Preparing the ground for CCS in the European cement industry – CEMCAP status

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The 8th Korea CCUS International Conference

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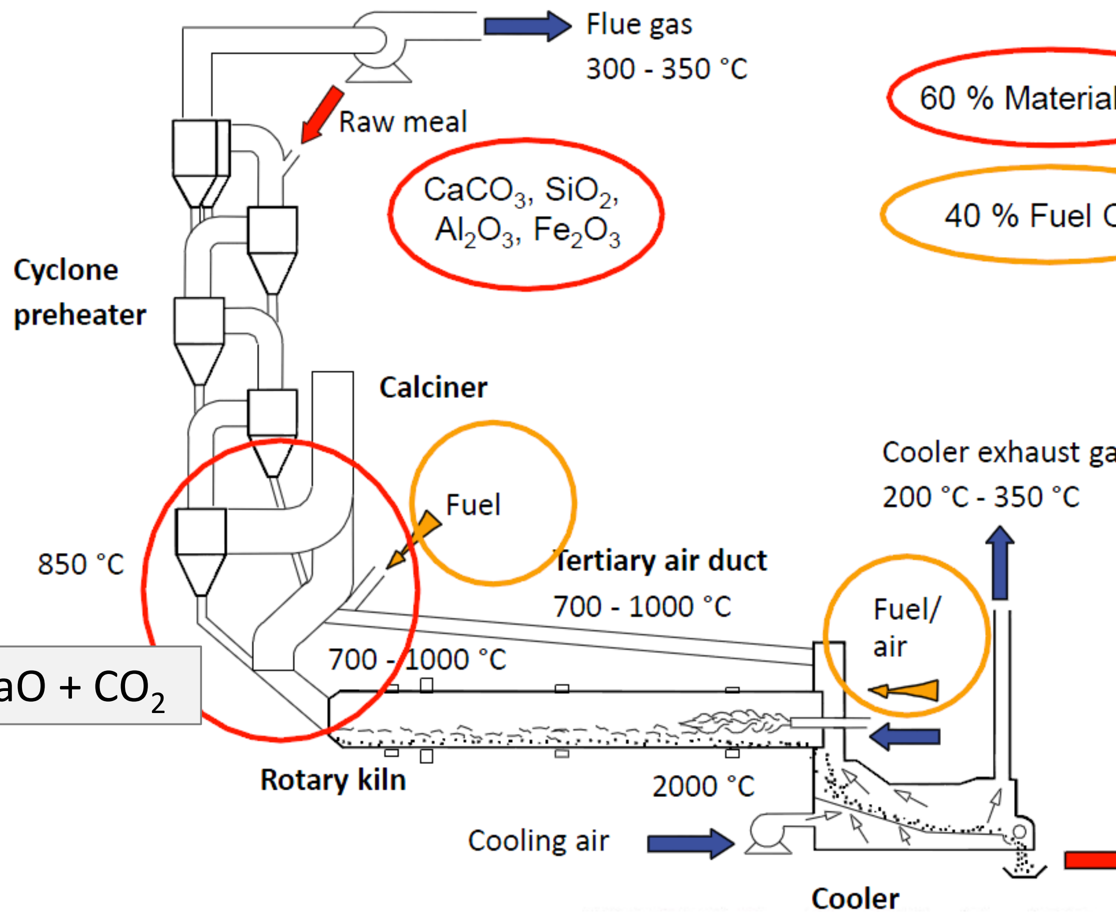
Background

- 6-7% of global anthropogenic CO_2 emissions from the cement industry
- CO_2 emissions an inherent part of the cement production process



$$CaCO_3 \rightarrow CaO + CO_2$$

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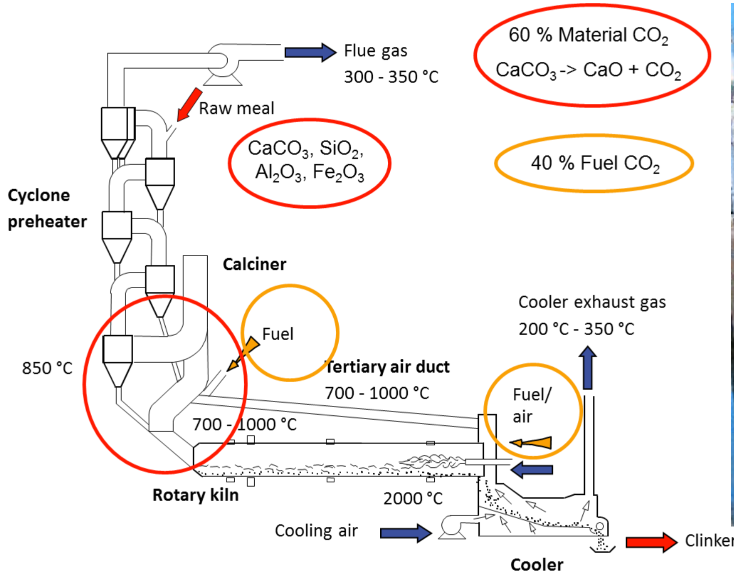
Cyclone preheaters



Calciner fuel feed

Some pictures

from the HeidelbergCement plant in Lixhe, BE

Rotary kiln

Burner

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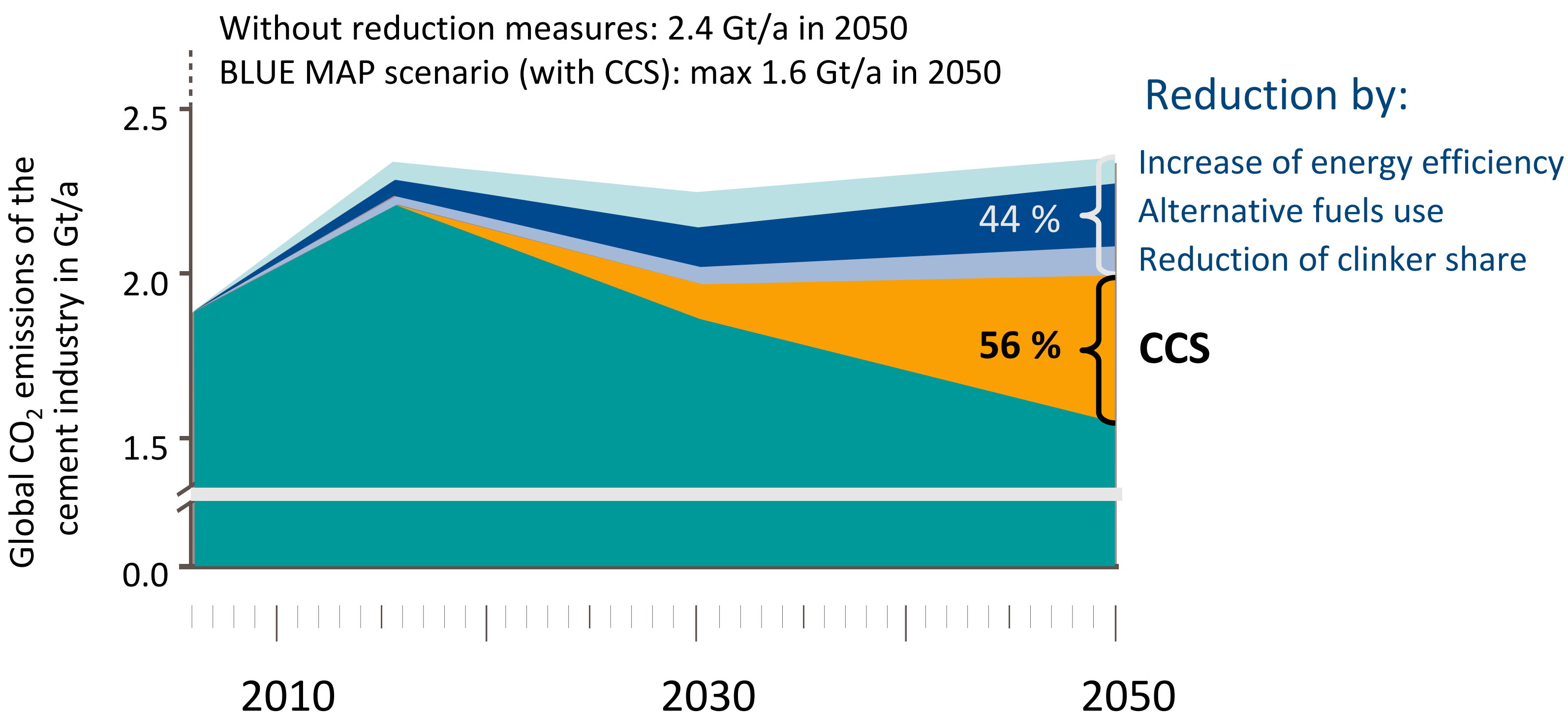
The need for CCS in Cement production



Source: IEA Cement Roadmap

- IEA target for 2050: 50 % of all cement plants in Europe, Northern America, Australia and East Asia apply CCS
- Cement plants typically have a long lifetime (30-50 years or more) and very few (if any) are likely to be built in Europe → **Retrofit**

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The CEMCAP project – CO_2 capture from cement production

The **primary objective of CEMCAP** is t***o prepare the ground for large-scale implementation of CO_2 capture in the European cement industry***

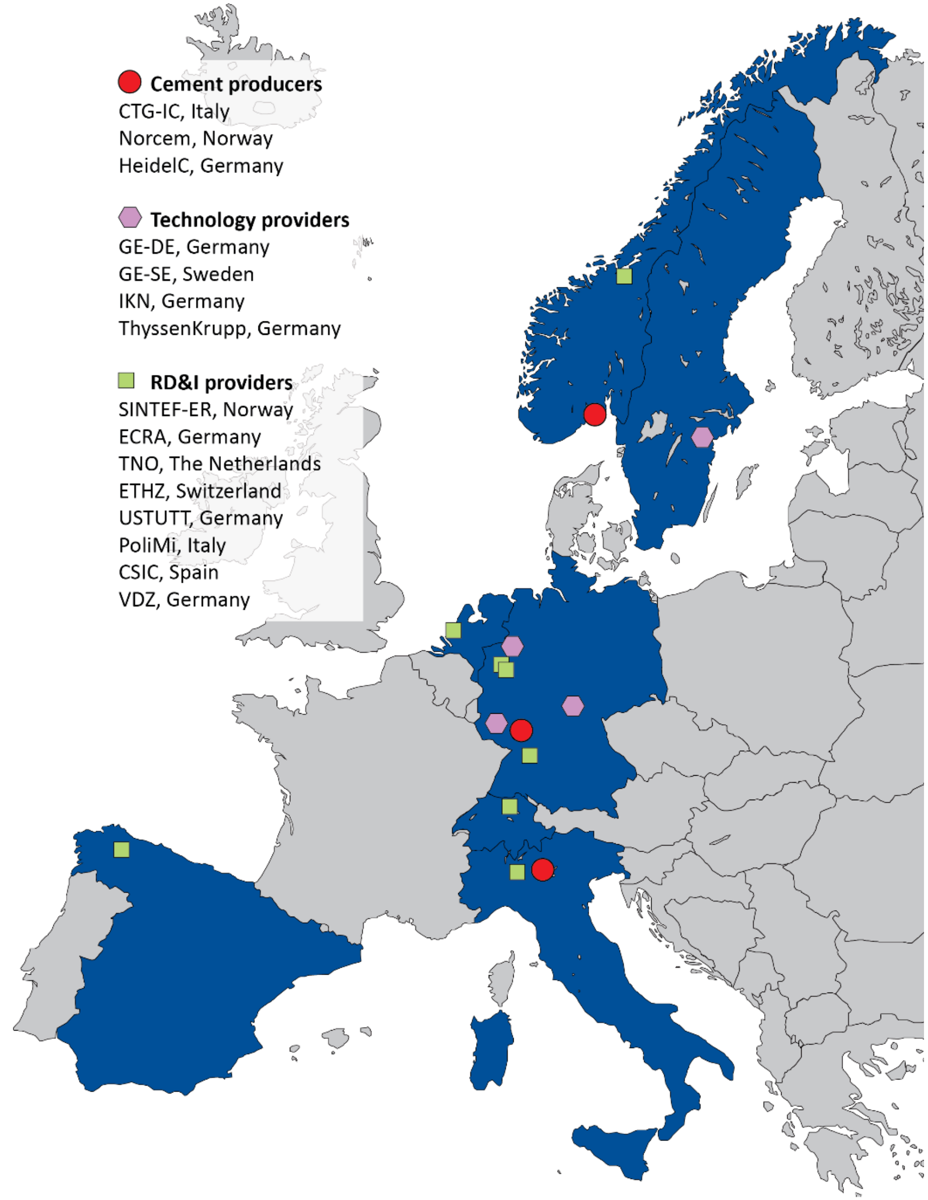
- Project coordinator: SINTEF Energy Research
- Duration: May 1st 2015 – October 31st 2018 (42 months)
- Budget: € 10 million
- EC contribution € 8.8 million
- Swiss government contribution: CHF 0.7 million
- Industrial in-kind ~€ 0.5 million
- Number of partners: 15

CEMCAP Consortium

<u>Cement Producers</u>
Italcementi, IT
Norcem, NO
HeidelbergCement, DE

<u>Technology Providers</u>
GE Carbon Capture (GE-DE), DE
GE Power Sweden (GE-SE), SE
IKN, DE
ThyssenKrupp Industrial Solutions, DE

<u>Research Partners</u>
SINTEF Energy Research, NO
ECRA (European Cement Research Academy), DE
TNO, NL
EHTZ, CH
University of Stuttgart, DE
Politecnico di Milano, IT
CSIC, ES
VDZ, DE



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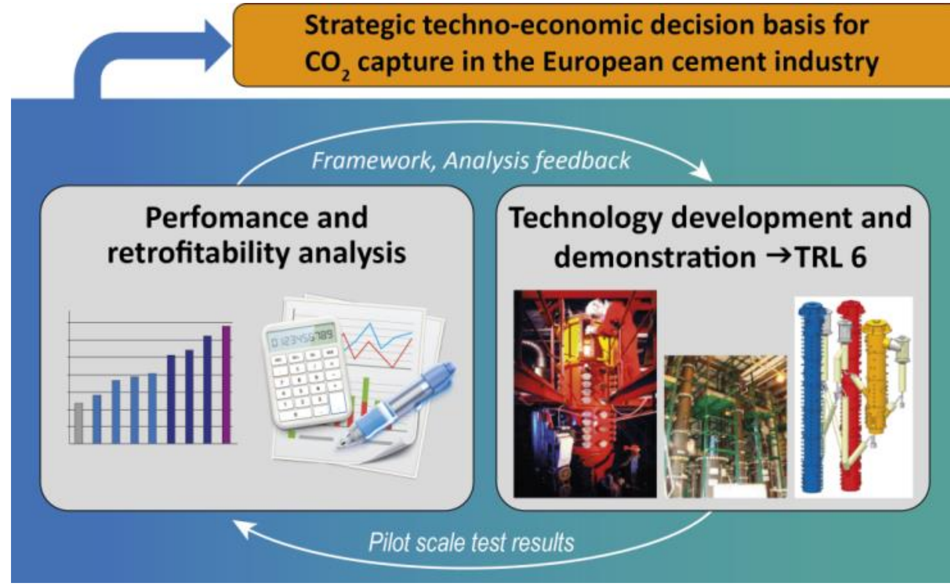


CEMCAP approach: iteration between analytical and experimental research

<u>Analytical work</u>

Framework document

Capture process simulations

Simulations of full cement plants (kilns) with CO_2 capture

Cost estimations/benchmarking

Retrofitability analysis

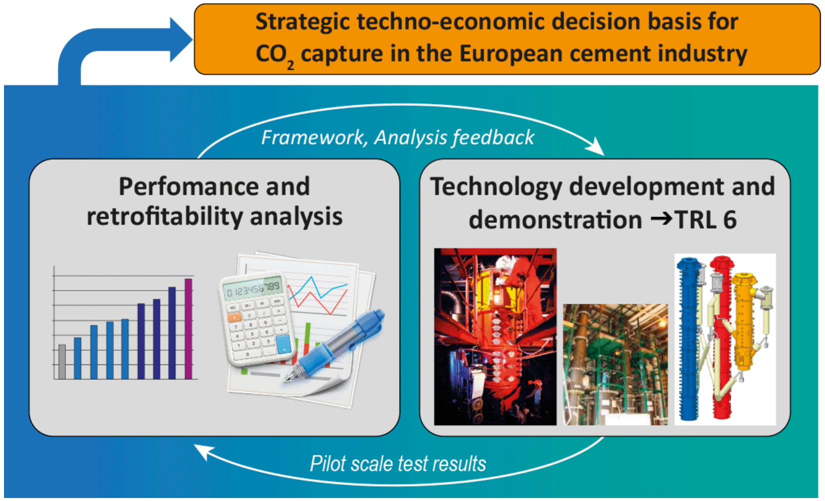
<u>Experimental work</u>

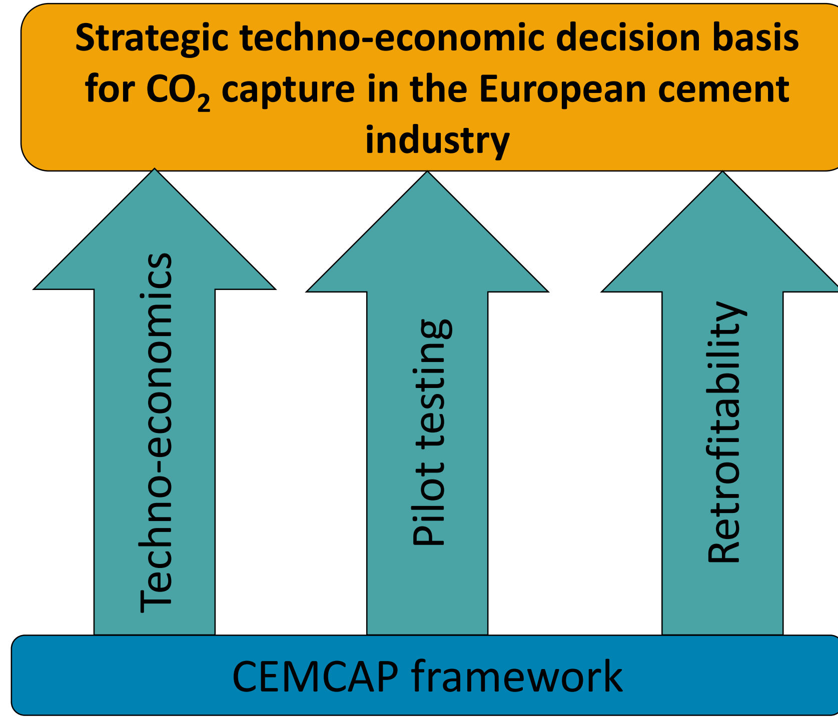
Testing of three components for oxyfuel capture (linked to ECRA CCS project)

Testing of three different post-combustion capture technologies

~10 different experimental rigs

CEMCAP concept and outcome



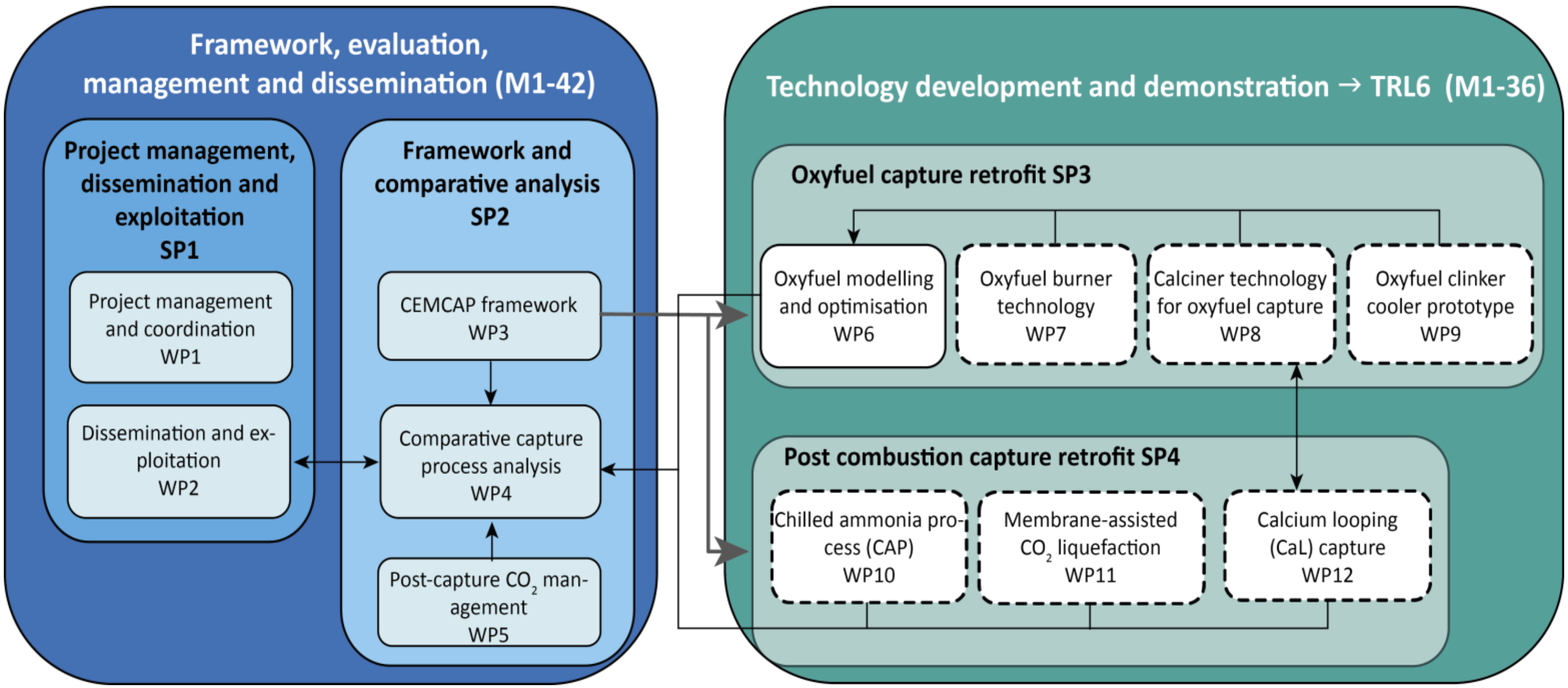


Capture technologies in CEMCAP:

- Oxyfuel capture
- Chilled ammonia process
- Membrane-assisted CO_2 liquefaction
- Calcium looping

Retrofitability: cement plants differ in construction, raw material, fuel et.c.
E.g. the capture technology suitable for Norcem in the Norwegian full-scale project is not suitable for all other cement plants

CEMCAP structure



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WP3: CEMCAP framework – finished and ready for sharing!

- For consistent comparative assessment of capture technologies
- Provides information relevant for experimental and simulation work
- Defines:
  - A reference cement burning line
  - Specs for standard process units
  - Utilities description, cost and climate impact
  - Extent of capture and CO_2 specs
  - Economic parameters
  - Key performance parameters

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Grant Agreement Number:
641185

Action acronym:
CEMCAP

Action full title:
CO_2 capture from cement production

Type of action:

H2020-LCE-2014-2015/H2020-LCE-2014-1

Starting date of the action: 2015-05-01
Duration: 42 months

D3.2
CEMCAP framework for comparative techno-economic analysis of CO_2 capture from cement plants

Due delivery date: 2017-01-31
Actual delivery date: 2017-05-11

Organisation name of lead participant for this deliverable:
SINTEF-ER

Project co-funded by the European Commission within Horizon2020		
Dissemination Level		
PU	Public	x
CO	Confidential , only for members of the consortium (including the Commission Services)	

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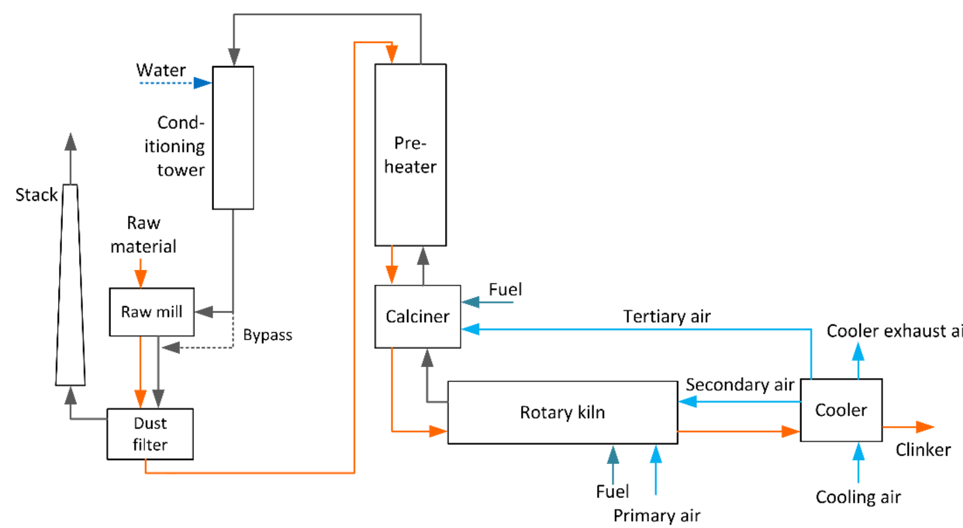
Reference cement burning line

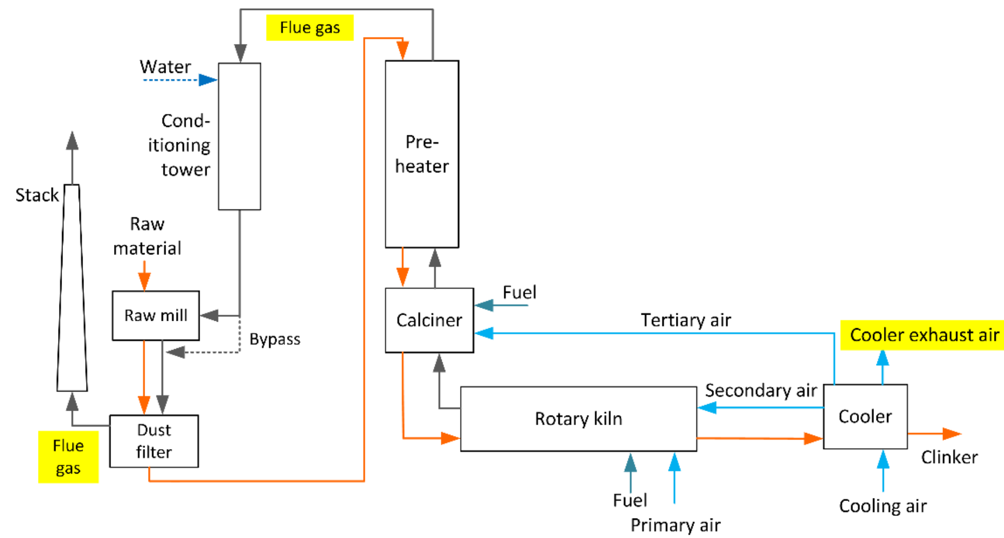
- All cement burning lines are different: 14-35 vol% CO_2 (dry basis)

- Reference cement burning line
  - Based on reference cement kiln of ECRA
  - 3,000 tonne clinker per day
  - Assumed BAT technologies
  - Defines
    - raw material
    - fuel properties
    - process components
    - etc.



Utilities: Steam

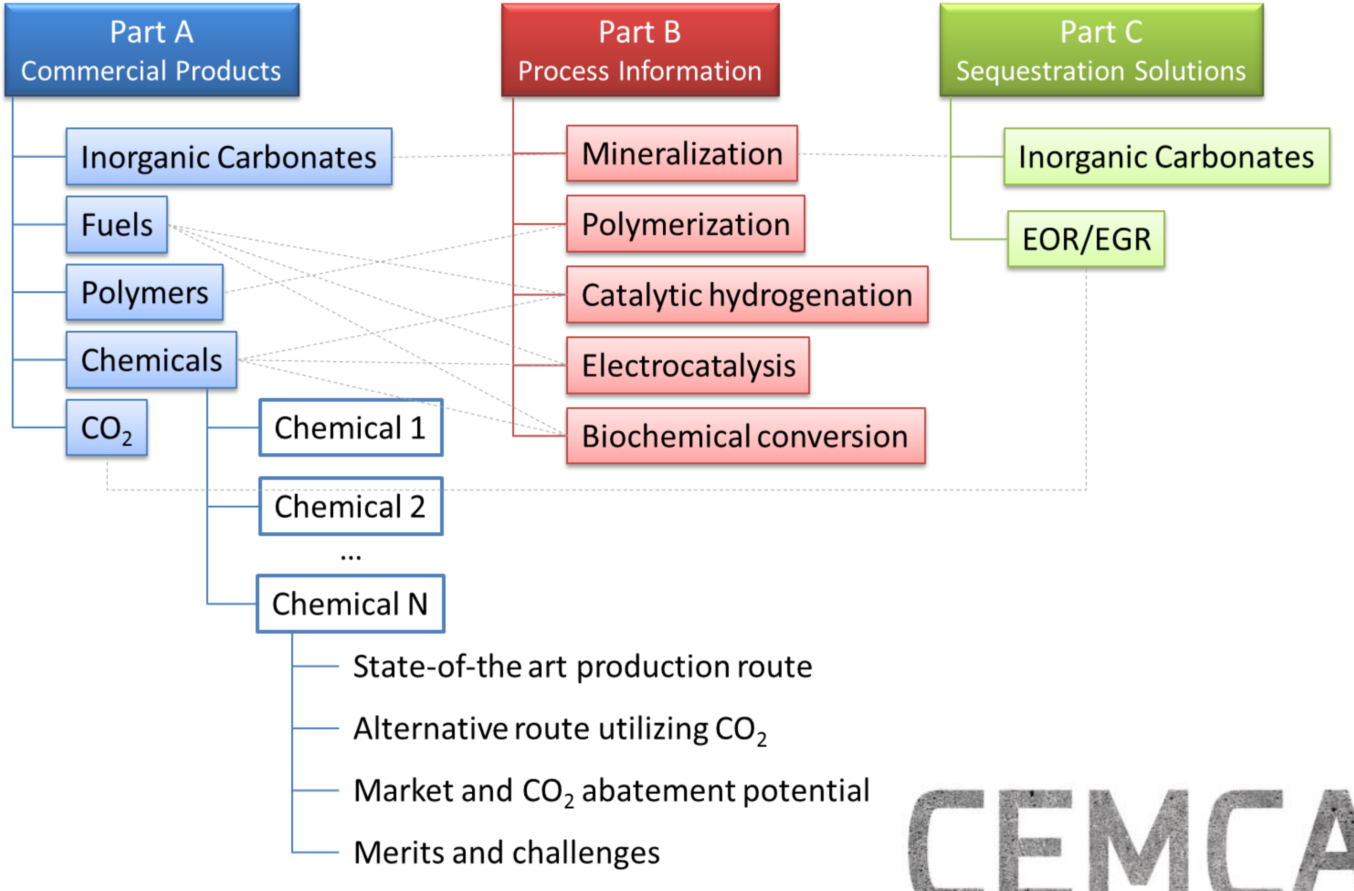
- No steam generated at the plant
- Small amount of waste heat



- Assume required steam is generated by:
  - Waste heat recovery
  - And either
    - Natural gas fired boiler (base case)
    - External CHP

Steam source	Climate impact [kg_{CO2}/MWh_{th}]	Cost (2014) [€/MWh_{th}]
Waste heat available on the plant	0	8.5
Natural gas boiler	224	25.3
External CHP steam plant at 100°C	101	7.7
External CHP steam plant at 120°C	136	10.3
External CHP steam plant at 140°C	170	13.0

WP5: Post-capture CO_2 management - options for the cement industry



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WP5: Post-capture CO_2 management - options for the cement industry

Market size
2017 and forecasts

Thermodynamics
Energy demand

TRL

1. $CaCO_3$
2. Aggregates
3. Carbonated cement
4. Methanol
5. DME
6. Hydrocarbons (liquids)
7. Methane
8. Ethanol
9. Isopropanol
10. Biodiesel
11. Poly(Propylene Carbonate)
12. Polyols
13. Cyclic carbonates
14. Formic acid
15. CO_2

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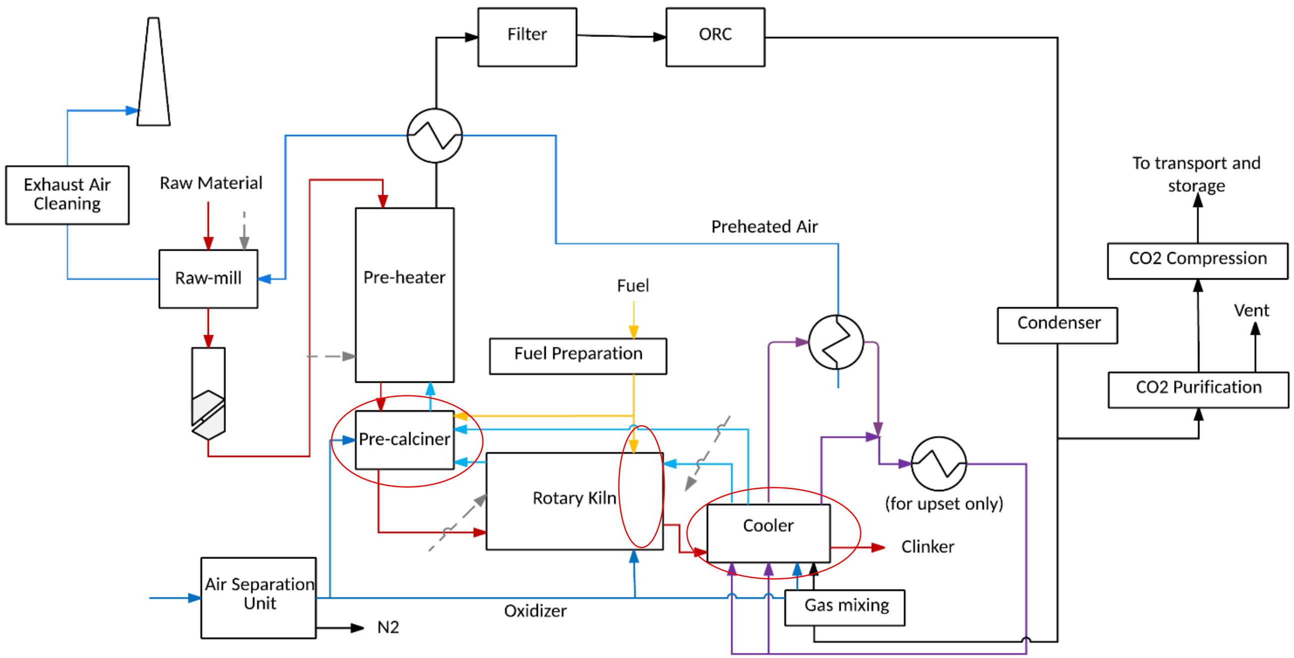
WP6: Oxyfuel modelling

Purpose: Optimization of the oxyfuel clinker burning process based on process modeling verified by prototype results

Oxyfuel principle: Air is replaced by recirculated CO_2 in the plant, to enable capture of highly concentrated CO_2

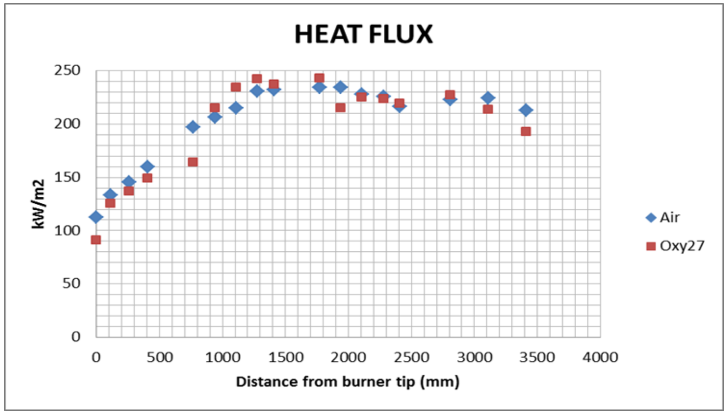
Oxyfuel research in CEMCAP is closely connected to the ECRA CCS project



Pre-calciner, burner and clinker cooler tested in CEMCAP

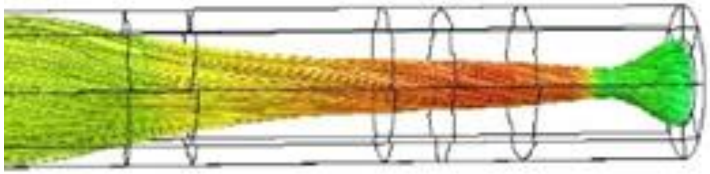
WP7: Oxyfuel cement burner tests

Oxyfuel burner design by ThyssenKrupp for cement plant operating conditions



Measurements of incident total heat flux to the furnace wall during second test campaign.

Oxyfuel burner testing at IFK, University of Stuttgart



Result from the SINTEF CFD simulation of the oxy-fuel case tested in the second campaign showing streamlines coloured by temperature.

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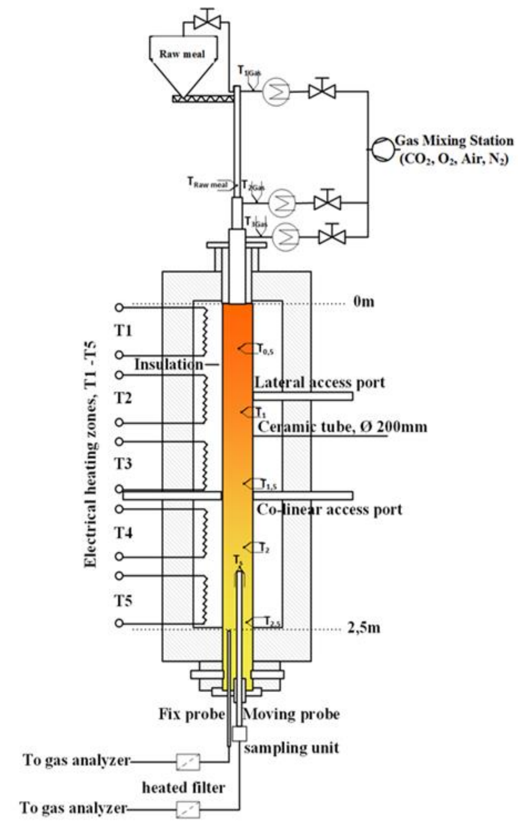
WP8: Calciner technology for oxyfuel capture

- An electrically heated 50 kW entrained flow reactor test facility (University of Stuttgart) modified for oxyfuel calcination tests, experimental investigation of entrained flow calcination is concluded.
- Purpose: experimental investigation of suspension calcination under industrially relevant oxy-fuel conditions
- Aim: to verify sufficient calcination of the raw material before its entering into the rotary kiln
- CEMCAP prototype tests show the direct interference of degree of calcination, temperature and residence time for oxyfuel entrained flow calciners.



WP9: Oxyfuel clinker cooler – designed, built, tested

Clinker cooler prototype and recirculation system installation at HeidelbergCement in Hannover

Hot commissioning of the oxyfuel clinker cooler and first oxyfuel clinker samples

A clinker cooler film is under prepration, will soon be published on YouTube

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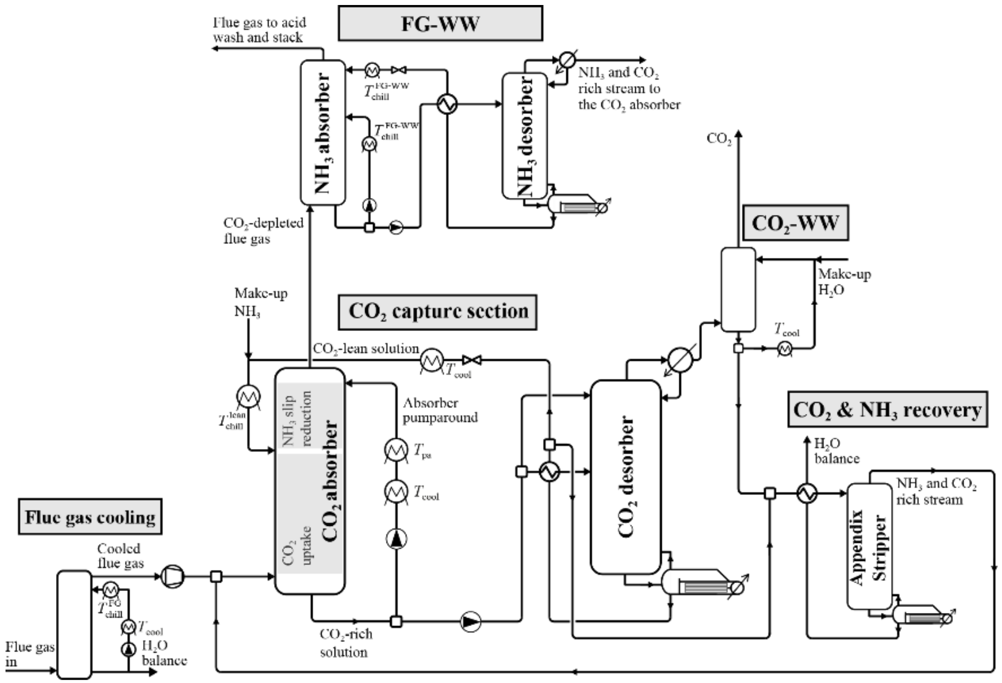
WP10: Chilled ammonia for cement plant CO_2 capture



ETHZ has simulated and adapted the CAP system to different cement-plant flue gases; a new rate-based model was developed and used to validate full-scale CAP simulations for cement plants.

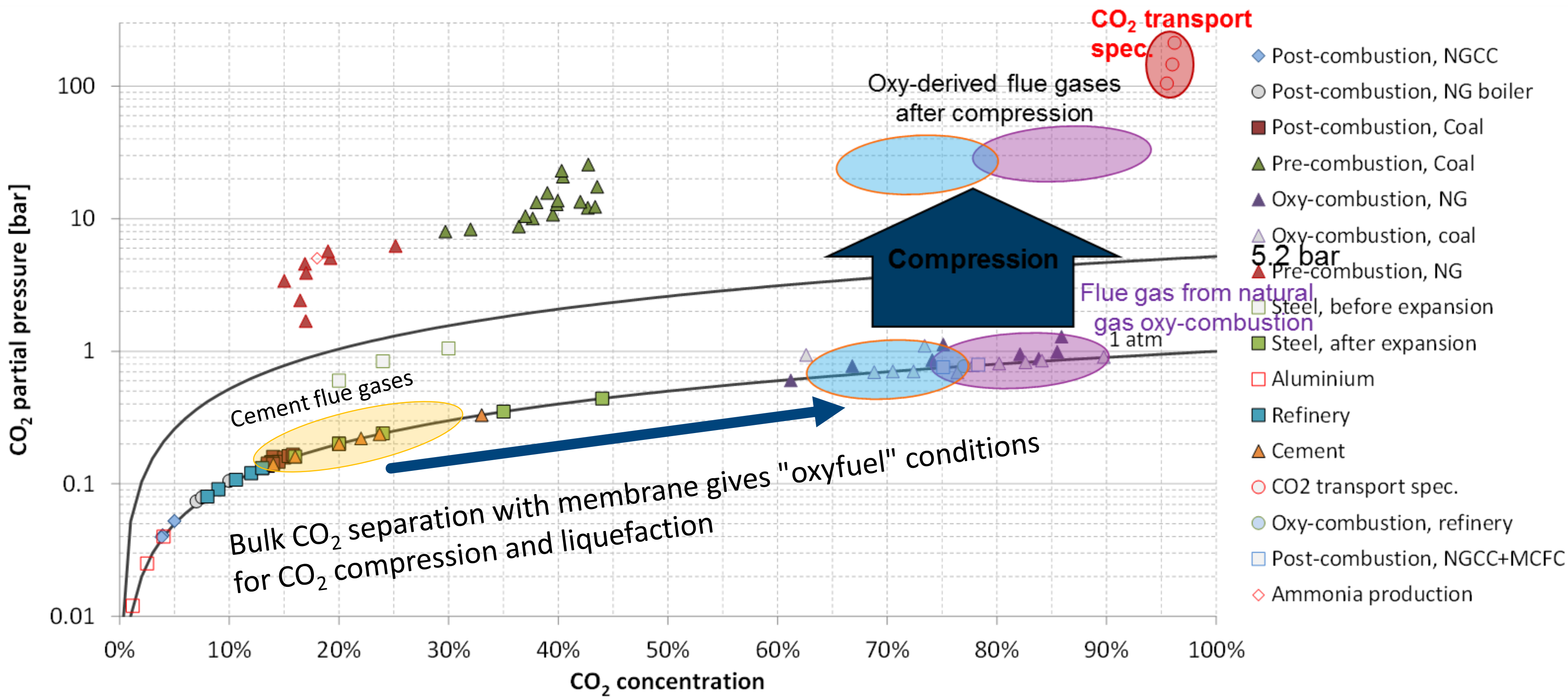
Chilled ammonia process (CAP) for cement plants

- An existing CAP pilot plant (1 tonne CO_2/day) at GE Power Sweden has been adapted for CEMCAP conditions (up til 34% CO_2 concentration)
- Absorber, Direct Contact Cooler and water wash sections have been tested at cement like conditions

CAP pilot plant used for CEMCAP tests (photo by GE Power Sweden)

WP 11: Membrane-assisted CO_2 liquefaction

Is there a role for CO2 liquefaction in post-combustion capture from cement?



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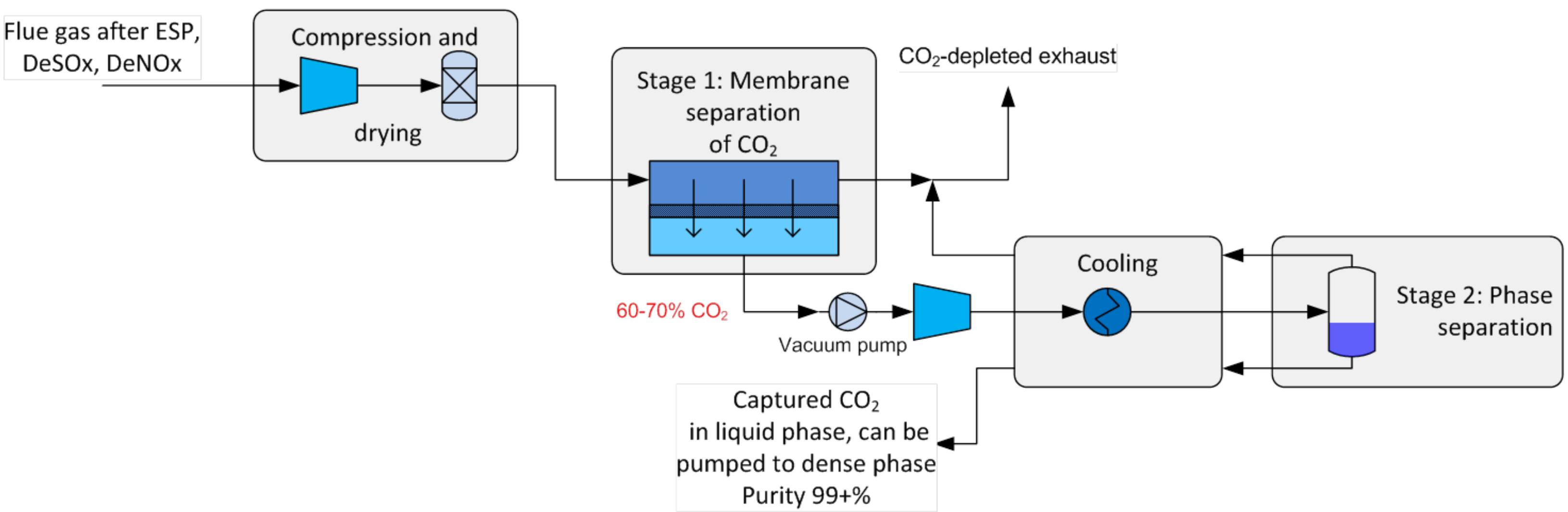
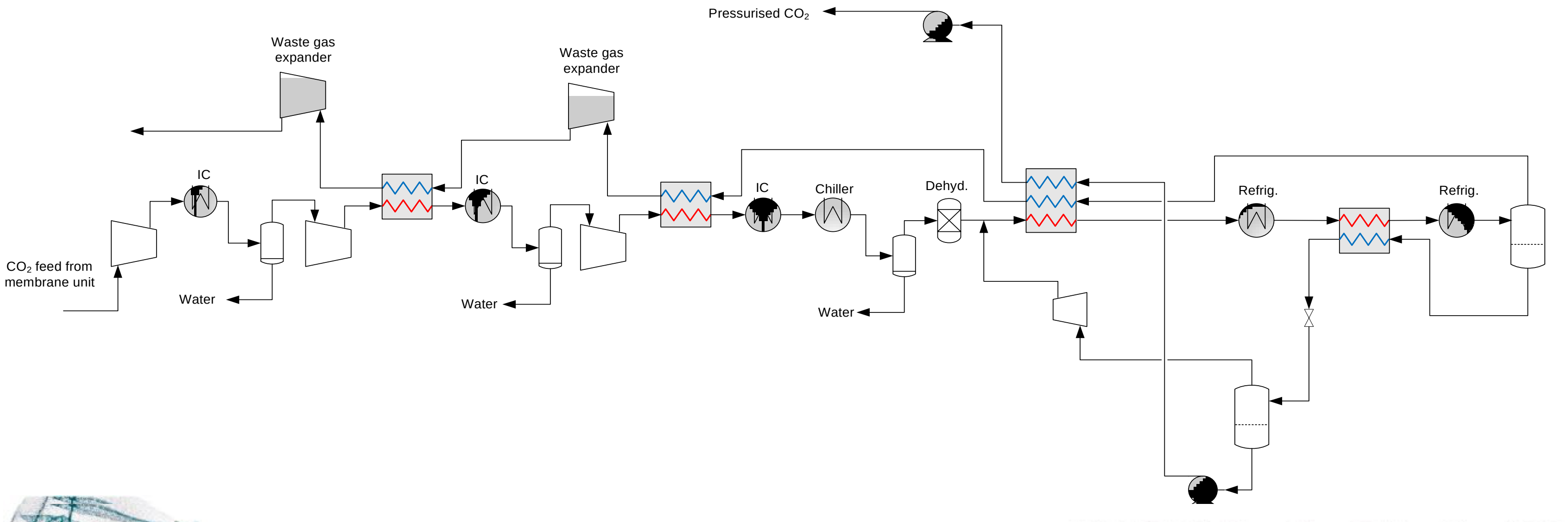
Membrane assissted liquifaction

- End-of-pipe technology
- No fuel input, only power



CO_2 separation and liquefaction unit - simulation

- Compression (3 stages with intercooling)
- Dehydration (bulk separation after each compression stage + final mol sieve dehyd.)
- Cooling and condensation
- Phase separation
- Heat recovery, CO_2 pumping and waste gas expansion



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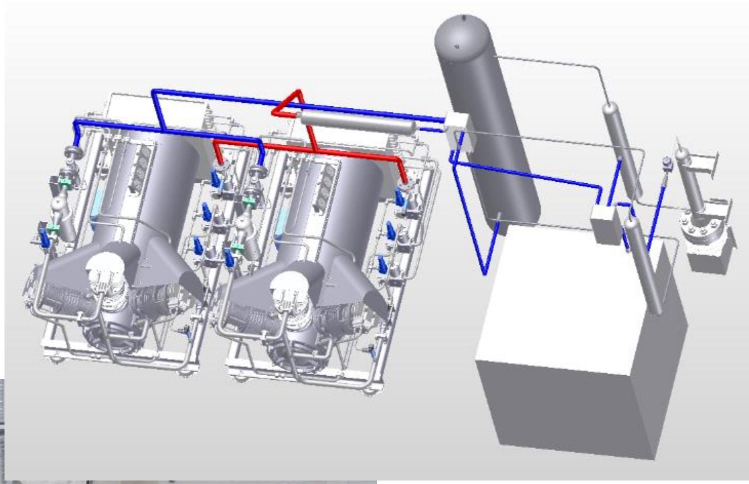
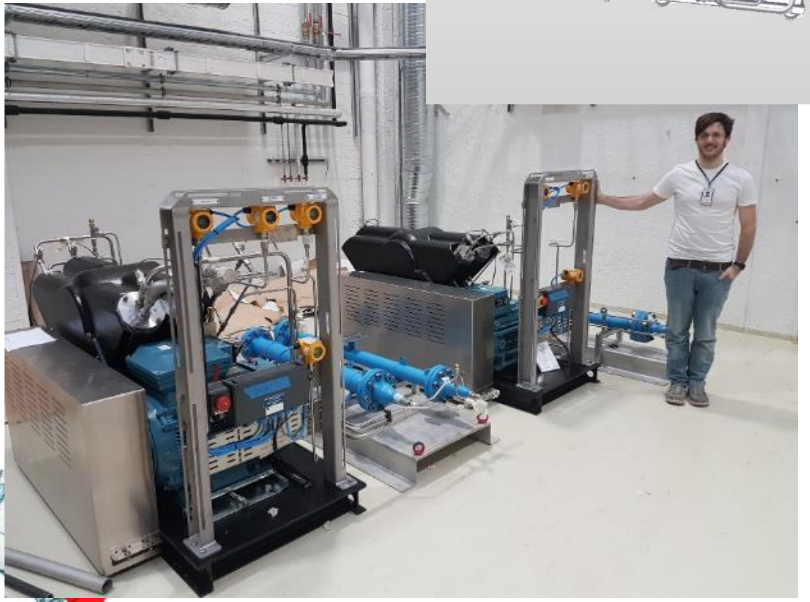
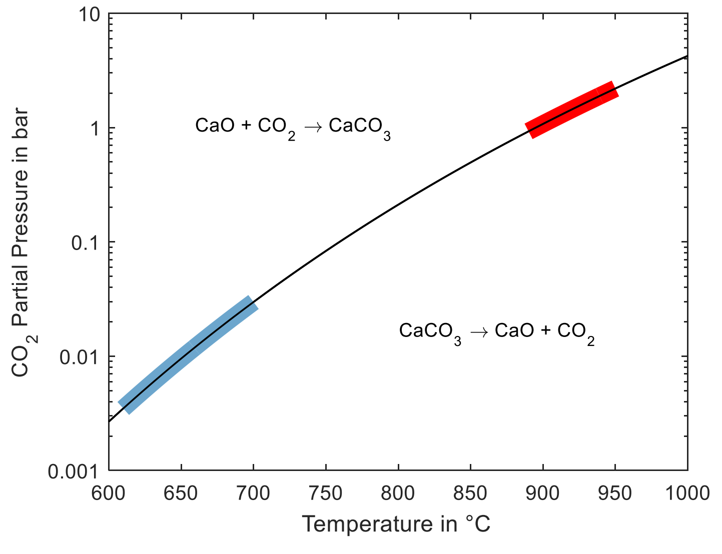
Operating conditions for CO_2 capture ratio and CO_2 purity to be tested in a 10-ton$_{CO2}$-per-day lab pilot rig at SINTEF

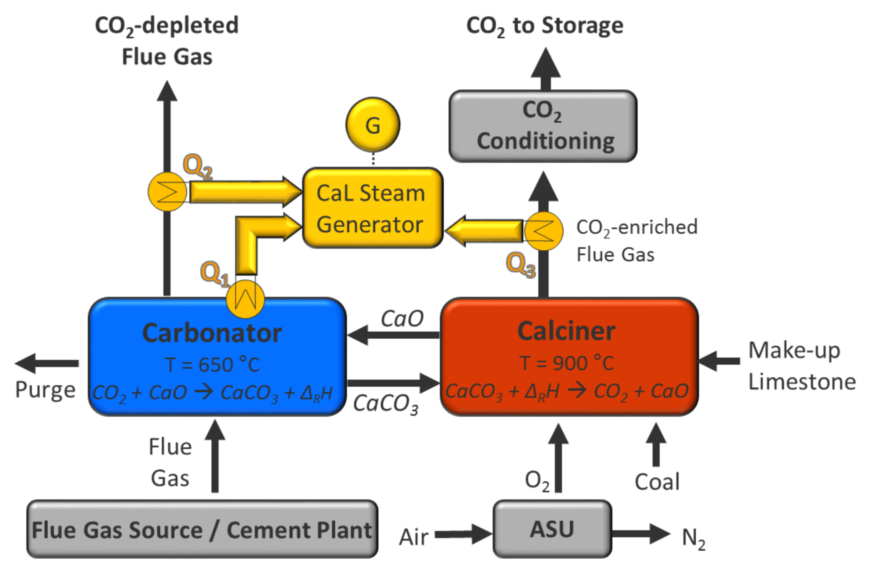




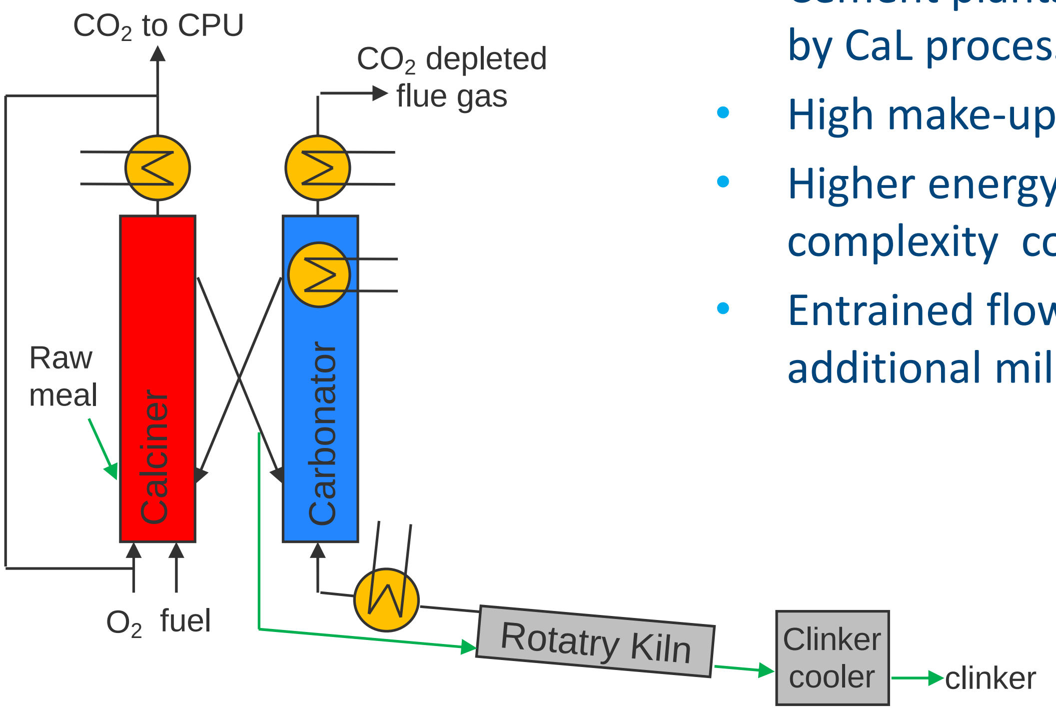
WP12: Calcium looping – General process description

- CO_2 capture by cyclic calcination and carbonation of Calcium carbonate ($CaCO_3$)
- High energy efficiency due to high temperature level



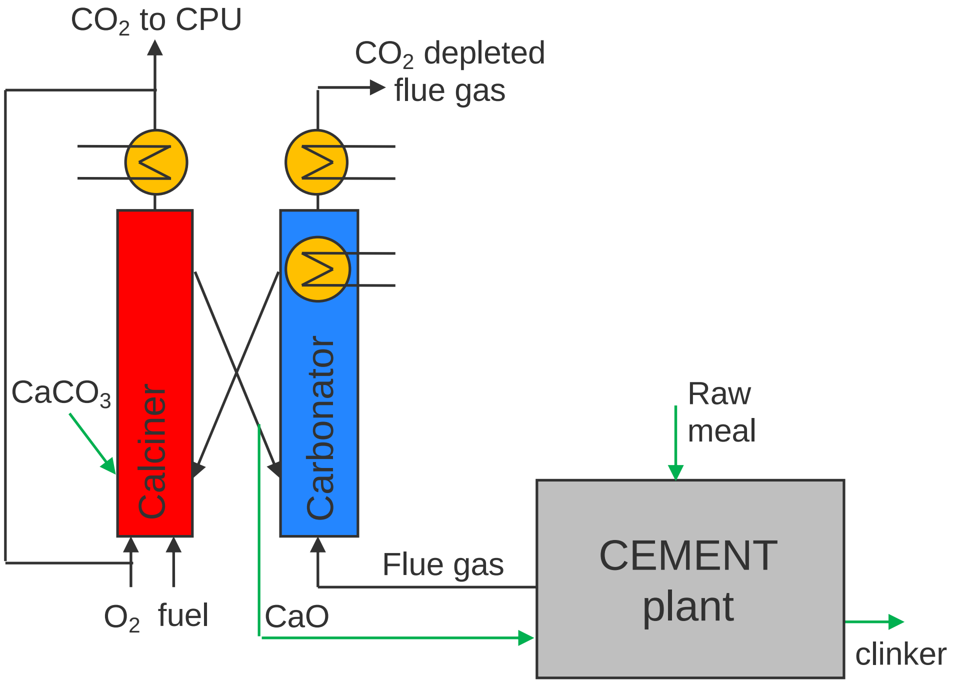


Cement plant integration - Integrated Ca-looping



- Cement plants' raw meal completely calcined by CaL process
- High make-up ratio realizable
- Higher energy efficiency and higher complexity compared to tail-end
- Entrained flow reactors or CFB reactors with additional milling step if necessary

Cement plant integration - End-of-pipe Ca-looping

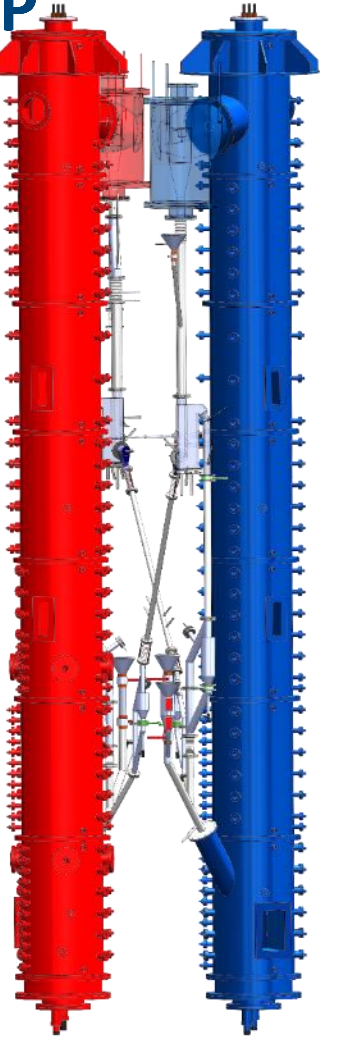


- Part of raw meal calcined in CaL process
- CO_2 flue gas concentration ~ 20 - 35 %
- Easy integration
- Reduced energy efficiency

Experimental research on Ca-looping in CEMCAP

- Two rigs adapted to operate under cement plant conditions: 200 kWth pilot rig at IFK, University of Stuttgart and 30 kW rig at CSIC
  - 200 KW rig: Stable calcium looping operation with CO_2 capture rates above 95% has been reached, using high limestone make up flows and a synthetically mixed flue gas.
  - 30 KW rig: experimental campaigns were conducted, investigating the influence of various process parameters upon CO_2 capture rate. Various raw materials for cement production tested and analysed.

CSIC 30 kW rig



IFK 200 kW rig

Characteristics of technologies included in CEMCAP

	Oxyfuel capture	**Post combustion capture technologies**		
		Chilled ammonia	Membrane-assisted CO_2 liquefaction	Calcium Looping
CO_2 capture principle	Combustion in oxygen (not air) gives a CO_2-rich exhaust	NH_3/water mixture used as liquid solvent, regenerated through heat addition	Polymeric membrane for exhaust CO_2 enrichment followed by CO_2 liquefaction	CaO reacts with CO_2 to from $CaCO_3$, which is regenerated through heat addition
Cement plant integration	Retrofit possible through modification of burner and clinker cooler	Retrofit appears simple, minor modifications required for heat integration	No cement plant modifications. Upstream SOx, NOx, H_2O removal required	Waste from capture process (CaO) is cement plant raw material
Clinker quality	Maintained quality must be confirmed	Unchanged	Unchanged	Clinker quality is very likely to be maintained
CO_2 purity and capture rate	CO_2 purification unit (CPU) needed. High capture rate and CO_2 purity possible (trade-off against power consumption).	Very high CO_2 purity, can also capture NOx, SOx. High capture rate possible.	High CO_2 purity (minor CO_2 impurities present). Trade-off between power consumption and CO_2 purity and capture rate.	Rather high CO_2 purity (minor/moderate CO_2 impurities present). High capture rate.
Energy integration	Fuel demand unchanged. Waste heat recovery + electric power increase.	Auxiliary boiler required + waste heat recovery. Electricity for chilling.	Increase in electric power consumption, no heat integration.	Additional fuel required, enables low-emission electricity generation.

To conclude: CEMCAP – aiming to be a visible project with an impact

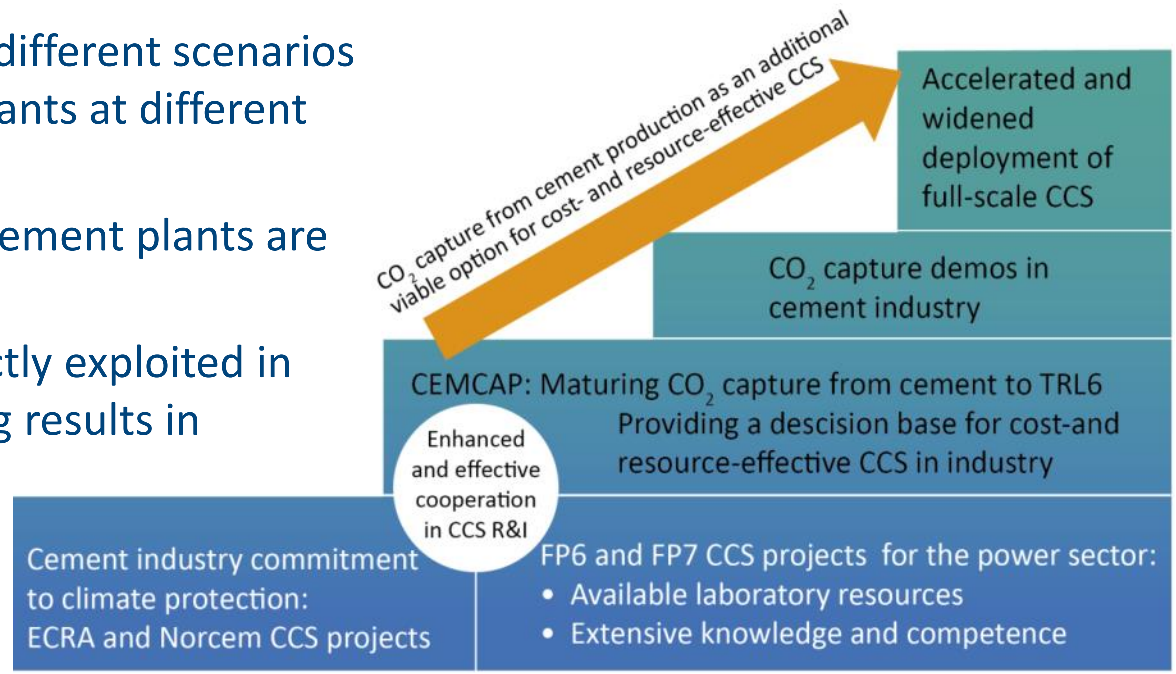
CEMCAP framework: a useful reference for any study on CO_2 capture from cement

CEMCAP will deliver strategic conclusions for how to progress CO_2 capture from cement plants from pilot-scale testing to demonstration

Recommendations will be given for different scenarios (i.e. different types of cement plants at different locations in Europe)

Focus is on retrofit – very few new cement plants are foreseen to be built in Europe

CEMCAP oxyfuel results will be directly exploited in the ECRA CCS project, Ca-looping results in CLEANKER project



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Cemcap on the tube

https://www.youtube.com/watch?v=fVaqFwhBEQI

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- On twitter (@cemcap_co2) we announce newly published deliverabes, newsletters, blogs and other CEMCAP-related info and events
- Subscribe to newsletters: send an e-mail to cemcap@sintef.no
- **Open workshop** about CEMCAP results, organised jointly with ECRA:
  - October 17th 2018 in Brussels (final CEMCAP/ECRA workshop)
  - Updates on workshop will be announced on the website, in newsletters and on Twitter

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