Evolving the well-established

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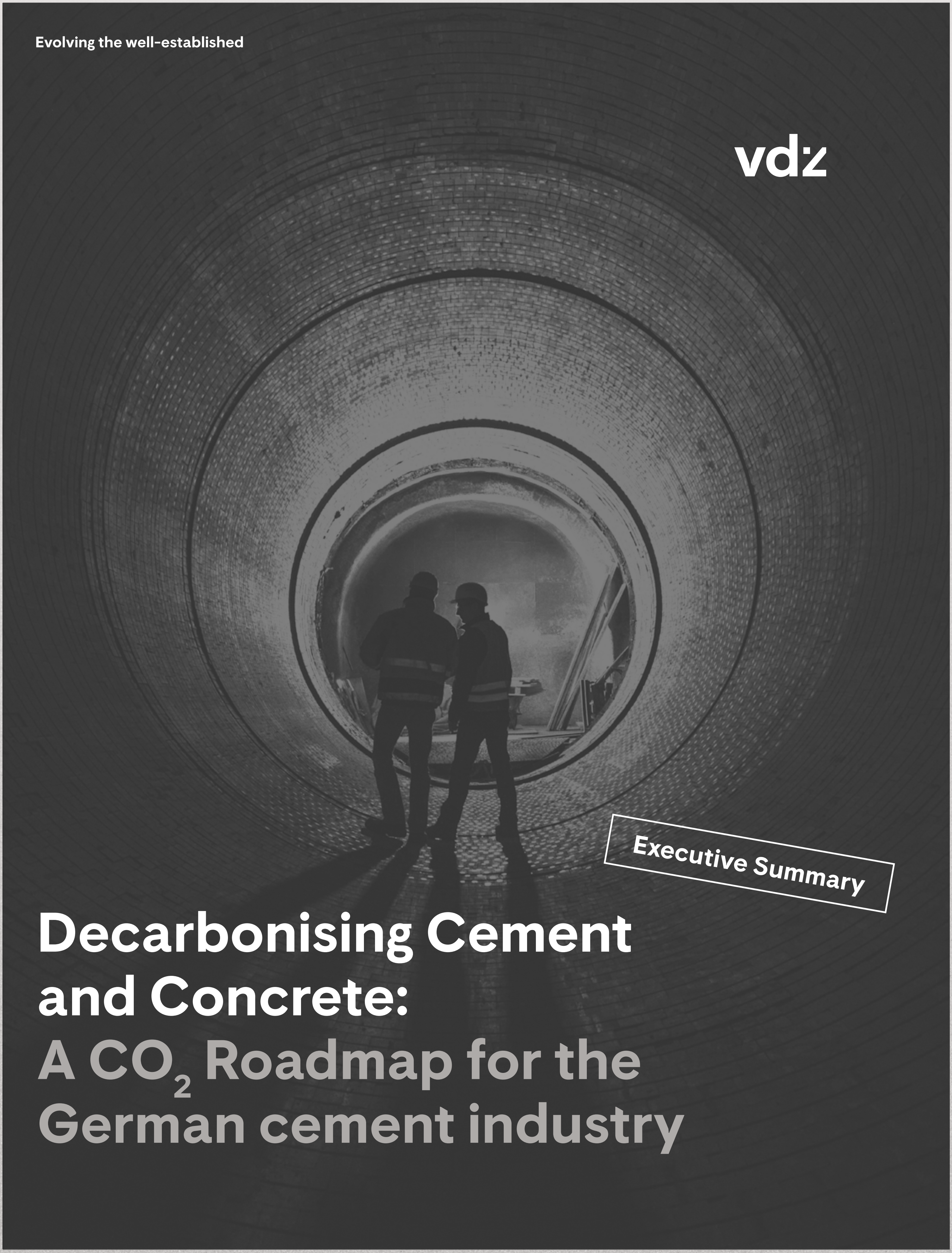

Executive Summary

Decarbonising Cement and Concrete: A CO_2 Roadmap for the German cement industry

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Achieving net zero emissions: Challenges and opportunities for the cement sector

There are major challenges which the cement industry in Germany and the entire cement and concrete value chain is facing in their quest for climate neutrality. This is due to the fact that large quantities of CO_2 are released in the production of cement and its preliminary product, cement clinker. Approximately two thirds of this can be attributed to raw material-induced process emissions from limestone calcination, whilst energy-related CO_2 emissions from the fuels used account for roughly one third.

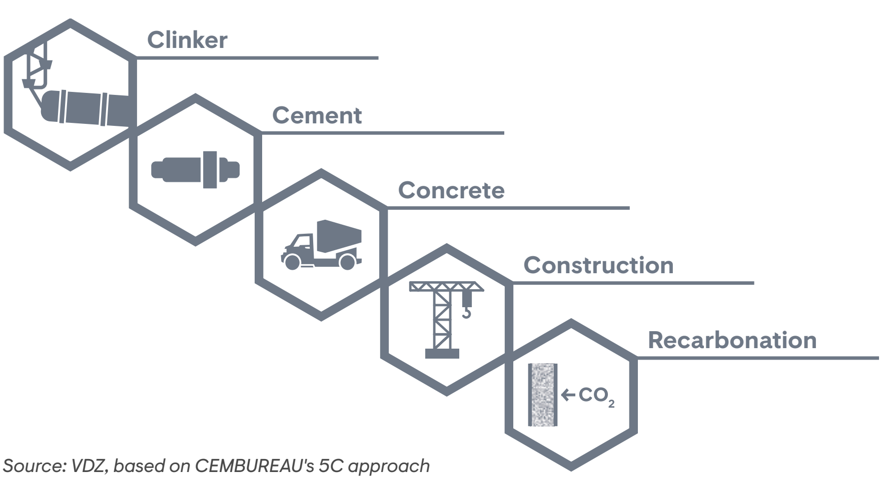
Since 1990 German cement manufacturers have managed to reduce CO_2 emissions by 20 - 25% in both specific and absolute terms. Alongside improvements in the area of thermal efficiency, two factors in particular have been crucial to achieving this success: Firstly, a reduction in the clinker content in cement, and secondly, the increased use of alternative fuels containing biomass as a substitute for the majority of fossil energy sources.

The cement industry is however reaching the limits of its potential to further reduce CO_2 emissions, as in particular the process-related CO_2 emissions associated with clinker production cannot be lowered by employing conventional means. In addition to partly new CO_2-efficient raw materials for the production of clinker and cement and alongside innovations in concrete manufacturing and construction, efforts to fully decarbonise the sector will rely heavily on carbon capture at the cement plant and its subsequent utilisation and storage (CCUS).

The cement industry in Germany is well aware of the responsibility it has to take on with regard to the decarbonisation of cement and concrete. At the same time it is clear that the industry cannot achieve this alone. It will require the cooperation of the entire value chain, from equipment suppliers and concrete manufacturers through to the building industry, designers and architects. A further prerequisite is an effective policy framework which will ensure a level playing field to allow the competitive production of low-carbon and successively decarbonised cements and concretes in Germany. At the same time it is necessary to promote markets for “green” products, taking into account that these tend to be considerably more expensive than those produced conventionally.

From a technical point of view it will only be possible to successfully master this transformation with the necessary infrastructure, for example for widespread carbon-free power consumption and the transportation of CO_2 and hydrogen. Ultimately, both the local population and society as a whole will also have to be engaged in this process at an early stage in order to create a common understanding of the technological and economic changes involved to ensure the successful decarbonisation of the industry and the achievement of a climate-neutral society.

Fig. 1: CO_2 reduction along the value chain



Source: VDZ, based on CEMBUREAU's 5C approach

Decarbonisation of cement and concrete: Scenarios up to the year 2050

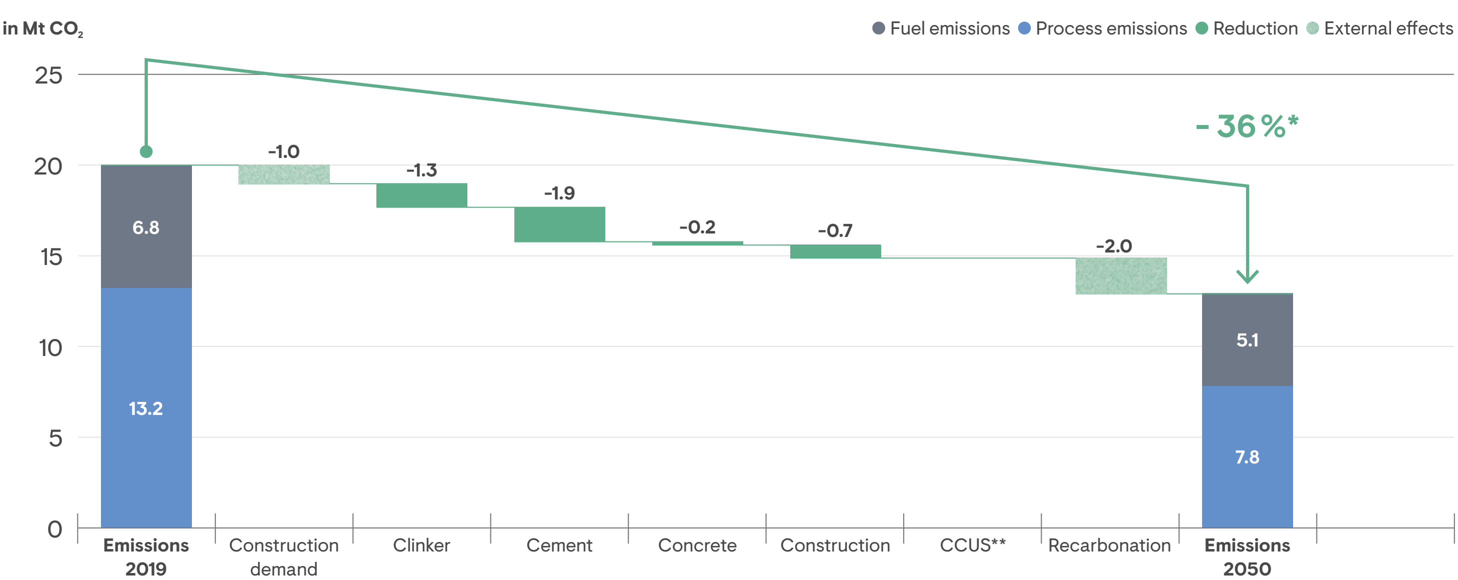
This study describes pathways to the decarbonisation of cement and concrete up to the year 2050. Specifically, it developes two scenarios aimed at reducing direct CO_2 emissions of the German cement industry and the cement and concrete value chain as a whole: An ambitious reference scenario and a climate neutrality scenario.

Assumptions

The **ambitious reference scenario** essentially provides the enhanced deployment of currently available CO_2 reduction technologies and is based on already very challenging assumptions. It should therefore in no way be seen as a "business-as-usual" pathway. Alongside further considerable increases in thermal efficiency and the use of alternative fuels containing biomass, it also for example assumes the widespread broader use of CO_2-efficient CEM II/C cements, the standardisation of which is shortly to be completed. This new cement type with a clinker content of between 50 and 65% can in itself make a significant contribution to CO_2 reduction. The advancement of concrete construction methods with regard to resource efficiency will also lead to material savings and will thus to a certain extent help to reduce CO_2.

The **climate neutrality scenario** goes even further than the ambitious reference scenario and thus reaches the limits of what would appear to be technically feasible today. What essentially distinguishes it from the reference scenario is the additional use of breakthrough technologies. This applies for example to establishing markets for CEM VI cements with a clinker content of between 35 and 50%, new binders and the use of hydrogen as an energy source. Further increases in efficiency and innovations in the production and use of concrete are also assumed. Finally, it also includes carbon

Fig. 2: Ambitious reference scenario – CO_2 reduction by 2050



* Thereof about 21 % reduction through measures along the value chain. Remaining emissions are reduced by a decreasing construction demand as well as the contribution of recarbonation.

** CCUS: Carbon Capture technologies aiming at reducing CO_2 emissions in the atmosphere through CO_2 storage (CCS) and appropriate procedures for CO_2 utilisation (CCU).

Source: VDZ

capture and its subsequent utilisation and storage (CCUS). This is based on the prerequisite that all other potential levers available for reduction have been exhausted to such an extent that the use of CCUS is solely restricted to the amounts of CO_2 which cannot be reduced by conventional means.

External effects which cannot be directly influenced and which are considered to be reduction factors in both scenarios include the natural process of recarbonation[1)], i.e. CO_2 absorption by the concrete, and a slight decrease in the construction demand. The possible active carbonation of fresh or hardened concrete (mineralisation) is assigned to the CO_2 utilisation technologies (CCU) in this study.

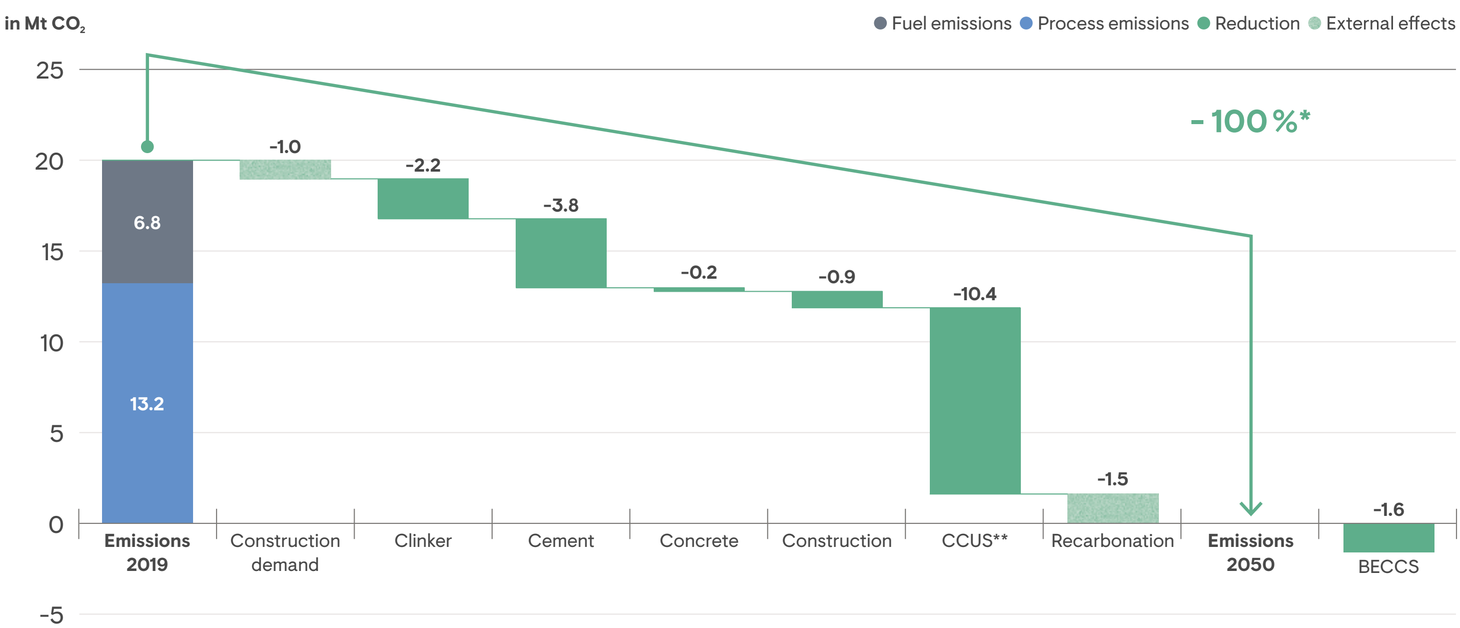
Results

The ambitious reference scenario yields a 19% reduction in CO_2 emissions by 2030 as compared to the status quo in the year 2019 (approx. 40% vis-à-vis 1990). Without the use of breakthrough technologies such as CCUS, a 36% reduction will be achieved by 2050 in comparison with 2019 (Fig. 2). This corresponds to around 50% vis-à-vis 1990. A 36% reduction in CO_2 by 2050 would thus be equivalent to completely eliminating today's volume of fuel emissions. This illustrates the ambitious nature of the reference scenario and at the same time highlights the fact that it will not be possible to fully decarbonise cement and concrete without breakthrough technologies.

The climate neutrality scenario already yields a CO_2 reduction of around 27% by 2030 as compared to 2019 (approx. 45% vis-à-vis 1990). Initial demonstration plants for carbon capture on an industrial scale already will contribute to annual CO_2 savings of roughly 1 million tonnes in 2030. With the exploitation of all available potential for CO_2 reduction along the value chain, including recarbonation and slightly lower construction demand, the cement industry will achieve net zero emissions by 2050 (Fig. 3). In this scenario, the widespread use of CCUS technologies would reduce the volume

1) Using a conservative approach the study estimates natural recarbonation to account for 20% of annual process emissions of clinker production.
2) BECCS = Bioenergy with Carbon Capture and Storage.

Fig. 3: Scenario climate neutrality – CO_2 reduction by 2050



* Thereof about 88 % reduction through measures along the value chain. Remaining emissions are reduced by a decreasing construction demand as well as the contribution of recarbonation.
** CCUS: Carbon Capture technologies aiming at reducing CO_2 emissions in the atmosphere through CO_2 storage (CCS) and appropriate procedures for CO_2 utilisation (CCU).

Source: VDZ

of CO_2 by around 10.4 million tonnes per annum. Through the sustainable use of biomass-containing waste as fuel in combination with carbon capture (BECCS[2)]) it is possible that the cement industry could even provide a carbon sink with a removal of roughly 1.6 million tonnes of CO_2 from the atmosphere.

Both scenarios include measures taken along the cement and concrete value chain which, based on the current state-of-the-art, will be able to make a significant contribution towards achieving climate neutrality by 2050. Apart from this, cement manufacturers are also actively engaged in many other relevant areas of environmental protection and nature conservation. This includes compliance with demanding emission limit values and the promotion of biodiversity in quarries. As these areas do not, however, have any direct effect on the CO_2 emissions of the industry, no consideration is given to such measures in this study. With regard to the circular economy, primarily those measures which have a direct influence on the CO_2 balance of the value chain have been recorded. This primarily relates to the use of alternative fuels and raw materials in clinker and cement production.

Fig. 4: Assumptions on the technology mix in the scenarios up to 2050

Ambitious reference scenario	Climate neutrality scenario
• Thermal efficiency: +13% • Alternative fuels: 85% (of which 35% biomass) • 15% conventional fuels • Without CCUS	• Thermal efficiency: +13% • Alternative fuels: 90% (of which 35% biomass) • 10% hydrogen • Use of CCUS
• Focus on CEM II/C • Clinker-cement factor 63% • Without new binders	• Focus on CEM II/C and CEM VI • Clinker-cement factor 53% • 5% market share of new binders
• Differentiated use of cement in concrete depending on requirement profile	• Differentiated use of cement in concrete depending on requirement profile
• Advancement of concrete construction methods • Expansion of industrialisation	• Further material savings, e.g. new concrete construction methods (incl. carbon concrete, additive production) • Further industrialisation
• Recarbonation of 20% of process emissions	• Recarbonation of 20% of process emissions

Source: VDZ

Successful industrial transformation: Prerequisites and boundary conditions

In awareness of these challenges, German cement manufacturers have been working intensively for years under the auspices of VDZ and the European Cement Research Academy (ECRA) to further enhance the reduction options available today and also to develop new technologies. As illustrated by the results of this study, carbon capture at cement plants and its subsequent utilisation and storage (CCUS) will be crucial in the decarbonisation of cement and concrete. The scenarios reveal that after exhausting all other levers of CO_2 mitigation it will be necessary to capture around 10 million tonnes of CO_2 annually from the year 2050 onwards in order to achieve a climate-neutral cement industry in Germany.

Following the completion of extensive preliminary work and research projects, the cement industry is now in a position to put carbon capture into practice in industrial applications. In this effort, equipment suppliers will have an important role to play. They are working closely together with the industry on advancement of these new technologies. The high costs involved in the construction and operation of such plants and the creation of appropriate infrastructures, however, constitute a major hurdle. This is all the more so as the cement and concrete value chain is dependent on local raw material deposits and is often situated at a considerable distance from other industrial clusters and infrastructures.

The transformation to a climate-neutral society is however not just a technical challenge. On top of this it will be a matter of having to satisfy the necessary external prerequisites and create the appropriate framework conditions in good time. This will demand concerted action in the fields of economics, politics, science and civil society in the following areas (Fig. 5).

Renewable energy and alternative fuels
The decarbonisation of cement and concrete is based on a comprehensive package of measures, which also depends to a considerable extent on a supply of green power. More than double the amount of power will be required for clinker production as a result of the widespread use of carbon capture technologies, for example. This makes the availability of renewable energy and high-performance power grids an important prerequisite for climate neutrality in all sectors. A further factor of particular significance for the cement industry is long-term access to adequate amounts of alternative fuels containing biomass, which now already play a major part in minimising fuel-induced CO_2 emissions in the cement industry. It is therefore important to identify possible interactions between climate, waste and resource policies and to balance potential effects on specific material flows accordingly.

CO_2 infrastructure
The creation of a functioning CO_2 infrastructure is also of crucial importance – both with regard to the decarbonisation of cement and concrete and to the development of new CCUS value chains. Only in this way will it be possible to ensure that CO_2

Fig. 5: Prerequisites and areas of activity for climate neutrality

Source: VDZ

can be appropriately utilised or stored following its capture. How urgent a coherent concept for a CO_2 Infrastructure is can be illustrated by the many industrial carbon capture projects that are currently being planned. In most cases, solutions are needed to address the question of how the captured CO_2 can be transported from the cement plant to its destination, for example a chemical park or refinery or even a storage site in the North Sea. In this context, an integrated approach with regard to the creation of suitable infrastructures for hydrogen and renewable electricity will be important.

CO_2 in the construction value chain

Despite the fact that carbon capture is indispensable for the decarbonisation of cement production, this method can only be employed once all other reduction options have been fully exploited on account of the very high costs and the immense outlay involved. Over the next few years it will therefore be essential to make further advances with regard to the efficient use of clinker, cement and concrete in the value chain. It is obvious to all concerned that merely producing clinker-efficient cements is not enough. It is essential to put them to practical use as well. Therefore, close cooperation along the entire value chain of cement and concrete is crucial, especially with the construction industry and with planners and architects. Overall, more significance has to be attached to the topic of CO_2 in construction work.

Policy framework for competitiveness and innovation

The decarbonisation of cement and concrete will give rise to a transformation process of previously unimaginable dimensions. Cement manufacturers in Germany are well aware of the responsibility they bear in this respect. They are already at the cutting edge of technology in many technical fields today, also at a global level. The aim must be to retain this leading position and create the framework conditions required to do so. Ultimately, competitiveness and innovation are two sides of the same coin. This calls for a comprehensive policy package along the entire cement and concrete value chain to provide the right incentives and create an environment in which business activities can be geared to the needs of climate protection. It includes the creation of a level playing field where low carbon products can compete on an equal footing with less cost- intensive conventional technologies and where carbon leakage is also effectively prevented.

Societal acceptance for industrial transformation

From the point of view of the cement industry, it will be most important over the next few years to reach a new fundamental consensus in the areas of politics, economics, science and civil society on the development of a climate-neutral technology mix for the future. The result will be a variety of reduction options, some specific to certain sectors and others of a general nature. The ultimate goal is to agree on a common transformation process paving the way to an era of decarbonisation. Cement manufacturers in Germany are prepared to make their contribution and assume responsibility accordingly.

The present study shows that there are many measures available which are suitable for immediate implementation. This applies in particular to building activities and the creation of a set of regulations which will continue to enable reliable and low-carbon construction in the future. It is nevertheless important not to lose sight of the fact that by far the greatest contribution to the decarbonisation of cement and concrete can only come from carbon capture at cement plants. Without this new technology the cement industry will not be able to achieve its goal of climate neutrality by 2050. Both VDZ and the cement industry are aware of the reservations which still exist in connection with this subject in Germany. At the same time, discussions about the use of CCUS technologies are becoming more and more objective in the context of the climate goals set down in Paris and the European Green Deal. This applies in particular to remaining process-related CO_2 emissions for which there is no other reduction method.

Requirements for a suitable framework for decarbonisation

- **Consideration of the entire construction value chain with regard to climate protection**, from clinker, cement and concrete to the construction site, the structure itself, the re-use of components and recovery of construction waste (e.g. the revision of construction law, the rapid adaptation of standards and regulations in the interests of climate protection and the accelerated standardisation of CO_2-efficient products).

- **Creation of incentives for investment in more climate-friendly cements and concretes** as well as making these competitive with regard to conventional products.

- **Attachment of greater significance** to the **climate footprint** of the construction materials in civil engineering sustainability certification.

- **Provision of sufficient incentives for customers** to make use of highly CO_2-efficient and in the long term decarbonised cements and concretes despite the higher costs of these in comparison to products with a larger carbon footprint.

- **Development and application of climate protection criteria for the awarding of public construction contracts in collaboration with the industry** (e.g consistent implementation of Green Public Procurement throughout the country).

- **Prioritisation of an integrated life cycle approach** for the assessment of the CO_2 performance of building materials and methods (consideration of the value chain, the sourcing of raw materials, the service life of structures/components, energy and CO_2 efficiency throughout the manufacturing and utilisation phase including the re-use or recovery of building materials after demolition of the structure).

- **Making economic incentives open to all types of technology**: Continuing to give priority to technical construction properties (stability, fire protection and environmental compatibility of a structure) when selecting the appropriate building material in the future.

- **Training and utilisation of the potential offered by digitalisation**: Corresponding training and information for members of the building trade, architects and clients. Climate-friendly planning of construction projects, employing digital methods such as Building Information Modelling (BIM).

- **Avoidance of undesirable carbon leakage effects** in cement clinker production: Creating a level playing field in particular to incentivise investments in low carbon technologies. Open-ended revision of schemes such as carbon border adjustment as a supplement to free benchmark allocation in EU emissions trading.

- **Promotion of breakthrough innovations**, e.g. CAPEX/OPEX for carbon capture, utilisation, transportation and storage, as well as new binder concepts (e.g. by way of Carbon Contracts for Difference (CCfDs) and the interlinking of subsidy schemes at national/European level). Incorporation of climate neutrality requirements into European State Aid law.

- **Development of concepts for (regional) CO_2 infrastructure networks** and the production of a reliable framework for infrastructure investments and operation.

- **Expansion of the renewable power supply system** to cope with the increasing demand for electrical energy in clinker production and the conversion of CO_2; Safeguarding of the reliability of supply and cost-effectiveness alongside technical availability.