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

Presented by Rahul Anantharaman

Kristin Jordal, Sigmund Størset, Helmut Hoppe, Mari Voldsund, Simon Roussanaly, Giovanni Cinti, Per Brevik, Juliana Montero, Armin Jamali, Francisco Carrasco, Eike Willms, Manoj Paneru, Marco Lindemann Lino, Simon Becker, Rob van der Meer, Francisco Perezcalvo, Ola Augustsson, David Berstad, Matthias Hornberger

1SINTEF Energy Research, 2VDZ GmbH, 3Italcementi, 4Norcem, 5TNO, 6IFK – University of Stuttgart, 7ThyssenKrupp Industrial Solutions, 8IKN, HeidelbergCement, 10ETH Zürich, 11GE Power Sweden
Background

- 6-7% of global anthropogenic CO₂ emissions from the cement industry
- CO₂ emissions an inherent part of the cement production process

\[
\text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2
\]
Some pictures from the HeidelbergCement plant in Lixhe, BE
The need for CCS in Cement production

Without reduction measures: 2.4 Gt/a in 2050
BLUE MAP scenario (with CCS): max 1.6 Gt/a in 2050

Reduction by:
- Increase of energy efficiency
- Alternative fuels use
- Reduction of clinker share

Global CO₂ emissions of the cement industry in Gt/a

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
The CEMCAP project – CO₂ capture from cement production

The primary objective of CEMCAP is to prepare the ground for large-scale implementation of CO₂ 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

Cement Producers
Italcementi, IT
Norcem, NO
HeidelbergCement, DE

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

Research Partners
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
CEMCAP approach: iteration between analytical and experimental research

Analytical work
Framework document
Capture process simulations
Simulations of full cement plants (kilns) with CO₂ capture
Cost estimations/benchmarking
Retrofitability analysis

Experimental work
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 CO₂ 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

Framework, evaluation, management and dissemination (M1-42)

- Project management, dissemination and exploitation SP1
  - Project management and coordination WP1
  - Dissemination and exploitation WP2

- Framework and comparative analysis SP2
  - CEMCAP framework WP3
  - Comparative capture process analysis WP4
  - Post-capture CO₂ management WP5

Technology development and demonstration → TRL6 (M1-36)

- Oxyfuel capture retrofit SP3
  - Oxyfuel modelling and optimisation WP6
  - Oxyfuel burner technology WP7
  - Calciner technology for oxyfuel capture WP8
  - Oxyfuel clinker cooler prototype WP9

- Post combustion capture retrofit SP4
  - Chilled ammonia process (CAP) WP10
  - Membrane-assisted CO₂ liquefaction WP11
  - Calcium looping (CaL) capture WP12
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 CO₂ specs
  - Economic parameters
  - Key performance parameters
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

<table>
<thead>
<tr>
<th>Steam source</th>
<th>Climate impact [kg CO₂/MWhₜₜ]</th>
<th>Cost (2014) [€/MWhₜₜ]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Waste heat available on the plant</td>
<td>0</td>
<td>8.5</td>
</tr>
<tr>
<td>Natural gas boiler</td>
<td>224</td>
<td>25.3</td>
</tr>
<tr>
<td>External CHP steam plant at 100°C</td>
<td>101</td>
<td>7.7</td>
</tr>
<tr>
<td>External CHP steam plant at 120°C</td>
<td>136</td>
<td>10.3</td>
</tr>
<tr>
<td>External CHP steam plant at 140°C</td>
<td>170</td>
<td>13.0</td>
</tr>
</tbody>
</table>
WP5: Post-capture CO$_2$ management - options for the cement industry

Part A
Commercial Products
- Inorganic Carbonates
  - Fuels
  - Polymers
  - Chemicals
  - CO$_2$
  - Chemical 1
  - Chemical 2
  - ...
  - Chemical N

Part B
Process Information
- Mineralization
- Polymerization
- Catalytic hydrogenation
- Electrocatatlysis
- Biochemical conversion

Part C
Sequestration Solutions
- Inorganic Carbonates
- EOR/EGR

State-of-the-art production route
Alternative route utilizing CO$_2$
Market and CO$_2$ abatement potential
Merits and challenges
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$_2$
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.

Result from the SINTEF CFD simulation of the oxy-fuel case tested in the second campaign showing streamlines coloured by temperature.
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
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
WP 11: Membrane-assisted CO$_2$ liquefaction

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

![Graph showing CO$_2$ concentration vs. CO$_2$ partial pressure](image-url)

- **CO$_2$ transport spec.**
- Post-combustion, NGCC
- Post-combustion, NG boiler
- Post-combustion, Coal
- Pre-combustion, Coal
- Oxy-combustion, NG
- Oxy-combustion, coal
- Pre-combustion, NG
- Steel, before expansion
- Steel, after expansion
- Aluminium
- Refinery
- Cement
- CO$_2$ transport spec.
- Oxy-combustion, refinery
- Post-combustion, NGCC+MCFC
- Ammonia production

**Key Points**:
- **Bulk CO$_2$ separation with membrane gives "oxyfuel" conditions** for CO$_2$ compression and liquefaction.
- **Compression** at various pressures:
  - 5.2 bar
  - 1 atm
- **Oxy-derived flue gases after compression**
- **Flue gas from natural gas oxy-combustion**

**CEMCAP** Co-funded by the European Union
Membrane assisted liquifaction

- End-of-pipe technology
- No fuel input, only power
CO₂ 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, CO₂ pumping and waste gas expansion
Operating conditions for CO\textsubscript{2} capture ratio and CO\textsubscript{2} purity to be tested in a 10-ton\textsubscript{CO2}-per-day lab pilot rig at SINTEF
WP12: Calcium looping – General process description

- CO₂ capture by cyclic calcination and carbonation of Calcium carbonate (CaCO₃)
- 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
- CO₂ 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 CO₂ 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 CO₂ capture rate. Various raw materials for cement production tested and analysed.
# Characteristics of technologies included in CEMCAP

<table>
<thead>
<tr>
<th>Oxyfuel capture</th>
<th>Post combustion capture technologies</th>
</tr>
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<tbody>
<tr>
<td><strong>CO₂ capture principle</strong></td>
<td></td>
</tr>
<tr>
<td>Combustion in oxygen (not air) gives a CO₂-rich exhaust</td>
<td>NH₃/water mixture used as liquid solvent, regenerated through heat addition</td>
</tr>
<tr>
<td><strong>Cement plant integration</strong></td>
<td></td>
</tr>
<tr>
<td>Retrofit possible through modification of burner and clinker cooler</td>
<td>Retrofit appears simple, minor modifications required for heat integration</td>
</tr>
<tr>
<td><strong>Clinker quality</strong></td>
<td></td>
</tr>
<tr>
<td>Maintained quality must be confirmed</td>
<td>Unchanged</td>
</tr>
<tr>
<td><strong>CO₂ purity and capture rate</strong></td>
<td></td>
</tr>
<tr>
<td>CO₂ purification unit (CPU) needed. High capture rate and CO₂ purity possible (trade-off against power consumption).</td>
<td>Very high CO₂ purity, can also capture NOₓ, SOₓ. High capture rate possible.</td>
</tr>
<tr>
<td><strong>Energy integration</strong></td>
<td></td>
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</tbody>
</table>
To conclude: CEMCAP – aiming to be a visible project with an impact

CEMCAP framework: a useful reference for any study on CO₂ capture from cement

CEMCAP will deliver strategic conclusions for how to progress CO₂ 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
Cemcap on the tube

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

• Public deliverables are uploaded to our website: [www.sintef.no/cemcap](http://www.sintef.no/cemcap)

• On twitter (@cemcap_co2) we announce newly published deliverables, newsletters, blogs and other CEMCAP-related info and events

• Subscribe to newsletters: send an e-mail to [cemcap@sintef.no](mailto: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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www.sintef.no/cemcap
Twitter: @CEMCAP_CO2
Newsletter subscription, inquiries: cemcap@sintef.no