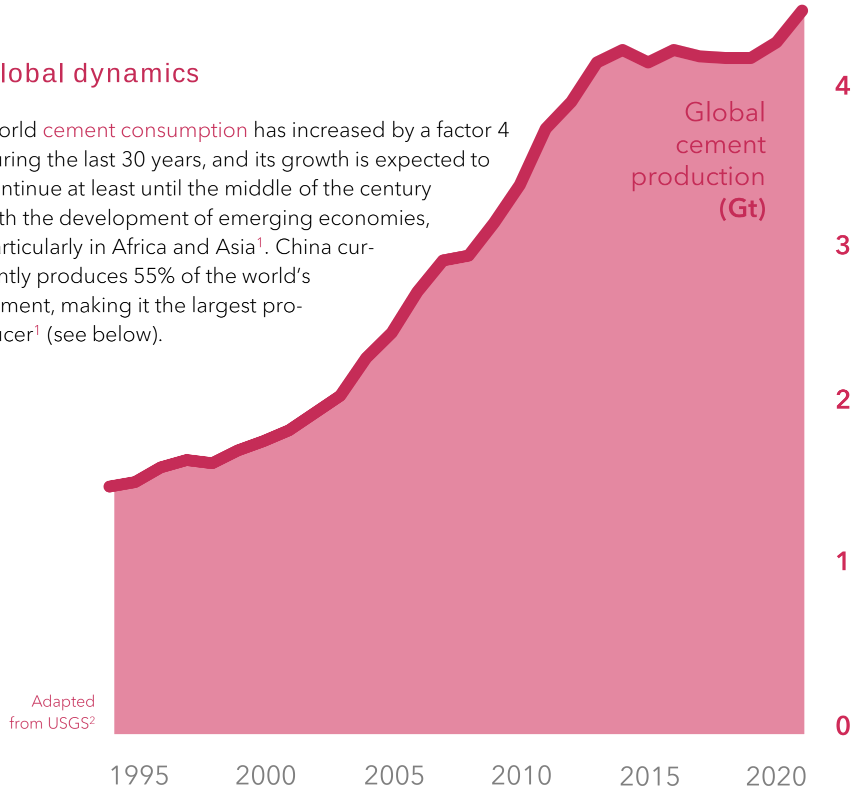
Cement

Cement is an integral part of our modern civilization. Used for the manufacture of concrete, the second most consumed product on the planet after water, cement plays a **key role in meeting our societies' needs for housing and** infrastructure.

Global dynamics

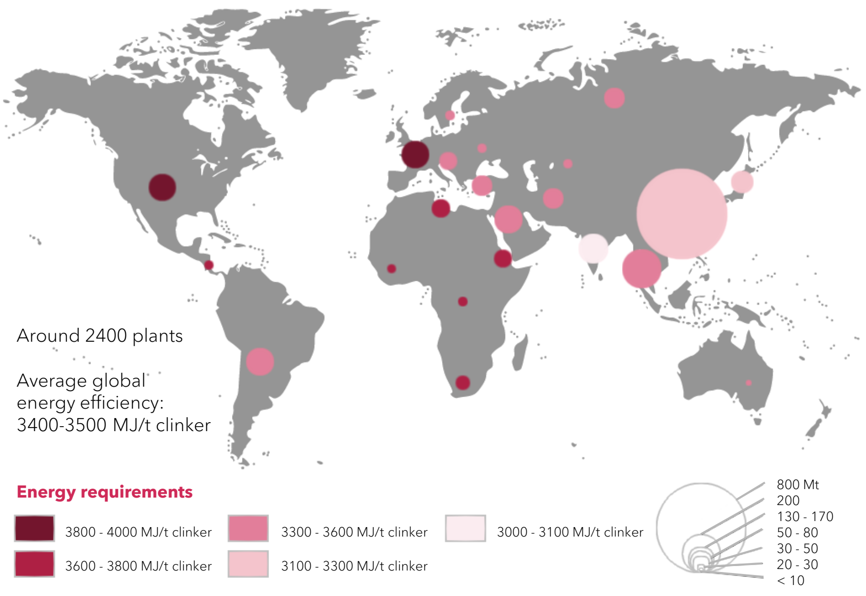
World cement consumption has increased by a factor 4 during the last 30 years, and its growth is expected to continue at least until the middle of the century with the development of emerging economies, particularly in Africa and Asia[1]. China currently produces 55% of the world's cement, making it the largest producer[1] (see below).



Adapted from USGS[2]

Cement production around the world

Energy efficiency of cement production has considerably improved during the last three decades. A recent dry-process kiln requires 50% less energy than a wet kiln that was built in the 1970s[3]. The best performing plants are located in Asia, since they were built rather recently to satisfy the fast growing demand for cement which accompanied the emergence of China. On the contrary, in Europe and North America, most of the cement plants are quite old, as cement production there has stabilized during the past decades - cement factories are long-lived infrastructures that last 30 to 50 years.



Adapted from The Shift Project[4] and GCCA[5]

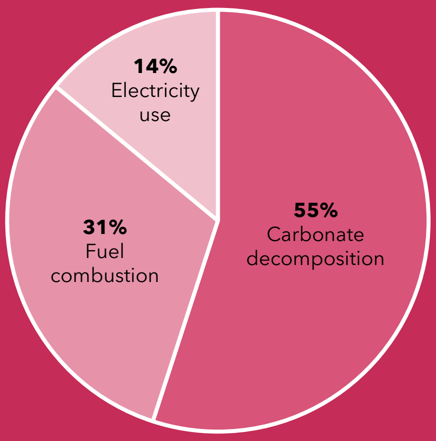
2.3 GtCO$_2$ per year[6]

6.5% of global CO$_2$ emissions[6]

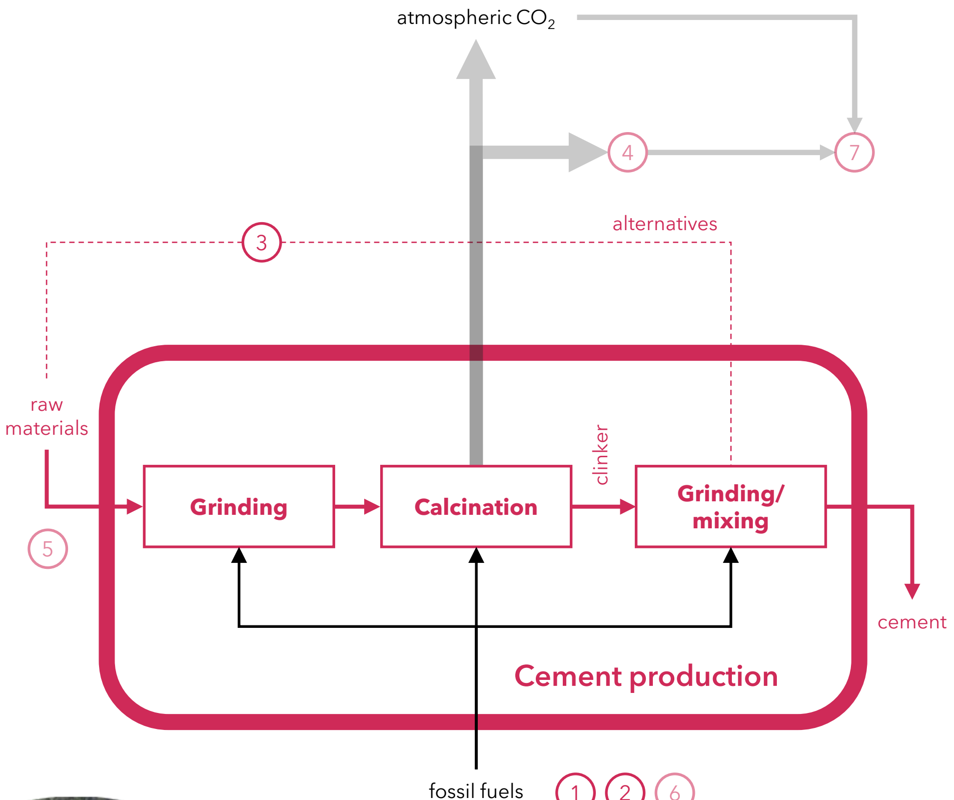
Emissions

Unlike other industries, CO$_2$ emissions from cement production are not only related to the consumption of fossil fuels. The decomposition of carbonates during the clinker manufacturing process is the main source of CO$_2$ emissions in the production process[1]. Since clinker is the main ingredient of cement, the amount of clinker used is directly proportional to the generated CO$_2$ emissions[4]. The "clinker-to-cement ratio" refers to the share of clinker in the cement by mass. This ratio normally varies between 0.5 and 0.95.

During their lifetime, cement-based materials like concrete absorb CO$_2$ from the air, though a natural and slow chemical reaction called "carbonation". The quantity of CO$_2$ absorbed depends on the composition of cement, its porosity, humidity and other factors. This phenomenon as an important impact: in average, a concrete structure can absorb as much as 16% of the CO$_2$ initially emitted during the production of clinker[7].



Emissions from cement production processes



Decarbonization levers

To decarbonize the cement industry, several already-existing action levers could be improved. These conventional levers include:

1. **Optimizing the energy efficiency** of cement plants. For example: replacing the latest wet kilns with energy efficient processes (dry process with preheater and precalciner)[8].
2. **Replacing fossil fuels** with low-carbon alternatives (waste or biomass fuels)[9].
3. **Reducing the clinker/cement ratio** by replacing clinker with substitutes (industrial by-products or calcined clay)[10].

These levers of action are, however, insufficient for a deep decarbonization of the cement industry. This is deploying new technologies is necessary, such as:

4. **CCS technologies** (carbon capture and storage, see Box)[11].
5. **Alternative clinkers and cements** with raw materials whose production emits less CO_2[12].
6. **Electrification** of production[13].
7. **Carbonation curing:** producing cement that can capture CO_2 during its curing phase[14].

Focus on CCS (carbon capture and storage)

CCS presents a high potential for reducing process emissions. This technology involves two distinct steps:

1. Carbon is **captured** before being released into the atmosphere
2. Carbon is **stored** permanently in geological formations.

Several carbon capture techniques are applicable to cement plants (see Table). None have yet gone beyond the industrial demonstrator stage and are still under development, the most mature being post-combustion by chemical absorption.

CCS projects are multiplying, mainly in the United States and Europe. The first large-scale CCS plant in the cement industry will be Heidelberg Cement's Norcem plant in Brevik, Norway, scheduled for commissioning in 2024. It will capture and liquefy 400,000 tonnes of CO2 per year which will be transported by ship and then pumped via a pipeline to offshore storage under the North Sea[15].

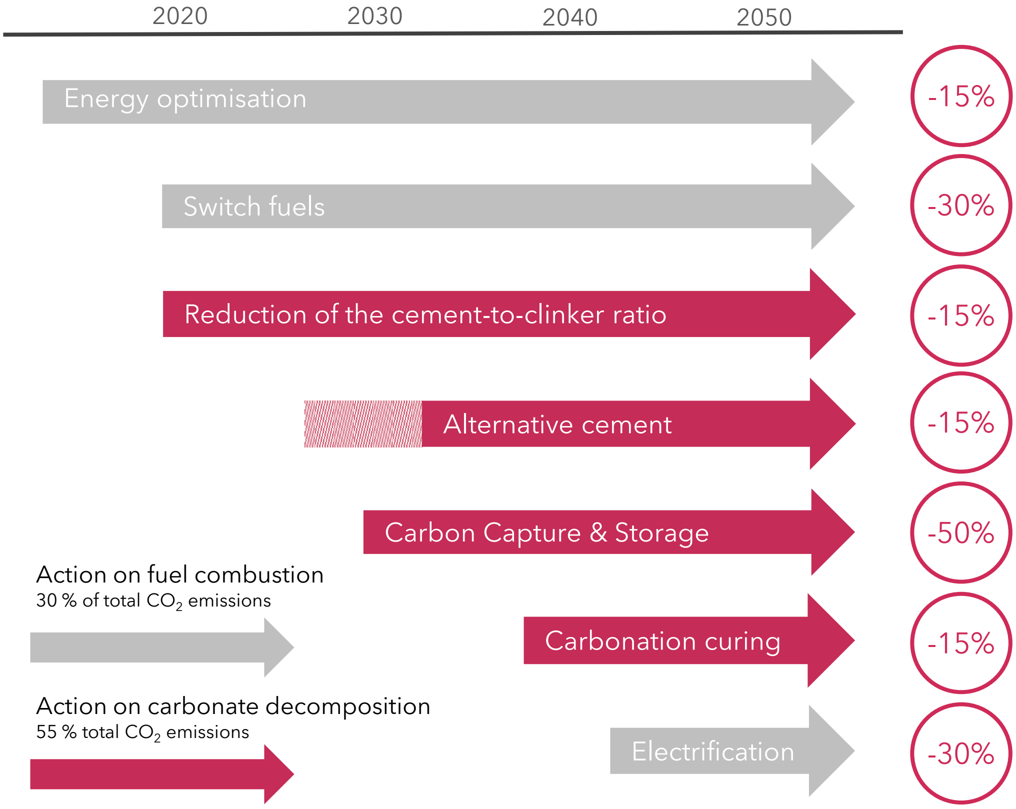
TECHNOLOGY	**Oxyfuel**[16]	**Post-combustion** chemical absorption[16]	**Post-combustion** calcium looping[16]	**Direct separation**[17]
MATURITY	TRL 5	TRL 7-8	TRL 6-7	TRL 6-7
PRINCIPLE	Combustion of fuel in a gaseous mixture and CO_2 purification.	Hot air 'washing' with a solvent to obtain a pure CO2 flow, solvent regeneration.	Fuel is burned with O_2 and $CaCO_3$, decomposed into CaO and CO_2 at high temperature (850-900°C).	Limestone is heated in a tank. In a calciner, pure CO_2 is released from limestone and captured.
+	Easier CO_2 purification, reduced fuel consumption.	End-of-line capture: no fundamental change to kiln firing.	End-of-line capture: no fundamental change to kiln firing.	No need for additional processes, no additional energy cost, no CO_2 dilution.
-	Difficult to adapt the process to existing cement plants, requires sophisticated redesigns of heat recovery systems.	High cost of solvents, produces toxic waste, excess thermal energy needed to regenerate the solvent.	High construction investments.	Heat losses in equipment and CO_2 compression (for transport and storage).
POTENTIAL (approx.)	-87% CO_2	-67% CO_2	-75% CO_2	-60% CO_2
PROJECTS	Joint research initative launched by 4 European cement companies in 2019, foreseeing the construction of a semi-industrial test facility in Germany.	Commercial scale plant (Texas, 2014), Anhui Conch pilot plant project (China, 2018), Norcem plant (Norway, 2014), Lehigh feasibility study (Canada).	Project CLEANKER: pre-commercial demonstration carried out in 2020 at a cement plant in Vernasca (Italy).	Project LEILAC, 2019: LEILAC 1 Lixhe (Belgium), LEICA 2 Hannover (Germany) Larger scale development in Germany by 2025.

Decarbonizing cement production: a roadmap

There are several decarbonization scenarios[4,6,11,18,19,20] for the cement industry that take up the various levers of action presented before. For all those levers, we compiled potentials for CO_2 reduction based on current knowledge, but several of these technologies are under development and their actual performances are still to be fully evaluated.

Percentages presented on the right side reflect the estimated potential for each single decarbonation lever, relative to the current cement industry situation. The total addition exceeds 100 %, for the complex interactions between action levers are not considered here.

Several scenarios are planning net zero emissions for cement production in 2050, using various combinations of these levers, as well as controlling demand. All of them rely on CCS to some extent, and some are based on rather strong hypotheses – such as a fully decarbonized electricity mix.



The start-up ecosystem

All the scenarios rely on CCS as the most important technological lever. Currently, CCS development is led by states and big cement companies, while start-ups are mostly focusing on innovative cement formula and materials, as shown in the illustrative selection below.

SOLIDIA
Calera
CARBON CURE

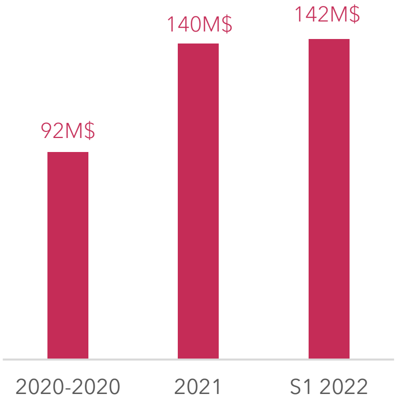
CARBON UTILIZATION & CARBONATION CURING

HOFFMANN GREEN CEMENT
Materrup
BIOMASON
FORTERA Low CO_2 Cement Inspired By Nature

CEMENT CHEMISTRY & LOW CLINKER CEMENT

BRIMSTONE

RAW MATERIALS SWITCHING



Investments

Investments in cement decarbonization are rising massively, following the general financing trends in the climate tech sector[21]. However, in 2021 these investments accountted only for 0.5% of the total funds, while cement contributes to 6.5% of CO_2 global emissions[22].

Key takeaways

► Chemical processes contribute the most to emissions during cement production, followed by the use of fossil fuels.

► Various decarbonization levers are being developed and should be deployable from now to 2040.

► CCS seems to be the most promising action, able to abate half of the current emissions.

► Current investments do not reflect the importance of cement production in global CO_2 emissions.

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1 Z. Cao et al., 2021 / 2 USGS, 2022 / 3 L. Barcelo et al., 2013 / 4 The Shift Project, 2022 / 5 GCCA, 2022 / 6 IEA, 2020 / 7 F. Xi et al., 2016 / 8 A. Cantini et al., 2021 / 9 A. Chatterjee and T. Sui, 2019 / 10 M.C.G. Juenger et al., 2019 / 11 Energy Transitions Commission, 2022 / 12 M. Antunes et al., 2021 / 13 R.M. Jacob and L.A. Tokheim, 2022 / 14 Z. Liu and W. Meng, 2021 / 15 K.O. Lie et al., 2021 / 16 C. Chen and S. Yang, 2021 / 17 T.P. Hills et al., 2017 / 18 GCCA, 2021 / 19 Cembureau, 2020 / 20 ADEME, 2022 / 21 Tensoriel / 22 HolonIQ, 2021