
Carbon dioxide capture — Overview of carbon dioxide capture technologies in the cement industry

*Captage du dioxyde de carbone — Vue d'ensemble des technologies de
captage du dioxyde de carbone dans l'industrie du ciment*

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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This document was prepared by Technical Committee ISO/TC 265, *Carbon dioxide capture, transportation, and geological storage*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Concrete is the most-used manufactured substance on the planet in terms of volume. For example, it is used to build homes, schools, hospitals, workplaces, roads, railways and ports, and to create infrastructure to provide clean water, sanitation and energy. These are important for quality of life, public health, and social and economic well-being.

Raw materials for concrete are abundant and available in most parts of the world. Concrete is affordable, strong, durable and resilient to fire, floods and pests. It has the flexibility to produce complex and massive structures. There is currently no other material that is available in the quantities necessary to meet the demand for buildings and infrastructure.

Cement is used to manufacture concrete. It is described as the glue that binds the aggregates together. The demand for concrete, and therefore for cement, is expected to increase, by 12 % to 23 % by 2050 compared to 2014, as economies continue to grow, especially in Asia.

Increasing global population, urbanisation patterns and infrastructure development will increase global cement production. The use of concrete and cement is expected to become more efficient, and concrete pours at the application phase are expected to decrease. The cement sector faces the challenge of meeting an increasing demand for its product while cutting direct CO₂ emissions from its production [2]. The cement industry is a large emitter of CO₂ worldwide. The industry is committed to reduce their carbon footprint to meet the targets of the 'Paris Agreement' on climate change.

Process emissions arising from the production of cement clinker present a fundamental challenge to decarbonization of cement. In normal cement production processes, these process emissions are in the range of 500 kg CO₂/tonne clinker to 540 kg CO₂/tonne clinker^[1], corresponding to 250 kg CO₂ to 500 kg CO₂ per tonne of cement depending on the type of cement. Replacement of limestone as raw materials with alternative raw materials with lower carbonate content can reduce these process emissions, but availability of these alternatives is limited, and the replacement potential is also limited (depending on required cement qualities).

Combustion emissions are another contributor to CO₂ emissions in addition to the process emissions. Replacement of carbon-based fuels by non carbon-based energy sources and thermal energy from biomass sources (being considered as CO₂ neutral) will contribute to lowering the carbon intensity of the energy supply for the cement industry in the future.

One way to reduce CO₂ emissions is capturing CO₂ that is released in the production of cement (both direct emissions during the production process and emissions related to local energy production). CO₂ capture is an emerging approach for CO₂ abatement in the cement industry. It means that CO₂ arising from the combustion of fuels and from the treatment of raw materials could be captured and permanently stored or re-used. The integration of CO₂ capture equipment typically increases the specific energy intensity of cement manufacture, as additional energy is needed to operate the CO₂ capture plant, followed by drying, purification and compression of the captured CO₂ for transportation, (geological) storage and/or utilization^[2]. CO₂ transportation, (geological) storage and utilization are beyond the scope this document.

To date, no large-scale CO₂ capturing technologies have been installed in the cement industry. However, different technologies are under development to support the cement industry in achieving their objectives. Various cement companies participate in one or more research, development and/or demonstration projects in the field of CO₂ capture. These projects provide useful information about the application of the various technologies in the cement industry.

To facilitate the assessment and comparison of the different CO₂ capturing technologies, this document summarizes these technologies that are currently under development. This summary supplements and updates the information provided in ISO/TR 27912:2016, Clause 10 on capture from cement production processes. This document will inform the cement industry and their stakeholders on CO₂ capture technology options and other relevant aspects.

CO₂ capture will be an item of interest for all cement producers in the years to come^[5]. Currently, about 2 000 cement plants with relevant CO₂ emissions are operating worldwide^[14] with the majority of these plants being located in Asia. CO₂ capture implementation in the cement industry at global level would need a transport and storage infrastructure to facilitate the decarbonization of cement plants not located close to a geological storage facility or CO₂ use facility. Together with the investments in CO₂ capture facilities, this will be a major cost factor for the cement industry.

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Carbon dioxide capture — Overview of carbon dioxide capture technologies in the cement industry

1 Scope

This document provides an overview of technologies that are under development to capture carbon dioxide (CO₂) that is generated during cement manufacture.

This document is intended to inform users about the different technologies, including the characteristics, the maturity and the boundaries of these technologies.

This document is applicable to organizations involved in the cement industry and other stakeholders (e.g. policy makers).

This document addresses technologies for CO₂ capture that have potential applications in the cement industry. This document does not address CO₂ transport, CO₂ storage or CO₂ utilization.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 27917, *Carbon dioxide capture, transportation and geological storage — Vocabulary — Cross cutting terms*

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3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 27917 apply.

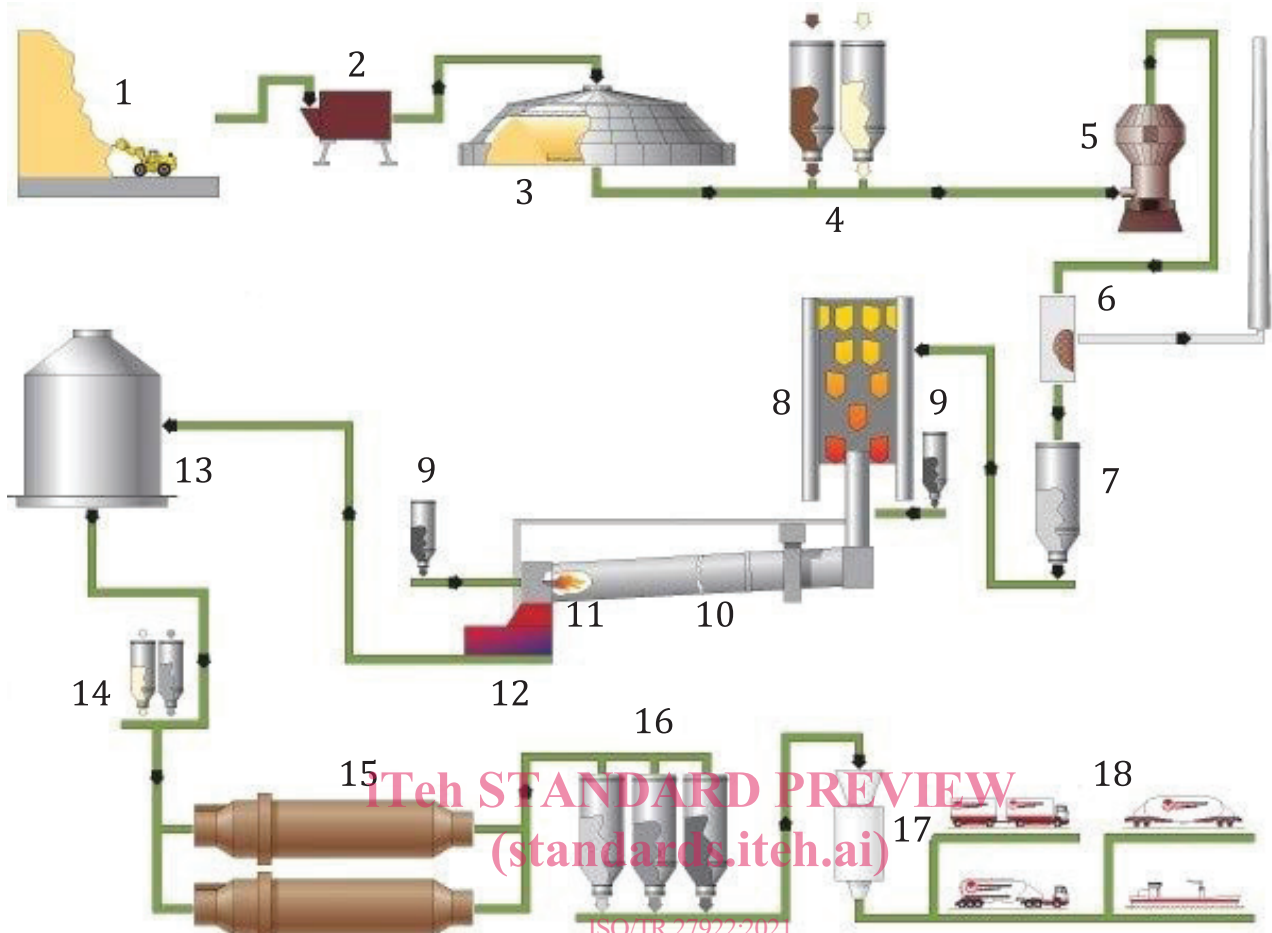
ISO and IEC maintain terminological databases for use in standardization at the following addresses:

- ISO Online browsing platform: available at <https://www.iso.org/obp>
- IEC Electropedia: available at <http://www.electropedia.org/>

4 CO₂ and the cement industry

4.1 Cement manufacture

Cement manufacture is a three-stage process: raw materials preparation, clinker production and clinker grinding with other components to produce cement. [Figure 1](#) illustrates the process of manufacturing cement. Different raw materials are mixed and milled into a homogeneous powder, from which clinker is produced in high-temperature kilns where direct emissions of CO₂ occur. Calcium oxide from the calcination of limestone is a precursor to the formation of calcium silicates that gives cement its strength^[Z].



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Key

- | | |
|--|--|
| 1 quarrying raw materials | 10 kiln |
| 2 crushing limestone | 11 calcination-burning raw meal to clinker |
| 3 storage and pre-homogenization of raw material | 12 cooling |
| 4 other raw materials | 13 clinker storage |
| 5 raw mill | 14 secondary additives |
| 6 filter and chimney | 15 cement mills |
| 7 raw meal homogenization | 16 cement storage |
| 8 preheating | 17 cement dispatch |
| 9 pulverized coal | 18 transportation by bulk or bags |

Figure 1 — Cement manufacture^[17]

Clinker is ground together with gypsum to produce cement. Depending on the required technical properties of the finished cement, other components, including fly ash, ground granulated blast furnace slag and fine limestone, can also be ground together with clinker or blended to produce different cement types. Cement can be produced at the kiln site, or at separate grinding or blending plants. Blended cements or “combinations” can also be produced at the concrete plant. The cement making process is complex – it requires control of the chemical formulation and involves multiple steps that require specialised equipment^[2].

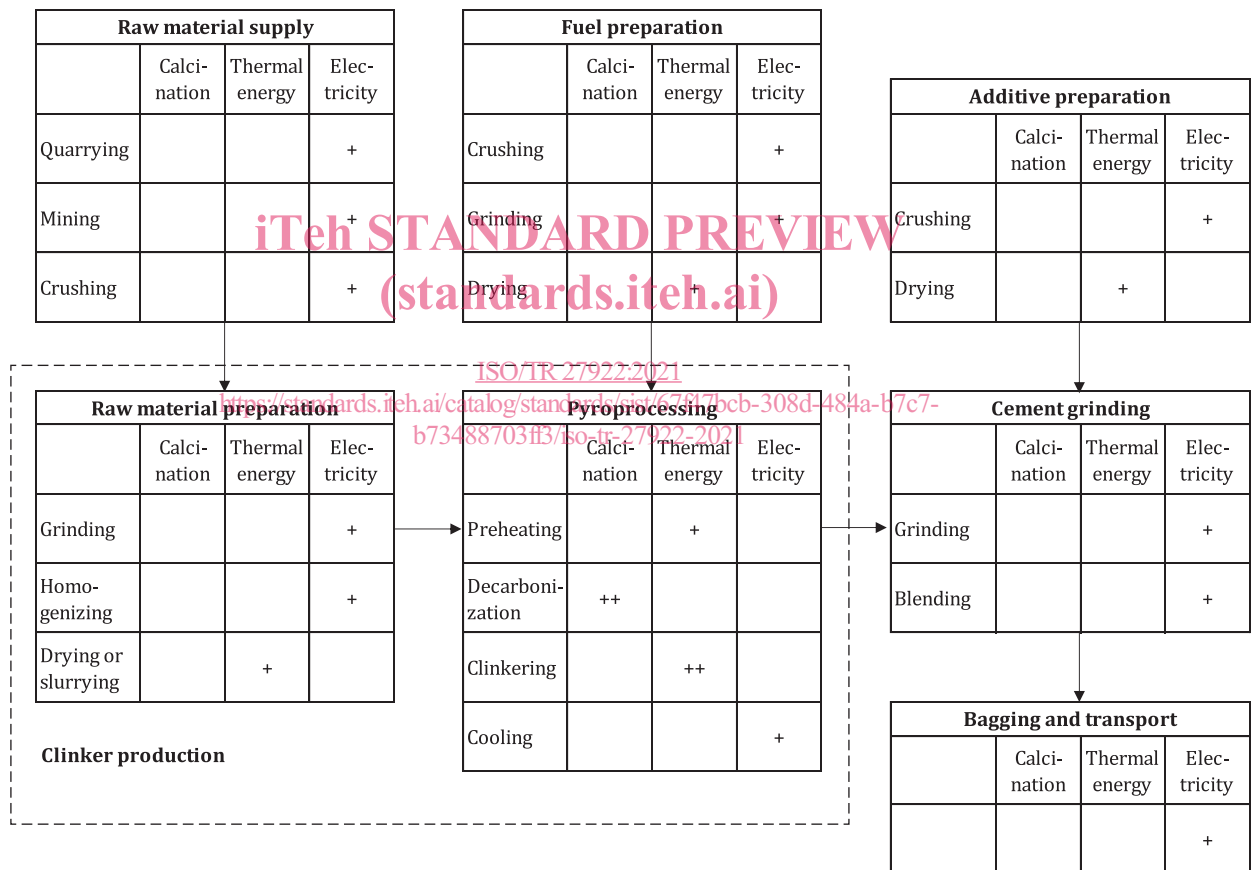
4.2 CO₂ emissions from the cement industry

4.2.1 Production process description

Figure 2 schematically shows the process steps of cement manufacture. There are two main sources of direct CO₂ emissions in the production process of cement:

- calcination of raw materials in the pyro-processing stage (60 % to 70 % of direct CO₂ emissions resulting from the chemical breakdown of limestone when it is heated to high temperature); and
- combustion of kiln fuels (30 % to 40 % of direct CO₂ emissions).

Flue gas in the cement industry has a relatively high CO₂ content (typically 20 % to about 30 % CO₂). Other CO₂ sources include direct greenhouse gas (GHG) emissions from non-kiln fuels (e.g. dryers for cement constituents products, room heating, on-site transport and on-site power generation), and indirect GHG emissions from e.g. external power production and transport. Apart from methane (CH₄) and nitrous oxide (N₂O), emissions of non-CO₂ greenhouse gases are negligible^[1].



Key

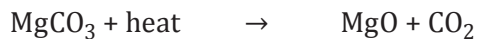
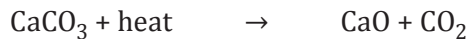
++ major CO₂ emission source

+ minor CO₂ emission source

Figure 2 — Process steps in cement manufacture with indication of CO₂ emission sources^[1]

4.2.2 Process emissions from calcination

In the clinker production process, CO₂ is released from the chemical decomposition of calcium carbonates, magnesium carbonates and other carbonates (e.g. from limestone) into lime by heating up the raw materials to above 900 °C:



This process is called "calcining" or "calcination". It results in direct CO₂ emissions through the kiln stack^[1].

4.2.3 Combustion emissions

The cement industry traditionally uses various fossil fuels to operate cement kilns, including coal, petroleum coke, fuel oil, and natural gas. Fuels derived from waste materials have become important substitutes for traditional fossil fuels. These alternative fuels include fossil fuel-derived fractions such as waste oil and plastics, as well as biomass-derived fractions such as waste wood and dewatered sludge from wastewater treatment. Furthermore, fuels which contain both fossil and biogenic carbon (mixed fuels) are increasingly used. Examples are (pre-treated) municipal and (pre-treated) industrial wastes (containing plastics, textiles, paper, etc.) or waste tyres (containing natural rubber and synthetic rubber)^[1].

4.2.4 Emissions compared to other sectors

Due to the nature of the production process (combustion, calcination for limestone and the drying of raw materials), the exhaust gas of a typical cement plant is significantly different from other production processes (e.g. thermal power generation). This difference is characterized by the cement exhaust gas conditions, such as flue gas composition, temperature, and dust and moisture content. Consequently, (standard) CO₂ capture technologies are not necessarily applicable in the cement industry.

4.3 CO₂ purification after capture (standards.iteh.ai)

For CO₂ transport, CO₂ storage and/or CO₂ utilization, purity levels above 96 % CO₂ are recommended. Different approaches are available to increase the CO₂-product purity level. A common approach is to add extra adsorption stages with recycling of the low-grade side stream. High-pressure flash separation can reduce investment and/or energy use. High-pressure flash separation can be attractive, as the produced CO₂ flow will be compressed before transport. Similarly, separation by low-temperature liquefaction of CO₂ can be attractive, as the product can be in a liquid state which is suitable for transport by ship or can easily be compressed with low energy penalty. Purification of the captured CO₂ is not specifically addressed in this document.

4.4 Abatement technologies in general

For decades, several CO₂ emission abatement technologies and measures have been used in the cement industry to reduce the process and combustion emissions. They generally fall into four categories^[2]:

- a) Improving energy efficiency: deploying existing state-of-the-art technologies in new cement plants and retrofitting existing facilities to improve energy performance levels when economically viable.
- b) Switching to alternative fuels (fuels that are less carbon intensive than conventional fuels): promoting the use of biomass and waste materials as fuels in cement kilns to offset the consumption of fossil fuels. Utilizing wastes, including biogenic and non-biogenic waste sources, which would otherwise be sent to a landfill site, burnt in incinerators or improperly destroyed.
- c) Reducing the clinker to cement ratio: increasing the use of blended materials and the market deployment of blended cements, to decrease the amount of clinker required per tonne of cement or per cubic metre of concrete produced.
- d) Using emerging and innovative technologies that:
 - contribute to the decarbonisation of electricity generation by adopting waste heat recovery technologies to generate electricity from recovered thermal energy, which would otherwise be

lost, and support the adoption of renewable-based power generation technologies, such as solar thermal power;

- integrate carbon dioxide capture into the cement manufacturing process for long-lasting or permanent storage;
- integrate carbon dioxide capture and re-use for new products, including recarbonation of concrete and mineralisation of (recycled) aggregates.

The CO₂ emissions reduction impact of these levers is not always additive since they individually affect the potential for emissions reductions of other options. For instance, the use of alternative fuels generally requires greater specific thermal energy and electricity due to their higher moisture content than fossil fuels, the operation of the kiln with increased input of ambient air compared to conventional fossil fuels and the pre-treatment of alternative fuels^[Z].

5 Overview of CO₂ capture technologies

5.1 Absorption with amines

The principle of post-combustion technologies is the separation of CO₂ from flue gases after combustion. Flue gases are normally at atmospheric pressure and high temperatures. CO₂ is removed from a mixture of primarily nitrogen, oxygen and water with flue gas impurities such as SO_x, NO_x and particulates.

Gas separation by absorption relies on the principle that CO₂ can be selectively, and reversibly, removed from the flue gas with a chemically reactive liquid in an absorption column. The CO₂-rich flow is then transferred to a desorption column/stripper and heated up to release the CO₂. The released CO₂ is dried, purified and compressed while the regenerated absorbent is cooled and returned to the absorption column. A schematic representation of the absorptive CO₂ capture is shown in [Figure 3](#).

In chemical absorption post-combustion capture, aqueous amine solutions are often used to chemically bond CO₂ to the amines. Absorption liquids based on monoethanolamine (MEA) are first generation and still widely used for CO₂ separation having high selectivity, fast reaction rates and low cost. MEA has a thermal energy requirement for regeneration of absorbent of at least 3 MJ/kgCO₂^[6]. In cement plants, the thermal energy is provided via waste heat recovery and/or an external unit. Equipment corrosion when using MEA solutions is an issue as well as oxidative degradation. Amine-based post-combustion processes require a prior clean-up (desulfurization and denitrification) as amines will react with SO_x and NO_x. These aspects increase the plant footprint as well as the capital and operating costs. Reported MEA requirements are between 0,5 kg MEA/tonne CO₂ and 3,1 kg MEA/tonne CO₂^[21].

Improved amine solutions, e.g. based on sterically hindered amines and amino acid salts, which require a lower regeneration temperature, are non-corrosive to carbon steel at 130 °C in the presence of oxygen and have a better resistance to degradation, and are also commercially available.