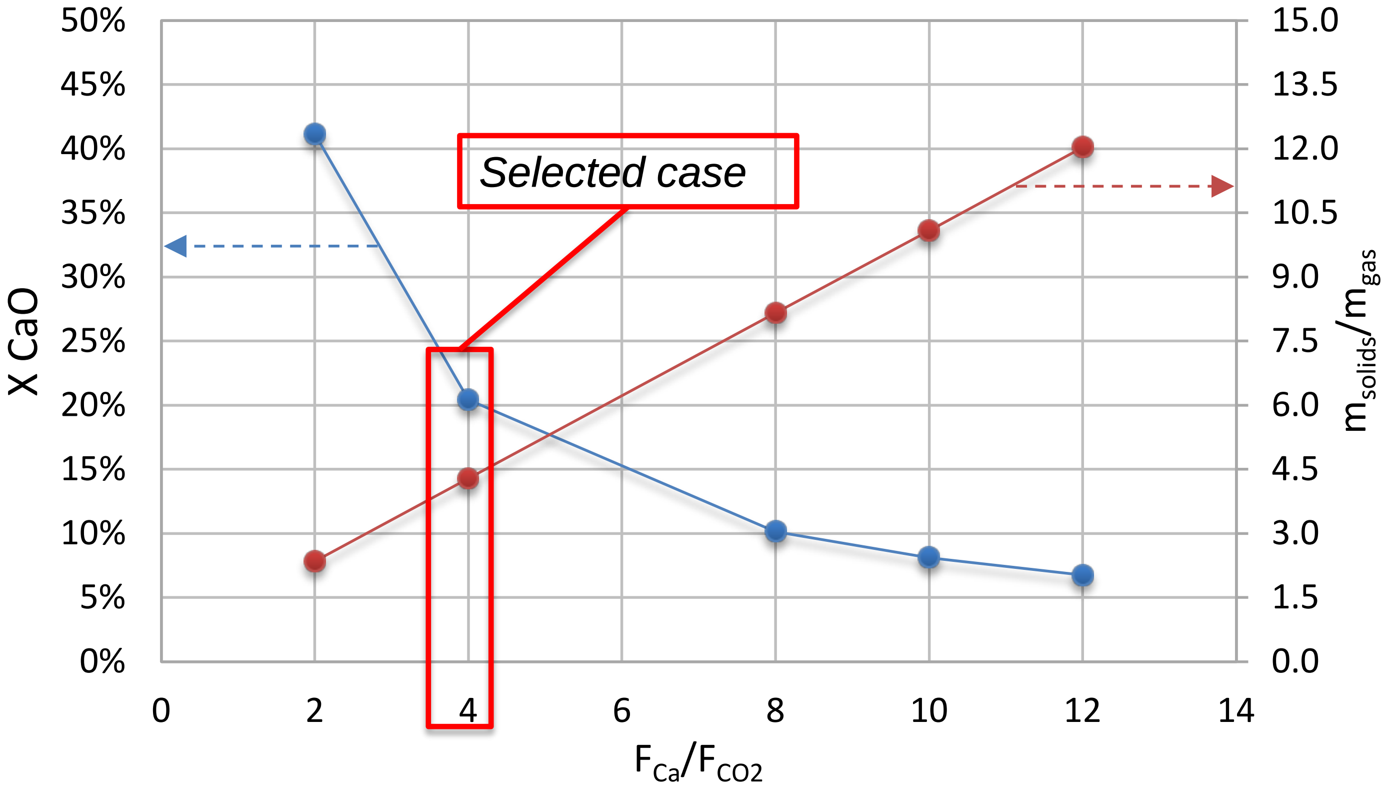
- CaL carbonator highly integrated within the preheating tower, on rotary kiln gas
- CaL calciner coincides with the cement kiln pre-calciner
- Calcined raw meal as CO_2 sorbent in the carbonator
- Sorbent has small particle size (d_{50}=10-20 μm) → entrained flow reactors



INTEGRATED CAL CONFIGURATION

A proper entrained-flow carbonator model (not available yet) is needed to estimate the size and capture efficiency of the reactor

→ 80% carbon capture efficiency assumed in the carbonator: sorbent conversion depends on sorbent circulation F_{Ca}/F_{CO2}



Heat recovery steam cycle

CaL process involves additional fuel consumption. Excess heat recovered at high temperature by steam cycle.

The resulting steam cycle size is:

- ~70 MW_e in the tail-end case
- ~20 MW_e in the integrated case

→ Steam cycle parameters:

- 100 bar
- 530°C
- 2 feed water heaters

} → Electric efficiency = 36%

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 (η_{ref}=44.2%)

- 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 ($e_{ref,el}$=785 kg/MWh)

KEY PERFORMANCE INDICATORS

- Specific primary energy consumption for CO_2 avoided:

$$SPECCA = \frac{q_{eq} - q_{eq,ref}}{e_{CO2,eq,ref} - e_{CO2,eq}}$$

Equivalent fuel consumption of reference cement plant without capture

Equivalent emissions of reference cement plant without capture

RESULTS

	Reference cement plant w/o CO_2 capture	tail-end CaL configuration	integrated CaL configuration
Integration level [%]	--	20	100
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	
Electric balance [kWh_{el}/ t_{clk}]			
Gross electricity production	--	579	163
ASU consumption	--	-117	-73
CO_2 compression	--	-146	-111
Carbonator and calciner fans	--	-25	-11
Cement plant auxiliaries	-132	-132	-132
Net electric production	**-132**	**159**	-164

RESULTS

	Reference cement plant w/o CO_2 capture	tail-end CaL configuration	integrated CaL configuration
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

CONCLUSIONS

Tail-end CaL configuration:

- high retrofitability
- CFB reactors → minor technical uncertainties
- Significant increase of fuel input (+270%)
- Electric power export and very low equivalent emissions

Integrated CaL configuration:

- Lower retrofitability (but no impact on rotary kiln)
- Moderate increase of fuel input (+47%)
- Electric consumption similar to reference cement plant
- Research questions exist, related to raw meal sorbent performance and entrained flow carbonator sizing

Thank you

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https://www.sintef.no/projectweb/cemcap/