The cost of constructing a greener future for the cement industry

Cement production is a major CO_2 emitter, but innovative solutions can make it greener. Capturing and storing emissions is the most cost-effective way to significantly cut CO_2 – although it may not be feasible for every site. We think that combining CCS with CO_2-injections in concrete could be the winning ticket for achieving net-zero emissions

If the cement industry were a country, it'd tower above many others as the fourth largest emitter in the world – on par with Russia and trailing behind only China, the US, and India

A much-needed green revolution in cement production

Cement is an essential material in today's modern world. It builds our homes, offices, bridges, dams, roads and sidewalks. Each year, we churn out over four billion tons of cement globally from around 4,000 plants, leading to 30 billion tons of concrete, its most common application.

Cement production is, however, a major carbon culprit. It's responsible for 7% of global emissions. If the cement industry were a country, it would rank as the fourth largest emitter, on par with Russia and trailing behind only China, the US, and India.

Emissions from cement are roughly on par with those from the steel industry. This makes cement and steel the top-polluting industrial sectors. Unlike steel, where technology can fundamentally change the production process and eliminate almost all emissions, cement production is inherently CO_2-intensive. The chemical transformation of raw materials into cement emits CO_2 and there's no way around that, with these 'process emissions' making up 60% of the total. The remaining 40% comes from the high temperatures required (around 1450°C), which are typically achieved by burning coal or plastic waste.

So, what can cement companies do to cut emissions, and at what cost? Fortunately, there are solutions. They can capture and store CO_2 permanently or switch to more sustainable heating sources. We dive into these business cases in this article.

> According to the International Energy Agency, cement production is set to rise by 17% by 2050 under current policies. Even in their Net Zero Economy scenario, production levels remain close to today's, highlighting the fact that cement and concrete will continue in their current roles as important building materials.
>
> In turn, we only explore ways to green the production of cement and concrete in this article. For now, we're not delving into ways of reducing demand for cement, for example by substituting concrete by wood in buildings or to optimise the design of buildings.

CCS: The importance of Carbon Capture and Storage

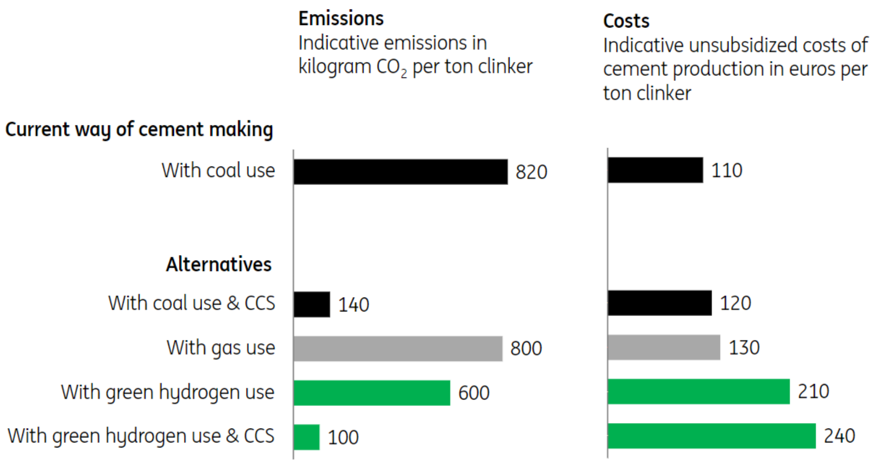
Deploying carbon capture and storage (CCS) is unavoidable without the availability of new technologies that can fundamentally change the chemical process of cement making. CCS is therefore an integral part of any decarbonisation scenario for the sector and can be applied to both the process and heating emissions.

CCS can reduce cement's emissions by about 85%

CCS can reduce cement's emissions by about 85%, based on our assumptions and calculations, which is a big achievement. Additionally, it increases the cost of cement production marginally – by about 10% in our reference case, where CO_2 can be transported through pipelines and stored within a 150 km distance. For many cement plants, CCS will be the most impactful and cost effective decarbonisation solution.

Capturing and storing CO2 emissions, along with using cleaner heating fuels, can significantly reduce emissions, though each comes with different costs

Indicative emissions and costs of clinker production



Source: ING Research

Assumptions can be found in the appendix at the bottom of the article.

Why CCS won't be a near-term solution for every cement plant

The cost of carbon capture and storage varies significantly depending on the location of the site, and cement production facilities are often widely dispersed across a country or region.

For instance, Europe has approximately 300 plants. Some of these are situated near the coast, allowing CO_2 to be transported to offshore storage sites via pipelines. Our calculations assume that CO_2 can be transported 'cheaply'. We assume transport via pipelines to an offshore storage location within a maximum distance of 150 kilometres, which is feasible for countries like Norway, the United Kingdom, and the Netherlands. Currently, CO_2 pipelines are being developed in the major industrial clusters in these countries, enabling cement plants in these areas to benefit from lower transportation costs. These sites are likely to be the first to apply CCS technology.

Many plants are located inland – far from industrial clusters with CO_2 pipelines, but near rivers, allowing CO_2 to be transported by ships. However, this method is considerably more expensive, especially for distances up to 500 kilometres. These sites can also apply CCS technology once there are ports available where ships can unload their CO_2 shipments.

Additionally, there are cement plants situated deep inland, with no feasible options for CO_2 transport via pipelines or ships, even in the future. In such cases, CO_2 could be transported by trucks, but this would further increase costs and carbon emissions as it creates many truck movements. CCS won't be applied easily or quickly on these sites.

All in all, the cost to capture, transport and permanently store a ton of carbon from cement production ranges from 50 euro to 200 euro, depending on site location and the transport mode (low cost for pipelines, high cost for ships).

Switching heating sources

Green hydrogen is powerful – but also too costly and precious

Using hydrogen as a fuel is one way to achieve the high temperatures necessary for cement manufacturing. In theory, green hydrogen could replace coal and waste as a heating source. While this wouldn't reduce process emissions (CCS is required for this), it would cut cement's overall emissions by a third since the heating process itself wouldn't emit CO_2.

> *Using green hydrogen could almost double the cost of cement production*

However, there are significant drawbacks to using green hydrogen in the cement industry. Currently, it would nearly double the cost of cement production. The technology is still untested, and there isn't enough green hydrogen available in the foreseeable future to meet the industry's vast energy demands.

Moreover, green hydrogen is an extremely valuable resource that could be more effectively used to decarbonise other sectors. In industries like steelmaking, shipping, and aviation, green hydrogen has the potential to transform carbon-intensive processes into fossil-free operations. For example, it can be used to produce synthetic fuels for ships, aeroplanes and trucks, or to eliminate coal in steel production.

These applications of green hydrogen are far more transformative than merely replacing a fossil fuel while leaving the cement-making process unchanged. Other industries are likely to pay higher prices for green hydrogen as a result. We therefore believe that hydrogen will progress quicker in other energy intensive sectors.

Small steps, big impact; marginal improvements matter

So far, we've explored the most radical solutions to reduce emissions. Fortunately, there are also smaller, incremental steps that can make a difference. While these measures may not cut emissions by tens of percentage points at each plant, their widespread application across all plants can significantly impact the sector's total emissions. Sure, they do not eliminate the need to capture and store carbon – but they do limit the extent to which CCS would be needed.

Improving energy efficiency

The process of making cement is almost unchanged from when it was first developed, except for increased energy efficiency. Traditional cement kilns have already achieved more than 60% energy efficiency and are unlikely to make significant upgrades, but on a plant level there might be room for improvement. Larger gains can be made by using the residual heat in other industrial processes, or to heat houses by building heating grids.

Using less clinker

Portland cement is the most used cement and has a clinker content of 95%. Clinker can be partially replaced by supplementary cementitious materials, like fly ash from coal power plants and blast furnace slag from steelmaking. This substitution reduces the clinker ratio, cutting down on energy use and avoiding some of the emissions inherent to clinker production. However, as the power and steel sectors in Europe move away from coal, these alternative feedstocks will become less readily available.

Co-processing biomass

Coal products and waste are the most common fuels for generating process heat in cement production. Biomass can also be used for co-firing, although fully substituting it is technically challenging due to the lower caloric value of most organic materials. Sustainably sourced biomass is considered a zero-emission fuel under current guidelines, thereby reducing the carbon footprint of cement. But here too, as with green hydrogen, biomass can add more value in greening other energy-intensive sectors. So, as we move towards a net-zero economy, we expect its use in the cement industry to be constrained by high demand in other sectors.

Applying circular economy principles

Adopting circular economy principles can significantly reduce the demand for cement. This includes optimising structural designs to use less concrete, creating infrastructure that can be easily disassembled for reuse and recycling, and substituting concrete with zero-CO_2 materials like wood. An important and interesting topic – but one that we won't dive into in this article due to its focus on greening cement production.

Greening concrete – turning cement into a carbon sink

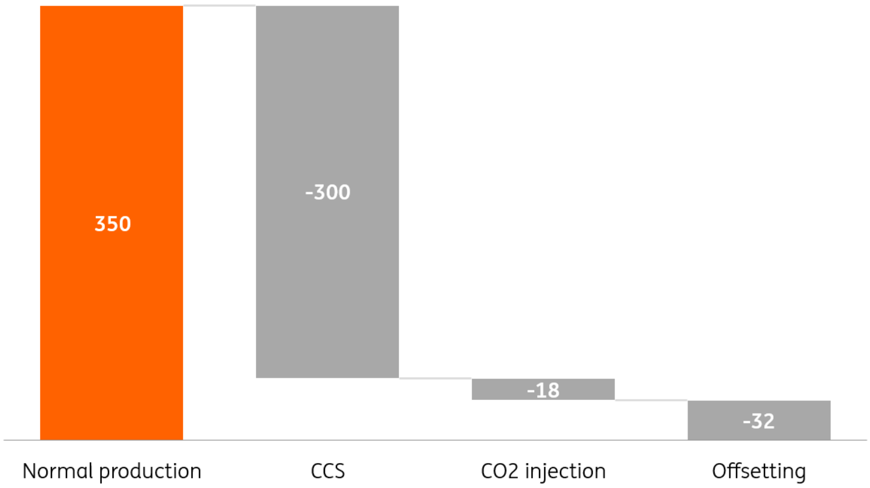
While cement's chemical reaction inherently produces CO_2, the same reaction can also be used in reverse order to store CO_2 in concrete, the main end product of cement. CO_2 injection during concrete production involves introducing captured CO_2 into the concrete mix. This chemical process permanently embeds CO_2 in the concrete.

Companies like CarbonCure are able to store up to 18 kilograms of CO_2 per cubic meter of concrete. This is still a tiny fraction of the 350 kilograms of CO_2 that comes with the use of unabated cement in concrete (depending on the type of cement and mixture of concrete, emissions range from 250 to 400 kilograms). But this figure drops to about 50 kilograms of CO_2 if the CO_2 is captured and stored during cement production.

So, CO_2 injection in concrete, together with CCS in cement production, could provide novel solutions and the possibility of carbon neutral cement and concrete in the future. The remaining emissions can be offset in voluntary carbon markets (32 kilograms of CO_2 per ton of concrete in our example).

Strategies towards carbon neutral concrete

Indicative impact of CO_2 reduction measures in kilograms CO2 per ton concrete



Source: ING Research

The cement industry has a long way to go to achieve carbon neutrality, and both CO_2 injection and CCS face significant challenges. These technologies are still in their infancy and come with high costs – that is, if they are available at all.

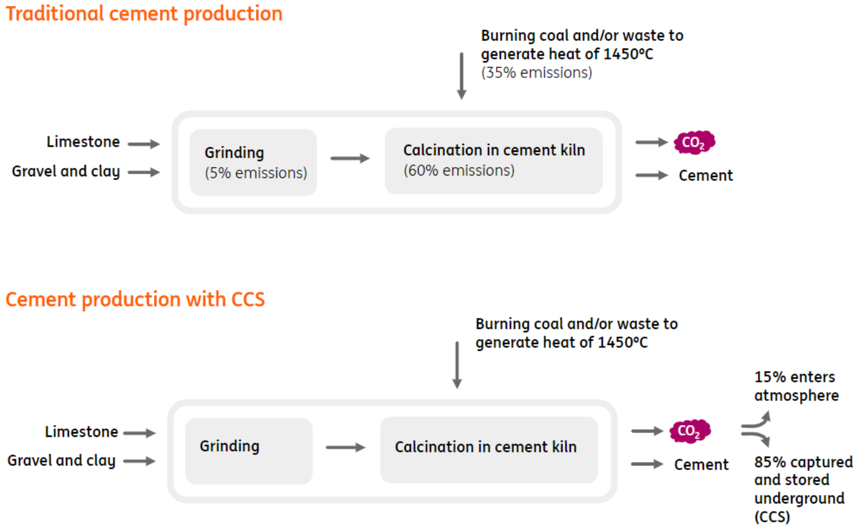
Further research and innovation in the cement supply chain will be crucial moving forward

Innovation in the cement supply chain and further research are crucial to ensure that CO_2-injected concrete meets local building codes and standards. Pilot projects can help build the business case for carbon-neutral concrete, making it scalable and cost-effective. Currently, demand isn't the issue; leading developers and investors are willing to make net zero buildings and pay a premium for it, especially in the high end markets. And policymakers need to meet their emission targets, of which cement takes a fair chunk. This puts pressure on cement producers and policymakers to green the industry site by site.

Appendix: cement's tech explainer by an economist

The production of cement begins with preparation of the raw materials – limestone, gravel and clay, where they are grinded into fine powder. Cement clinker is then produced by adding the prepared limestone into a cement kiln at a temperature around 1450 degrees Celsius. This allows for the calcination of limestone into cement and CO_2. The CO_2 is either emitted into the atmosphere or captured and permanently stored with CCS.

Cement production with and without CCS



Source: ING Research

Economic assumptions explained

Costs are calculated from a Northwestern European perspective and based on many economic and chemical assumptions. We list our main economic assumptions here: a gas price of €35/MWh, a power price of €85/MWh, a carbon price of €65/ton with full carbon pricing (no free allowances), and a coal price of €110/ton.

We have applied technology costs of €21/ton/year for a cement kiln that runs 95% of the time (capacity factor). CO_2 is captured and transported through pipelines over 150 kilometres to be permanently stored in an offshore empty oil or gas field. We've assumed the total cost to capture, transport and store CO_2 of €100/ton and the CCS capture rate is set at 85%.

We apply a Western-made alkaline electrolyser that costs around 1,000€/kW and runs with an efficiency of 70% and capacity rate of 70%. This results in green hydrogen costs around €5/kg at a power prices of €85/MWh.

In practice, all these input variables show considerable variation which yields a wide range of outcomes for every technology. We have chosen to present point estimates as they often capture the main insights better than wide ranges. Treat these numbers as indicative outcomes around which real time projects will vary.

This note is part of an ongoing series based around the greening of hard-to-abate sectors. Please find our other updates on the steel, plastics, aviation and shipping industries here.

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