PRODUCING CEMENT WITHOUT EMITTING CO_2

The production of cement inevitably produces carbon dioxide. To ensure that this gas does not fuel climate change, it must be captured and then reused or disposed of. In the future, cement producers want to use the so-called oxyfuel process, among other technologies, to capture CO_2. To accelerate a market launch, an international consortium with the participation of the cement group Holcim has developed key components for oxyfuel combustion cement plants.

Holcim cement plant in Siggenthal, Switzerland, not far from Baden in the canton of Aargau. Photo: Holcim

According to the Swiss industry association BETONSUISSE, cement is the most widely used material in the world. Cement is a key component of concrete and therefore indispensable for the construction of stable structures. The downside: Cement production produces the greenhouse gas CO_2. The cement industry is the second largest industrial source of CO_2 emissions after the steel industry. In Europe, cement production is responsible for around a quarter of CO_2 emissions from the industrial sector. This figure also applies to the six cement factories in Switzerland. They were responsible for 2.41 out of 9.64 million metric tons of CO_{2eq} in 2022.

The process of cement production requires high temperatures and a correspondingly large amount of energy, which has so far mostly come from fossil fuels. CO_2 emissions can be reduced by replacing coal, oil and natural gas with alternative fuels for heat generation that cause no or at least fewer greenhouse gases. The Swiss cement industry in particular has already made considerable efforts in this direction. Al-

A technical report about the results of a pilot and demonstration project in the field of CCUS / NET, which is financially supported by the Swiss Federal Office of Energy. The report has been published in the technical magazine Schweizer Wirtschaft (issue August 2024).

CEMENT PLANT WITH OXYFUEL COMBUSTION

The production of cement clinker – the main component of cement – is a multi-stage process consisting of drying, preheating, calcination and sintering. Calcination is the process step in which the CO_2 is removed from the raw material. In this process, ground limestone is heated together with other substances to approx. 900 °C (in modern plants, a calciner embedded in a tower is used for this step).

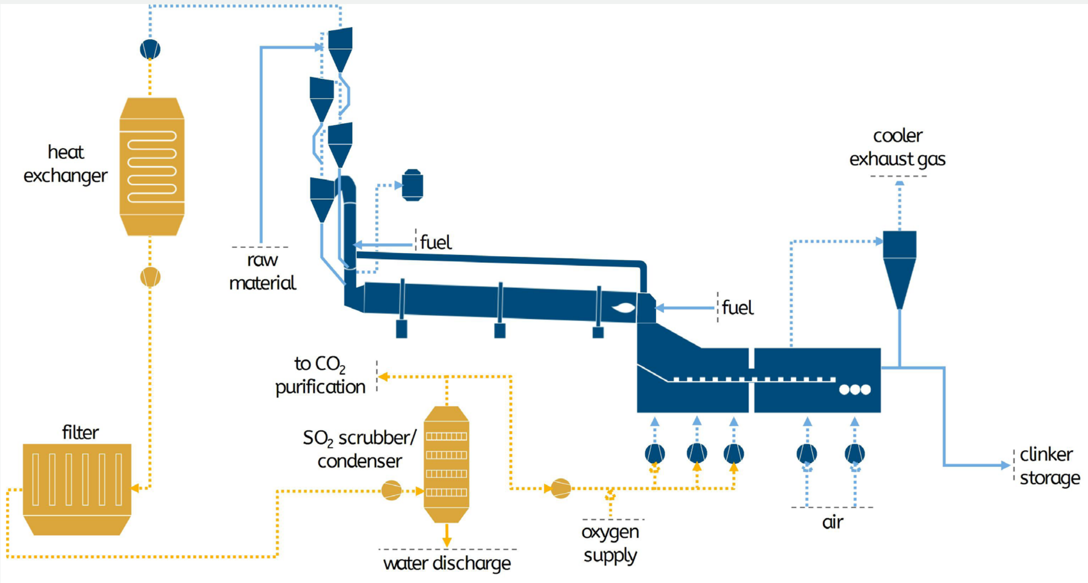


Illustration: ThyssenKrupp Polysius

In 1st generation plants that use oxyfuel combustion, oxygen is added to the process and the CO_2 produced during calcination is partly recycled (shown in yellow in the illustration) and also partly processed in such a way that it can be reused or landfilled. The recirculated, CO_2-enriched flue gas replaces the nitrogen in the combustion air. The remaining exhaust gas is cooled in a heat exchanger for CO_2 purification, particles are then filtered out of the gas and sulfur dioxide (SO_2) and steam are removed.

The oxyfuel combustion process in 2nd generation plants does not recycle the flue gases. Instead, more oxygen is added to the combustion process (over stoichiometric combustion).

ternative fuels account for 67% of the Swiss industry's energy use and thus it is in a better position than many cement plants in other countries.

Unavoidable source of CO_2

The crux: Even if the heat required for cement production is generated entirely from fossil-free fuels, a cement plant still emits considerable amounts of CO_2. This is due to so-called calcination, an important process step in the production of cement clinker, the main component of cement. In this process, finely ground limestone (calcium carbonate/$CaCO_3$) is heated to 900 °C with other substances, whereby the CO_2 contained in it is released, and then burned at 1450 °C to form cement clinker. The CO_2 released accounts for 15 to 20% of the total exhaust gas.

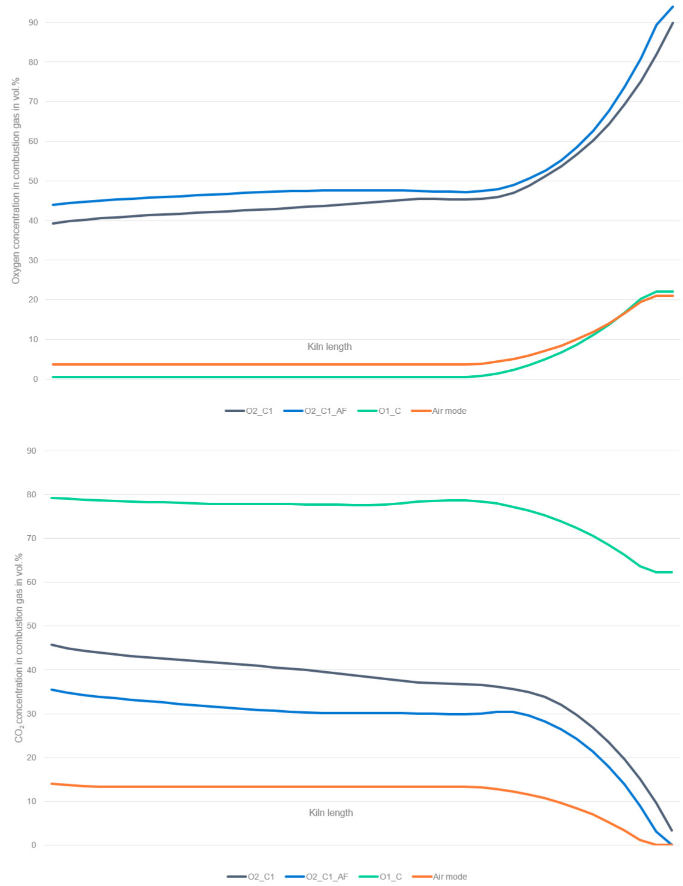
The formation of CO_2 during calcination is unavoidable. To prevent the release of CO_2 gas into the environment, there is only one alternative: The greenhouse gas must be collected at the source and then recycled as a raw material or deposited in a suitable storage facility. This is called Carbon Capture and Storage (CCS), or Carbon Capture, Utilization and Storage (CCUS) when the aim is to recycle CO_2. The CO_2-enriched gas typically must be processed to a specific quality before transport, storage or reuse. This processing may include filtering, water condensation and/or desulfurization. The higher the CO_2 content in the starting material, the less complex this purification step is.

Extraction of CO_2 that is as pure as possible from the exhaust gas stream of calcination is possible in various ways. It works particularly well when so-called oxyfuel combustion is used for calcination. In this process, it is not air (a mixture of nitrogen, oxygen and other gases) that is used for calcination, but pure oxygen. This trick produces an exhaust gas with a CO_2 content of 80 to 90 % (compared to 15 to 20 % in the conventional production of cement clinker). The CO_2-rich exhaust gas is then cooled, cleaned of other gases and water vapor and finally liquefied. This does not eliminate the greenhouse gas, but it can be reused as a raw material (for plastic production or for building materials, for example) or deposited in a suitable storage facility.

International research project

In order to accelerate the application of the oxyfuel process in cement production, 11 academic and industrial partners from five European countries (Germany, France, Greece, Norway, Switzerland) founded a consortium in 2019 under the acronym AC2OCem. On the Swiss side, the international cement group Holcim is involved. The five-year project was funded by the EUs ACT program, which promotes CCS technology. The Swiss Federal Office of Energy supported the research network from its pilot and demonstration program.

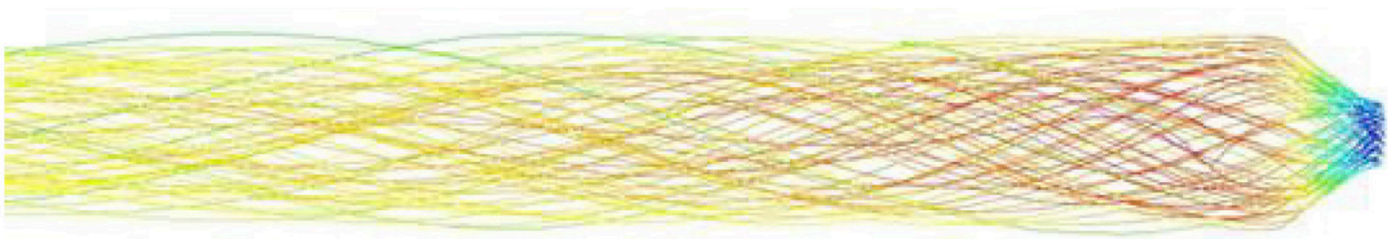
As part of the project, oxyfuel combustion experiments were carried out at a pilot plant at the University of Stuttgart using 100% alternative fuels. Among other things, researchers gained a better understanding of the process, including the separation of water vapor. “The results from the project have confirmed that oxyfuel combustion is one of the most promising CCUS solutions,” says Holcim project manager Mirko Weber. Holcim wants to use the technology to convert the cement plants in Lägerdorf, north of Hamburg and Obourg in Belgium to “net zero” by 2028/29 – the plants will no longer emit any CO_2 gas into the environment.



O_2 concentration (top graphic) and CO_2 concentration (bottom graphic) in the combustion gas of the kiln. Orange: conventional combustion with air. Green: 1st generation oxyfuel process. Black and blue: two versions of the 2nd generation oxyfuel process. The left side of the diagram shows the material inlet into the rotary kiln, the right side the burner area. Illustration: Verein Deutscher Zementwerke (VDZ)

For retrofitting and new systems

Oxyfuel technology can be used to retrofit existing calcination plants (1st generation) or to build new plants (2nd generation). The two generations use different process management systems. For example, in the 1st generation, the flue gas is partially returned to the combustion chamber, but not in 2nd generation plants (see text box p. 2). According to the simulations created in the AC2OCem project, retrofitting 1st generation plants achieves a CO2 concentration of 80% in the exhaust gas stream, 2nd generation plants around 90%. As part of the AC2OCem project, both methods were investigated with simulations and experiments. In addition, a



Computational Fluid Dynamics simulation of the rotary kiln of a clinker production process: The recycled exhaust gas flow mixed with oxygen is fed into the combustion chamber (oxyfuel process of the 1st generation). The fluid flow lines of the CO_2-enriched flue gases are colored according to temperature. Illustration: Sintef guideline for the retrofitting of existing systems has been developed. A new kiln burner was also developed for the 2nd generation and tested in practice.

However, many technical challenges remain before oxyfuel technology can be developed to a point where it can be applied. For example, additional treatment is required to extract the CO_2 from the exhaust gas stream. To do this, steam, nitrogen oxides and sulfur dioxide must be removed from the exhaust gas.

P+D PROJECT OF SFOE

The project presented in the main text was supported by the pilot and demonstration program of the Swiss Federal Office of Energy (SFOE). With this program, the SFOE promotes the development and testing of innovative technologies, solutions and approaches that make a significant contribution to energy efficiency or the use of renewable energies. Applications for financial aid can be submitted at any time.

Additional costs and higher energy consumption

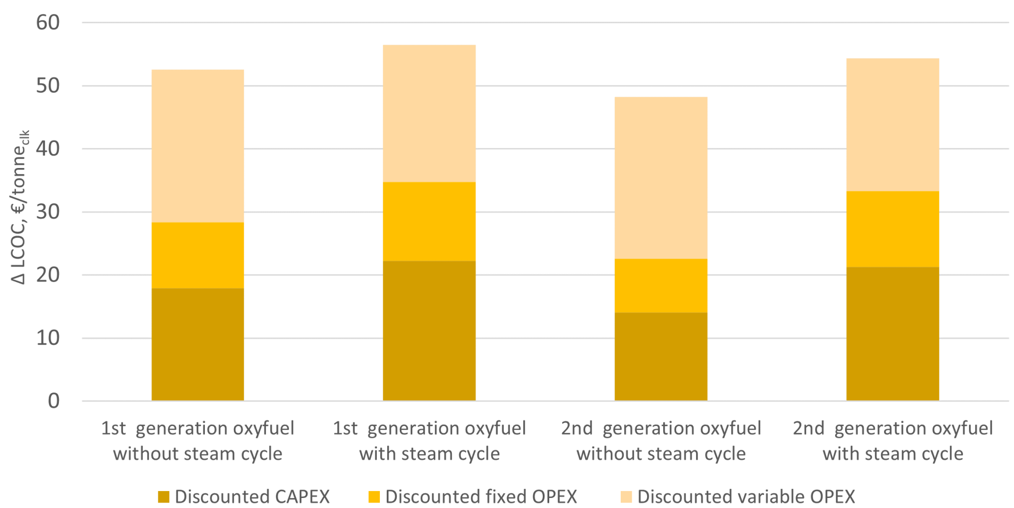
Oxyfuel technology offers a comparatively cost-effective solution for CO_2 capture. The AC2OCem project included estimating the cost of retrofitting two existing cement plants in Germany and Sweden. According to the study, additional costs of €49 to €63 euros per metric ton of cement clinker (excluding transport and storage of CO_2) is be expected – more expensive than the amount calculated by the EU-funded Cemcap study (2015 - 2018). In this regard, the AC2OCem final report states: "The higher costs are due to a better understanding of the complexity of modifying existing plants, higher investment costs for the CO_2 purification unit, more realistic expectations won through the application of existing plants, generally higher costs for raw materials, and an expanded scope through the inclusion of pipelines and CO_2 buffer tanks."

If oxyfuel technology is installed in a new cement plant, the costs are somewhat lower than for retrofitting existing plants. An important influencing factor is energy costs, because CO_2 capture requires a lot of electricity: A cement plant with oxyfuel carbon capture of the 2nd generation requires around four times more electricity than a conventional cement plant (33 compared to 8 MW). Holcim is working towards optimizing the costs of CCUS, but is also relying on support from grants such as the EU Innovation Fund.

Demonstration plant planned

By 2030, Holcim aims to produce 8 million tons of decarbonized cement worldwide each year. By comparison, the six Swiss cement plants have a production capacity of 5 million metric tons per year. Holcim relies on various CO_2 capture processes for decarbonization, including the oxyfuel process. Based on the results of the AC2OCem project, large-scale pilot plants for CO_2 capture using the oxy-fuel process should pave the way to market maturity. Corresponding plants are to be built in Lägerdorf, Germany and Obourg, Belgium. The plants will be converted to oxyfuel technology in a second step.

↗ Further information on the **project AC2OCem** is available at: https://www.eu-projects.de/ac2ocem/



Higher clinker costs in the four cases examined compared to the reference plant without CCS. Illustration: Sintef

Researchers of the AC2OCem project at a workshop in spring 2023. Photo: VDZ

- The SFOE's **final report** on the project "Accelerating Carbon Capture using Oxyfuel Technology in Cement Production" (AC2OCem) is available at: www.aramis.admin.ch/Texte/?ProjectID=44216

- **Information** on this topic can be obtained from Men Wirz (men.wirz@bfe.admin.ch), head of the SFOE's pilot and demonstration program.

- Further **technical articles** on research, pilot, demonstration and flagship projects in the field of CCUS / NET can be found at www.bfe.admin.ch/ec-ccus-net.

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