Cement production contributes globally with 6-7% of anthropogenic CO2 emissions. CO2 generation is an inherent part of the cement production process through the calcination of limestone (CaCO3 converted to CaO and CO2). Retrofitting CO2 capture to existing cement plants is the most viable option for significant emissions cuts in the cement industry.

Before CEMCAP, capture technologies for cement were typically considered to be at Technology Readiness Level (TRL) 4-5 or lower, except amine capture which had been demonstrated on-site at the plant of CEMCAP partner Norcem (TRL7).
The primary objective of CEMCAP has been to prepare the ground for large-scale implementation of CO2 capture in the European cement industry. CEMCAP has developed and broadened the portfolio of CO2 capture technologies for the cement industry, with focus on retrofitability, and brought them to a higher TRL and thus closer to deployment.

To achieve this primary objective, secondary objectives have been to:
• Leverage to TRL 6 for cement plants three oxyfuel cement kiln components (the oxyfuel clinker cooler, calciner, and burner), and three fundamentally different post combustion capture technologies (chilled ammonia process (CAP), membrane-assisted CO2 liquefaction (MAL), and calcium looping (CaL) capture).
• Identify the CO2 capture technologies with the greatest potential to be retrofitted to existing cement plants in a cost- and resource-effective manner, maintaining product quality and environmental compatibility.
• Formulate a techno-economic decision-basis for CO2 capture implementation in the cement industry, where the current uncertainty regarding CO2 capture cost is reduced.

Work performed from the beginning of the project to the end of the period covered by the report and main results achieved so far

For consistency in analytical and experimental work, a framework document was established early in the project. This document is a general knowledge basis about cement plant operation with information relevant for CCS related research.

A techno-economic evaluation, as well as a retrofitability analysis, was carried out for the CEMCAP Technologies, i.e. oxyfuel, CAP, MAL and CaL (tail-end and integrated configuration), with MEA as reference. The techno-economic evaluation was based on process simulations, with input from experimental research. The main outcomes of the analytical work were:
• CEMCAP technologies generally outperform MEA regarding energy performance.

• Cost of clinker increases with 49-92% when the technologies are implemented in a reference cement plant under base case conditions. Cost of CO2 avoided (excl. CO2 transport and storage) lies between 42 €/tCO2 (oxyfuel process) which is approximately halved compared to MEA, and 84 €/tCO2 (MAL process), which is on the same level as MEA.

• In the techno-economic evaluation the oxyfuel technology seemed most promising, with the lowest CO2 avoided cost in the base case, followed by the calcium looping technologies. Results however depend on economic parameters, that vary over time and with location.

• Post combustion technologies are the most easy to retrofit – in particular MEA. The more integrated technologies (oxyfuel and integrated CaL) are assessed as more challenging. No retrofit showstopper was identified for any technology.

• The CEMCAP cost evaluation excel model is available online and can be used for plant-specific evaluations.
Post-capture CO2 management options for the cement industry were evaluated. It was found that CO2 utilization (CCU) always should be considered in combination with storage (CCS), as the realistic CO2 fraction to utilize from in a cement plant is expected to be lower than 10%. High added-value products may lead to positive business cases, but the usable amount of CO2 will be strongly limited by the product’s market. Further, the degree of sustainability of CCU (as opposed to CCS) is greatly dependent on the CO2 footprint of the product being displaced by a CO2-derived product.

Experimental research was carried out for three oxyfuel cement kiln components (burner, calciner and clinker cooler) and for CAP, MAL and CaL:

- Results from a downscaled burner tested in a 500 kWth pilot facility under relevant industrial oxyfuel conditions were used to validate models and simulate oxyfuel combustion in a large scale rotary kiln. It was concluded that the tested burner design is suitable for oxyfuel operation.
- Calcination experiments in a 50 kW electrically heated entrained flow reactor indicate that an oxyfuel calcination degree comparable to that of air calcination can be achieved, with temperature increase of around 60 °C.
- An oxyfuel clinker cooler prototype was installed at a cement plant, and clinker cooling under oxyfuel conditions was performed. No negative impact on clinker quality or cement strength was observed.
- CAP pilot-plant tests were carried out for absorber, direct contact cooler (DCC), and water wash units, confirming that the CAP can be adapted to cement plant flue gas capture with only minor process modifications and lower energy penalty than for coal-fired power. SOx levels out of the DCC can be reduced to negligible levels.
- For the MAL, two polymeric membranes were tested in lab, and verified that one membrane complied with the CO2 concentration required for subsequent liquefaction. Pilot-scale testing of CO2-liquefaction verified the efficient separation and purification of a membrane permeate gas.
- For CaL, operational parameters were screened in a 30 kW test facility. Tail-end CaL was demonstrated in industrial relevant conditions in a 200 kW pilot facility. Building on CEMCAP research, the promising but less mature integrated CaL concept is being further developed in the

Progress beyond the state of the art and expected potential impact (including the socio-economic impact and the wider societal implications of the project so far)

The CEMCAP research has filled technology gaps, and five capture technologies for Cement Production are now ready for or already progressing towards on-site testing and demonstration.

The oxyfuel pilot-scale clinker cooler is unprecedented in its innovative design, just as the oxyfuel burner adaptations.

Raw meal calcination in a CO2 rich-environment relevant for oxyfuel and CaL was tested. CaL with a high substitution rate of sorbent has not been tested before.

CaL and CAP technologies has never before been tested at such high CO2 concentrations (up to 35%). An innovative CO2 liquefaction system was designed and demonstrated. At the end of the project, it is concluded that TRL 6 was reached for all three oxyfuel components, for the CAP, the tail-end CaL, and the liquefaction part of the MAL.

The technology demonstrations in CEMCAP were important also for increasing certainty about CO2
The consistent techno-economic and retrofitability analyses provided new insight on emissions abatement, energy performance, retrofitability and cost, and found that all technologies are relevant options for CO2 capture retrofit at existing cement kilns. Capture technology selection should based on plant-specific analyses, considering e.g. local electricity and fuel price, availability of waste heat, options for steam supply, available space and capacity of local electricity grid.

An oxyfuel burner
Preparing the rig for experiments of membrane-assisted CO2 liquefaction.

Experimental rig used for the Direct Contact Cooler (DCC) tests carried out by GE Power Sweden.
Oxyfuel clinker cooler pilot plant.

Experimental facility at IFK, University of Stuttgart, for entrained calciner tests.
Calcium looping pilot plant at IFK (University of Stuttgart).

CEMCAP Retweetet

**Thomas Hills** @Tom_P_Hills · 17. nov. 2016
@CEMCAP_CO2 presenting their own #ccs @inea_eu #H2020 project at #GHGT13 - it's good to have some friendly competition with @ProjectLEILAC!

 Oversett fra engelsk
CEMCAP present at GHGT13 in Lausanne to disseminate results on CO2 capture from cement plants.

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