CO₂ capturing in cement production

Johannes Ruppert, VDZ
Workshop CO₂-Infrastructure in NRW
Düsseldorf, 22. August 2019
AGENDA

1. Cement production and process emissions
2. CO₂ abatement in the cement industry
3. Carbon Capture – the ECRA project
4. Perspectives for CCS and CCU in the cement industry
The German cement industry

- 20 companies, 53 cement works
  - cement clinker production 34
  - grinding stations 19
- Cement production: 34 Mt *
- CO₂ emissions: 20 Mt CO₂
- Cement sales in Germany: 29 Mt *
- Turnover: 2.8 Bn €
- Employees: ca. 8,100

Sources: VDZ, Statistisches Bundesamt, DEHSt, * estimate
Cement clinker production in NRW

- 11 plants with production of cement clinker
- Direct relation to especially suitable limestone available in Westphalia
- Ca. 5.2 Mio. t CO$_2$ / year
- Intensive use of industrial by-products and alternative resources:
  - Blast furnace slag and fly ash as other main constituents in cement
  - Alternative fuels with biogenic carbon content
Cement is a CO₂ intensive product
Concrete is a CO₂ efficient product

Direct CO₂ emissions
estimate for Germany

- t CO₂ / t cement clinker
- t CO₂ / t cement
- t CO₂ / m³ concrete

Share related to the use phase of a building: 2 - 12 %
CEMBUREAU, 2013: https://lowcarboneconomy.cembureau.eu/
Process emissions in cement production

Quarrying of limestone (CaCO$_3$)

Calcination

\[ \text{CaCO}_3 \rightarrow \text{CaO} + \text{CO}_2 \]

and sintering of raw materials

Preheating of the raw material in counter flow

Cement clinker production

Cement grinding

Process emissions

\[ 400 \text{ kg CO}_2/\text{t cement} \]

Fuel emissions

\[ 200 \text{ kg CO}_2/\text{t cement} \]
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CO₂ and energy efficiency in the cement industry

CSI/ECRA Technology Paper 2017

- Thermal
- Electrical
- Grinding
- Alternative fuels and raw materials
- Use of clinker in cement
- New binding materials
- CCS
- CCU

Material- and energy efficiency in the cement industry, VDZ/UBA study:

- Workshops with sector experts
- VDZ-Model2018, scenarios and examples for GE
- Plant optimisation, grinding, use of blast furnace slag
- CO₂ capturing
- New binding materials
- Concrete production, recycling

https://ecra-online.org/research/technology-papers/

Publication in Sept. 2019

https://www.vdz-online.de/forschung/aktuelle-projekte/prozesskettenorientierte-ermittlung-der-material-und-energieeffizienzpotentiale-inder-zementindustrie/
# Net zero greenhouse gas emissions in cement production and application

## Global CO₂ emissions 2016

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<thead>
<tr>
<th>Direct emissions</th>
<th>Indirect emissions</th>
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<tr>
<td>Thermal efficiency</td>
<td>Renewable electrical energy</td>
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<tr>
<td>Alternative fuels</td>
<td>Transport efficiency</td>
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<tr>
<td>Clinker efficient cements</td>
<td>Re-carbonation of concrete</td>
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<tr>
<td>New binding materials</td>
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<td>CO₂ capturing</td>
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**Breakthrough innovations**

Schematic diagram, * global CO₂ emissions estimate with statistical uncertainty Schneider 2019: The cement industry on the way to a low-carbon future.  
[https://doi.org/10.1016/j.cemconres.2019.105792](https://doi.org/10.1016/j.cemconres.2019.105792)
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European Cement Research Academy: Project on carbon capture in the cement industry

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<tr>
<th>Phase</th>
<th>Activities</th>
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<tr>
<td>I</td>
<td>Literature study (2007)</td>
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<tr>
<td>II</td>
<td>Study on technical and financial aspects of CCS projects, concentrating on oxyfuel and post-combustion technology (2007-2009)</td>
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<tr>
<td>III</td>
<td>Laboratory-scale / small-scale research activities (2009-2011)</td>
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<td>IV</td>
<td>Appropriate pilot-scale plant design, capacity, set-up, cost estimation (2012-2016)</td>
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<td>V</td>
<td>Prepare pilot plant, technical and economic concept for retrofitting of a full-scale cement plant with oxyfuel (2017-2019)</td>
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<td>VI</td>
<td>Next step: Build and operate pilot plants for industrial scale CO₂ capture technology demonstration at TRL 8 (time-frame: 3-5 years)</td>
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<td>Demonstration plant at TRL 9 (time-frame: 3-5 years)</td>
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www.ecra-online.org/research/ccs
Technologies for CO₂ capture in the cement industry

Post-Combustion Technology

- Tail-end separation of CO₂ from flue gas by e.g. chemical absorption, adsorption, membranes or Ca-looping
- Comparatively energy-intensive technology

Oxyfuel Technology

- Integrated, combustion with pure oxygen in combination with flue gas recirculation to achieve high CO₂ concentration up to 80 vol%
- Lowest energy demand, electrical power
- Oxyfuel process requires major plant retrofit
Energy demand for CO₂ capturing in cement plants

Based on M. Voldsund et al.: CEMCAP Techno-Economic and Retrofitability Analysis. In: European Cement Research Academy, ECRA; Research Group CEMCAP; Research Group CLEANKER, Ed. Presentations and Posters of the ECRA/CEMCAP/CLEANKER Workshop 2018 on Carbon Capture Technologies in the Cement Industry (Brussels 17 October 2018). Available at: https://ecra-online.org/research/ccs/presentations-and-posters/

ECRA and CEMCAP results as basis for ISO TC 265 TR (2019) „Overview of carbon capture technologies in the cement industry“
Challenges of carbon capture

Costs and competitiveness

- Significant increase of production costs
- Competitiveness of cement production threatened under current economic and legal conditions for carbon capture
- Demonstration at industrial scale needed
- Appropriate CO$_2$ infrastructure for storage and use
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Storage and use of CO₂ from the cement industry

Geological storage of CO₂

- Required for CO₂ neutrality of cement production and use of cement in construction
- Re-direction of process related CO₂:
  - Offshore, e.g., North Sea with appropriate CO₂ infrastructure
  - Local storages onshore?
- Potential for negative Emission shares (NET)
  - Up to 10% biogenic CO₂ from use of waste biomass as alternative fuel (without additional production of biomass)
  - CO₂ absorption at the surface of concrete during its use phase
Storage and use of CO$_2$ from the cement industry

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Storage of CO$_2$ in concrete
- CO$_2$ absorption at the surface of concrete can be enhanced during concrete recycling
- Use of CO$_2$ in the application of cement in concrete production and in the production of precast concrete elements
Storage and use of CO₂ from the cement industry

Geological storage of CO₂

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Carbon-use

- Raw material CO₂ as carbon source for products: Basic chemicals, methane, plastics, synthetic fuel
- Link to other industry sectors
5 technologies for CO₂ capture facilitate plant specific solutions

- CO₂ capture can be applied to existing cement plants (Retrofit)

- Energy demand, technical and economic assessments are available:
  About double production cost for CO₂ neutral cement

- Create demand for CO₂ neutral cement as enhanced carbon leakage protection:
  E.g. by targeted tendering and requirements for the construction of new buildings

- CO₂ neutrality will require significant shares of CO₂ storage (CCS + CCU)

- Essential steps are the demonstration at industrial scale and an appropriate CO₂ infrastructure
Thank you!

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VDZ gGmbH, Düsseldorf
CCS & use of alternative fuels with waste biomass allow sustainable negative emissions technology (NET)

Cement plant CCS scenario

<table>
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<tr>
<th>Year</th>
<th>Fossil CO₂ emissions kg CO₂/t cement</th>
</tr>
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<tr>
<td>2016</td>
<td>process CO₂</td>
</tr>
<tr>
<td>CCS 2030-2050</td>
<td>* negative CO₂ emissions from capture of up to 10% biogenic CO₂</td>
</tr>
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**CO₂ emissions**
- direct, 2/3 process-related
- indirect, electricity mix
- * negative CO₂ emissions

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Concrete as a CO₂ sink during its life cycle and after use

- CO₂ uptake in concrete is a relatively slow process over many years.
- Primary uptake is due to the hydrated Portland cement.
- Also latent hydraulic concrete additions, such as blast-furnace slag and pozzolanic additions such as fly ash.
- Potential for increased CO₂ uptake in end-of-life stages by demolishing, crushing, and storage.

## CO₂-Minderungsmöglichkeiten in der Zementindustrie

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<thead>
<tr>
<th>Technologie</th>
<th>Beschreibung</th>
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<td><strong>Konventionelle Technologien</strong></td>
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<tr>
<td>Thermische Effizienz</td>
<td>▪ Sehr hoch verglichen mit allen anderen Industrieprozessen / chemisch-mineralogische Grenzen</td>
</tr>
<tr>
<td>Alternative Brennstoffe</td>
<td>▪ Geringerer Kohlenstoffanteil + hoher Biomasse-Anteil / energetische + stoffliche Verwendung</td>
</tr>
<tr>
<td>Klinkereffiziente Zemente</td>
<td>▪ Senkung des Klinkeranteils im Zement / begrenzte Verfügbarkeit geeigneter Ersatzmaterialien</td>
</tr>
<tr>
<td>Alternative Rohstoffe</td>
<td>▪ Einsatz bereits kalziniertem Rohstoffe / sehr begrenzte Verfügbarkeit geeigneter Materialien</td>
</tr>
<tr>
<td>Elektrische Effizienz</td>
<td>▪ Sehr begrenzte Reduktionspotenziale / Zielkonflikte mit Markt- und Regulierungsanforderungen</td>
</tr>
<tr>
<td><strong>Breakthrough Technologien</strong></td>
<td></td>
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<tr>
<td>Neue Bindemittel</td>
<td>▪ Absehbar keine alternativen Zemente, um Portlandzement in größerem Umfang zu ersetzen</td>
</tr>
<tr>
<td><strong>CO₂-Abscheidung (Carbon-Capture-Technologien)</strong></td>
<td>▪ Aussichtsreich, aber sehr hohe Kosten / CO₂-Speicherung bzw. CO₂-Nutzung bislang ungeklärt</td>
</tr>
<tr>
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<td>▪ Oxyfuel ist wirtschaftlichste Carbon-Capture-Technologie für Zementherstellung (derzeit TRL 6)</td>
</tr>
<tr>
<td></td>
<td>▪ Demonstrationsprojekt (TRL 7/8) erfordert umfangreiche Mittel für Investition und Betrieb</td>
</tr>
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Building carbon neutrality in Europe

- Secure a level playing field with other regions and across industrial sectors;
- Based on lifecycle performance; material neutral
- Integrate both the supply and demand sides;

- Supports the development of breakthrough technologies and solutions, including through large-scale technology demonstration.
CO₂ reduction potential in the global cement industry; Sources: IEA/CSI Technology Roadmap 2018: http://www.wbcsdcement.org/technology
CSI/ECRA Technology Papers 2017: https://ecra-online.org/research/technology-papers/

Without CCS the aim of climate neutrality can not be achieved
Requirements: Storage, Infrastructure and effective Carbon-Leakage-Protection