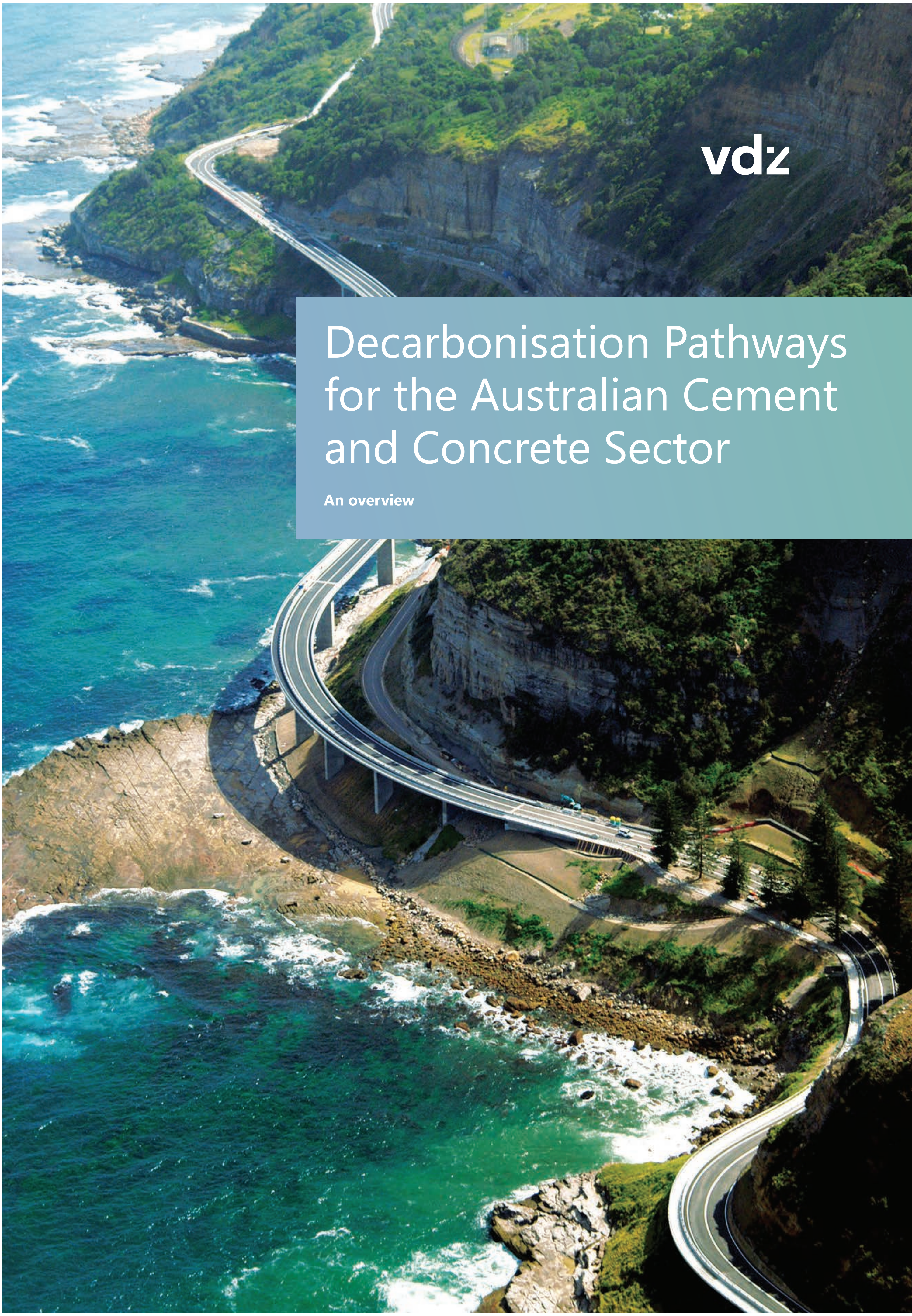

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Decarbonisation Pathways for the Australian Cement and Concrete Sector

An overview

Introduction

The **key purpose of this report** is to identify and communicate the critical pathways that will enable the cement and concrete sector value chain to continue to lower its CO_2 emissions and to decarbonise by 2050.

This **report has been developed by VDZ**, a world-renowned research centre, providing practical and quality-oriented joint research and services in the field of cement and concrete. VDZ has been commissioned to undertake this report based on its international credentials. VDZ has – for example – provided cement and concrete decarbonisation advice to the International Energy Agency, the World Business Council for Sustainable Development and the Global Cement and Concrete Association. VDZ employs over 100 research scientists, engineers and economists who are dedicated to international cement and concrete sector research and innovation.

The **Australian cement and concrete sector has a long history of reducing its CO_2 emissions** having delivered a 25 per cent reduction since 2000. The sector understands the challenge of decarbonising by 2050, which will require significant regulatory, technological, structural and behavioural changes across all segments of the cement and concrete value chain. It will also require cement and concrete customers, developers, designers, building material procurers, architects, standards authorities, government and non-government agencies, and concrete and cement manufacturers to work together closer than ever before.

The **development of interdependent engagement plans**, addressing the identified pathways in this report, will be an important next step. This will build on the past and current initiatives undertaken by the sector. For the industry to be successful in continuing to reduce its emissions, further R&D, investment and commitment from researchers, government and all stakeholders across the value chain will be crucial.

The **long term economic and societal benefits** of harnessing the identified decarbonisation pathways are

clear, however, the investment requirements will be lumpy and significant. Financial and policy support will be essential to ensure the Australian cement and concrete sector remains sustainable during the transition. As a trade exposed sector, a fundamental requirement will be that the transition does not lead to undermining the competitiveness of the Australian cement and concrete manufacturing base and the thousands of jobs it supports.

It is important to note that **this report does not propose targets for each identified pathway** – assumptions are provided to demonstrate the important role the pathways can play across the Australian cement and concrete value chain based on the expert advice of VDZ.

A **review of the pathways is also recommended by VDZ at least every five years** to ensure new technologies and innovation (as well as regulatory and other changes) are included and current proposed pathways can be updated.

The set of interdependent pathways outlined by VDZ in this report demonstrates that **Australia can have a decarbonised cement and concrete sector** if all stakeholders harness the opportunity to continue to work cooperatively across the value chain developing and implementing the required engagement plans recommended in this report.

Financial and in-kind contributions have been provided by the Cement Industry Federation (CIF), Cement, Concrete and Aggregates Australia (CCAA), the SmartCrete CRC and the RACE for 2030 CRC to commision this indpendant report.

The Australian Cement and Concrete Sector – Key Facts

5 Integrated cement plants in Australia which produce clinker and cement as a continuous process.

60% of the cement manufactured in Australia is produced in integrated manufacturing plants

40% of cement involves the use of clinker which is imported and manufactured into cement at grinding facilities located around Australia’s coastline

29 million m^3 ready-mixed concrete produced annually in more than 1,500 batching plants across Australia

40% of all concrete is used for infrastructure projects

30% of all concrete is used for commercial and non-residential buildings

30% of all concrete is used for housing

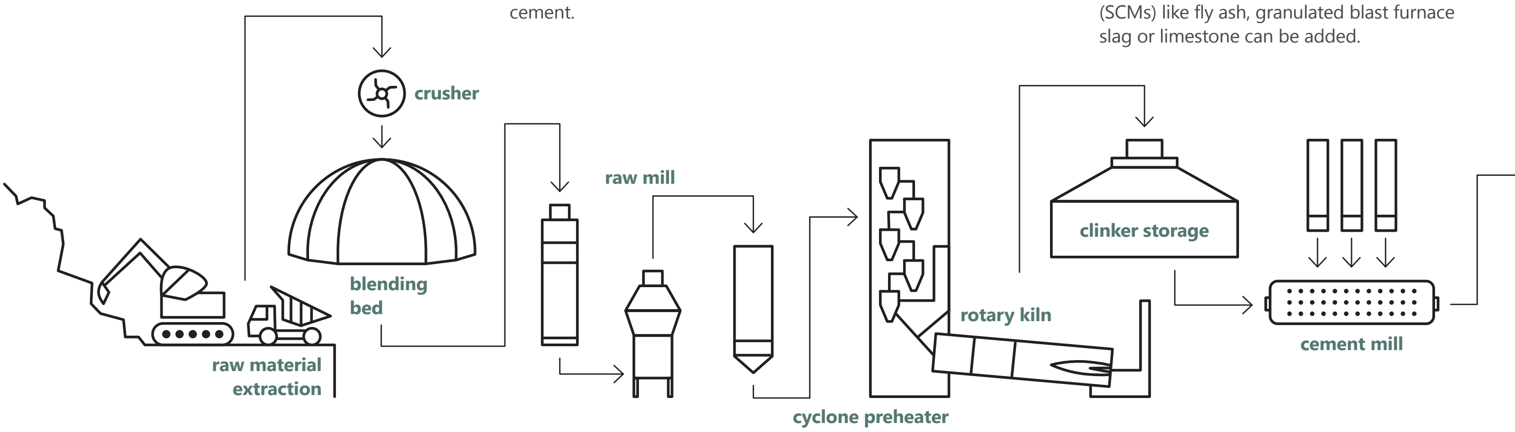
80,000 people are indirectly employed in the whole cement, concrete and aggregate sector, compared to 30,000 who are directly employed

A$15 billion revenue is generated by the cement and concrete sector

1. How cement and concrete is manufactured, transported and used

Raw material preparation
Crushing, blending and the homogenising of the raw materials are important to ensure consistent high quality cement.

Cement grinding
Clinker is ground to cement in cement mills where supplementary cementitious materials (SCMs) like fly ash, granulated blast furnace slag or limestone can be added.



Raw material extraction
Limestone and clay are the natural raw materials for cement which are locally sourced from quarries.

Clinker production
The ground raw materials are heated in a cyclone preheater and calcined in a calciner, where CO_2 from the limestone is released. In the rotary kiln, clinker is formed under high temperatures of around 1,450 °C.

2. Cement and concrete

Cement is a binder material manufactured from limestone and clay and is a key ingredient in concrete.

Concrete is the final building and construction material made from a mixture of cement, crushed stone/gravel, sand and water. Concrete (and therefore cement) is the second most consumed substance (after water) in the world. Over 70 per cent of the world's population live in a structure that contains concrete.

2.1 Cement manufacturing

The key constituent of cement is clinker, which is produced at a very high temperature of 1,450°C in rotary kilns from locally sourced raw materials such as limestone and clay.

An essential part of the production process is the cement mill, in which clinker and other supplementary cementitious materials are ground to the required particle size to make cement.

Chemically speaking, cement is a mixture of calcium silicates and small amounts of calcium aluminates that react with water and cause the cement to set. The mix is completed with the addition of gypsum to help retard the setting time of the cement.

2.2 Concrete production

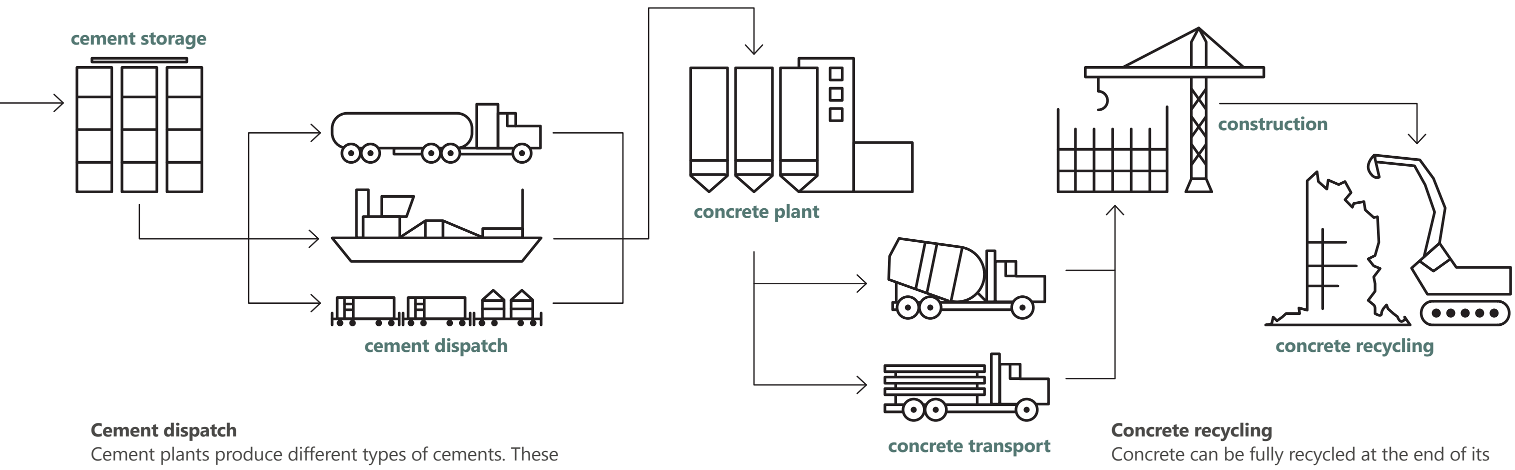
A typical concrete mix is made up of 12 per cent cement, 8 per cent water, 77 per cent crushed stone/gravel and sand and 3 per cent supplementary cementitious materials (SCMs), although proportions may vary depending on the type of concrete and other factors. Small percentages of admixtures are also used, which help to achieve good workability of the concrete.

2.3 The use of supplementary cementitious materials

Cement and concrete can contain constituents or additions, such as fly ash (a by-product from the power sector), granulated blast furnace slag (a by-product from the steel manufacturing process) or unburnt ground limestone. These so-called supplementary cementitious materials (SCMs) have been used in the sector for a long time. They contribute to the cement and concrete performance and are also used to produce cements and concretes that can exhibit properties for dedicated applications. At the same time, SCMs can substitute for clinker in cement and in concrete and thus lower the CO_2 footprint of both.

Concrete plant
Concrete is produced from cement, additions (SCMs) and admixtures, and includes aggregates like gravel and sand. Fibres can also be added. Mixed with water, the fresh concrete takes about an hour to begin hardening.

Construction
Design can be aligned with the goals of decarbonistaion and resource efficiency. Also service life of structures can be prolonged by sufficient maintenance and repair.



Cement dispatch
Cement plants produce different types of cements. These are stored in silos until they are transported to concrete plants or distribution centres.

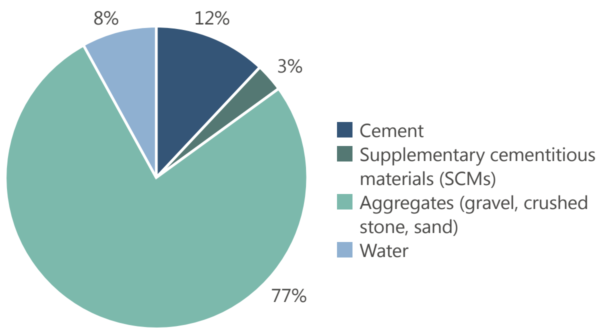
Concrete recycling
Concrete can be fully recycled at the end of its service life. It can be used as aggregates for new concretes, saving natural resources. Crushed and ground concrete fines can also be used to produce new cement.

3. Emissions profile of the cement and concrete industry

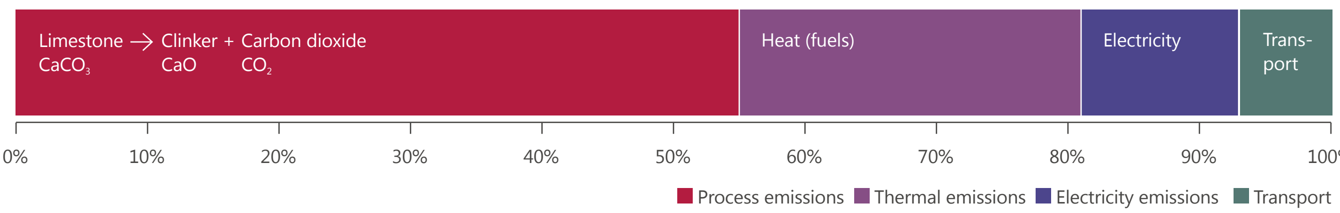
The manufacture of cement involves the conversion of limestone into clinker. This chemical process generates carbon dioxide and is the main source of greenhouse gas emissions from the cement production process. As a consequence approximately 55 per cent of the CO_2 emissions of the Australia cement and concrete sector originate from this calcination of limestone and are commonly referred to as 'process emissions'. 26 per cent can be identified as fuel-based emissions, mainly from the heating of the cement kiln, and around 12 per cent are indirect emissions from electrical energy usage. Indirect emissions based on the transport of cement and concrete to the customer are estimated to be 7 per cent[1].

[1] VDZ proposes that a survey be conducted to enable an estimate of all transport emissions to be calculated.

The main constituents of concrete in weight per cent



Today's CO_2 emission profile of the Australian Cement and Concrete Industry

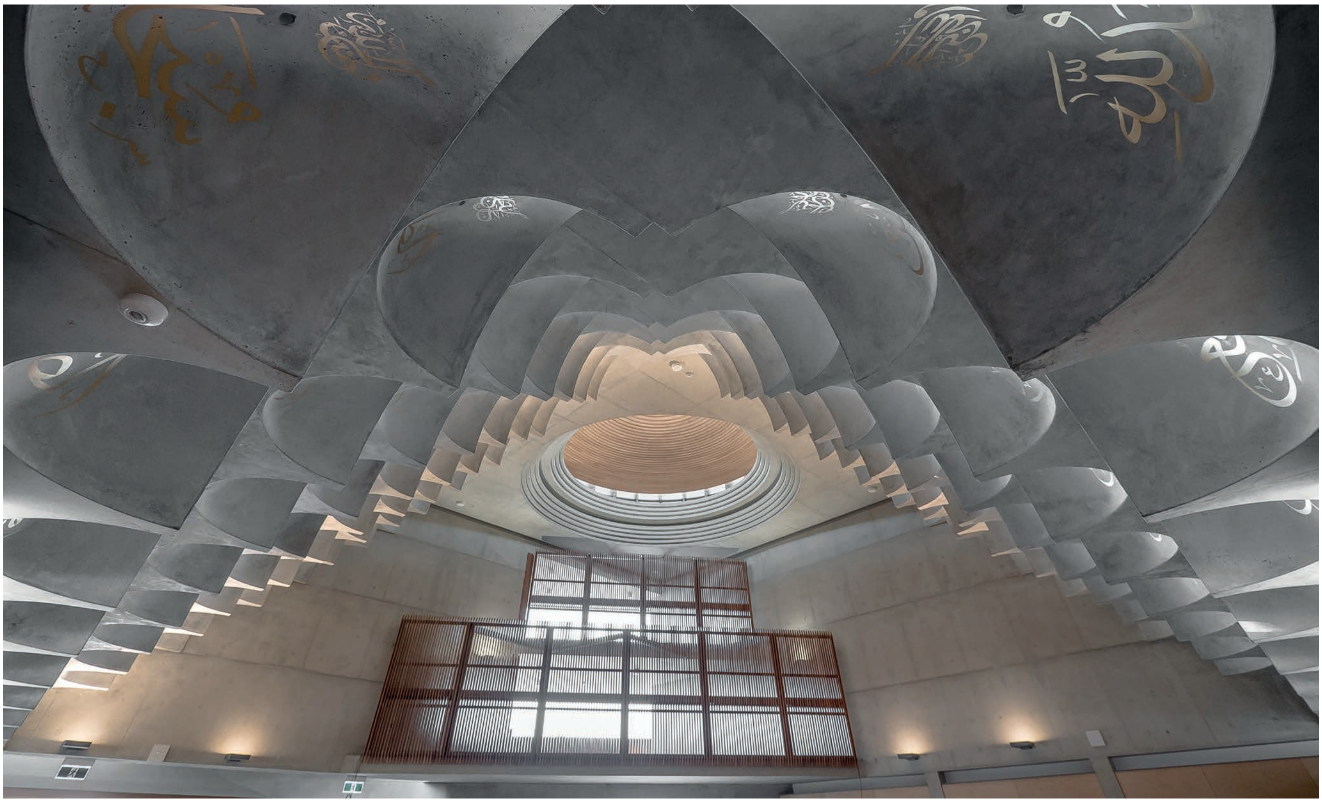


4. Report assumptions

This report uses 2020 as a base year and emissions reductions have been measured in terms of absolute and relative CO_2 emission reductions compared to the base year. The report covers all direct emissions (scope 1) and indirect emissions from electricity usage (scope 2) as well as the transport of cement and concrete to the customer, which account for a major part of scope 3 emissions.

Key assumptions underlying the model include:

- The Australian electricity grid will be decarbonised by 2050.
- Transport will be decarbonised by 2050.
- There will be sufficient zero carbon fuels available, including biomass waste and hydrogen for cement production.
- Carbon capture for cement production is technologically deployable.
- Australia has appropriate infrastructure for CO_2 transport, storage and utilisation.
- Product and design standards allow for lower carbon cement formulations and these are adopted by the market.
- A conservative amount equivalent to 20 per cent of cement process emissions are recarbonated during the concrete lifecycle stage (the International Panel on Climate Change notes in 2021 that the "uptake of CO_2 in cement infrastructure (carbonation) offsets about one half of the carbonate emissions from current cement production").



5. Key themes for success

Addressing decarbonisation in the cement and concrete sector will initiate a significant transformation of the full value chain. The following key themes highlight a number of positions and fundamental approaches for the successful decarbonisation of the sector.

Lowering the clinker factor
Lowering the clinker factor in concrete will bring a fundamental shift in focus and requires a-whole-of-supply-chain approach. There are different ways to deliver the required outcome and there will be no "hard lines" between the pathways, in particular between the use of SCMs in cement and concrete respectively.

New regulatory frameworks to reduce the clinker factor across the supply chain
The existing regulatory frameworks, which include standards and work methods that interact across the supply chain, must be updated. Barriers to lowering the clinker factor should be addressed such as cement and concrete standards.

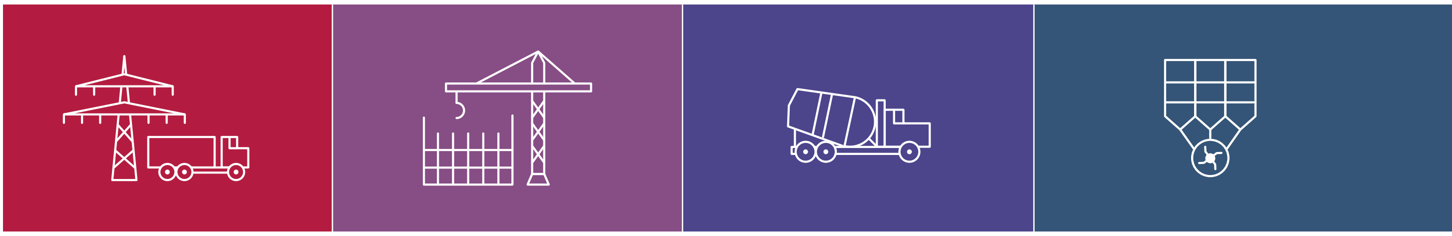
Standardisation of regulations to accelerate the transition process
Feedback from the supply chain clearly highlights the need to make regulations more coherent across the country avoiding multiple interpretations and implementations of regulatory frameworks across multiple jurisdictions such as specifications of road authorities or waste to energy regulations.

Transition from product push to market pull
While public investment provides a major part of infrastructure spending, and since state regulator´s standards and specifications will continue to determine how the majority of concrete is produced, the supply chain is expecting governments and regulators to take leadership in procurement processes with a strong focus on embodied carbon and subsequently the clinker factor in concrete construction.

Context for approaching the different pathways
Some pathways are available now, such as the increased use of SCMs – for example ground granulated blast furnace slag and fly ash. Others such as carbon capture, utilisation and storage (CCUS) are being tested and will need time for their commercial implementation in existing plants. An engagement plan for the different pathways should be framed with the relevant time horizons, which will be useful in gaining early success and developing new technology for its commercial use. Government funding across these horizons should support R&D, commercialisation and lower investment and operating cost hurdles as pathways and technologies will be implemented.

6. Cement and concrete decarbonisation pathways – percentage CO_2 reductions 2020-2050

Decarbonisation Pathways



Zero emission electricity and transport

- Promoting methods to decarbonise Australia's electricity network, whilst ensuring it remains reliable and affordable.
- Sourcing price competitive renewable power purchase agreements.
- Adopting energy efficiency measures – including artificial intelligence and sensors.
- Supporting and adopting competitive technologies and energy sources to decarbonise the transport sector.

Innovation through design and construction

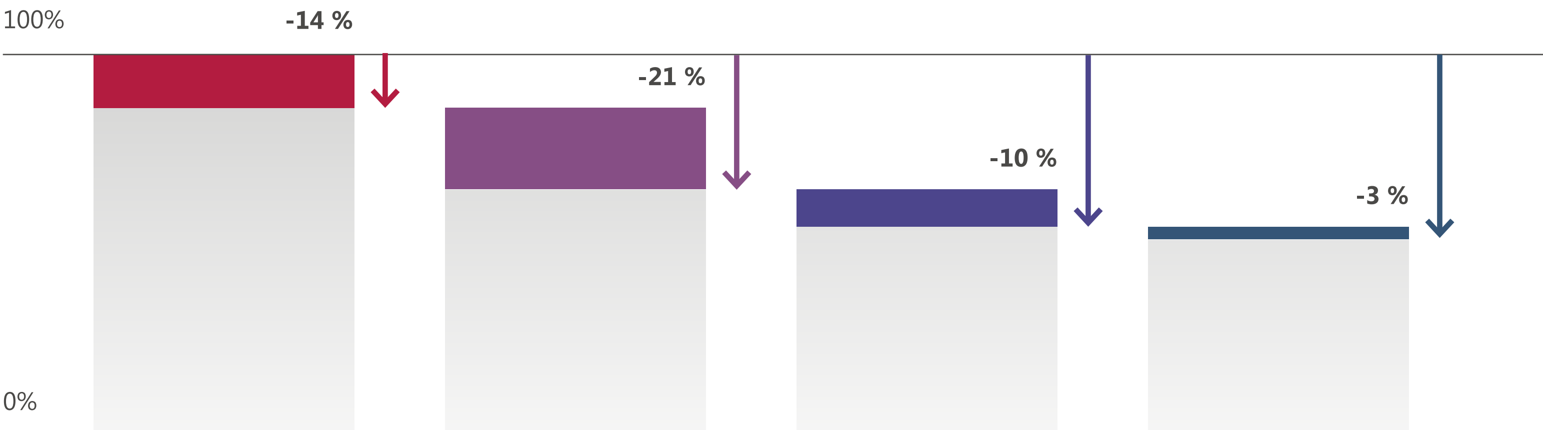
- Promoting design of building and infrastructure that includes a clear focus on material efficiency, specifying lower carbon concrete and improved construction technologies.
- Ensuring structural optimisation that allows for lifetime extension, repair and reuse.

Continue to further innovate concrete

- Improving the mix design for concrete, e.g. packing density optimisation, optimised use of admixtures.
- Improving mixing technology, e.g. replacing dry mixing with wet mixing technology.
- Developing an appropriate balance between performance/descriptive approach in standards and building codes to lower clinker content in concrete.
- Lowering volumes of fresh concrete wastes.

Use of supplementary cementitious materials in concrete

- Ensuring the benefits of using SCMs in cement and concrete are understood and reflected in procurement strategies.
- Focussing strongly on embodied carbon in concrete construction to create a market pull for low CO_2 concretes.
- Changing standards and building codes that reflect the benefits of increased use of SCMs.



New CO_2-efficient cements

- Producing cements with higher content of SCMs like fly ash, GGBFS, calcined clay and unburned limestone.
- Further lowering the clinker factor in cement.
- Creating and obtaining acceptance of new innovative cements.
- Developing standards and application rules which will be required to reflect the benefits of CO_2 efficient cements and enable their use in concrete.

Use Alternative fuels and green hydrogen

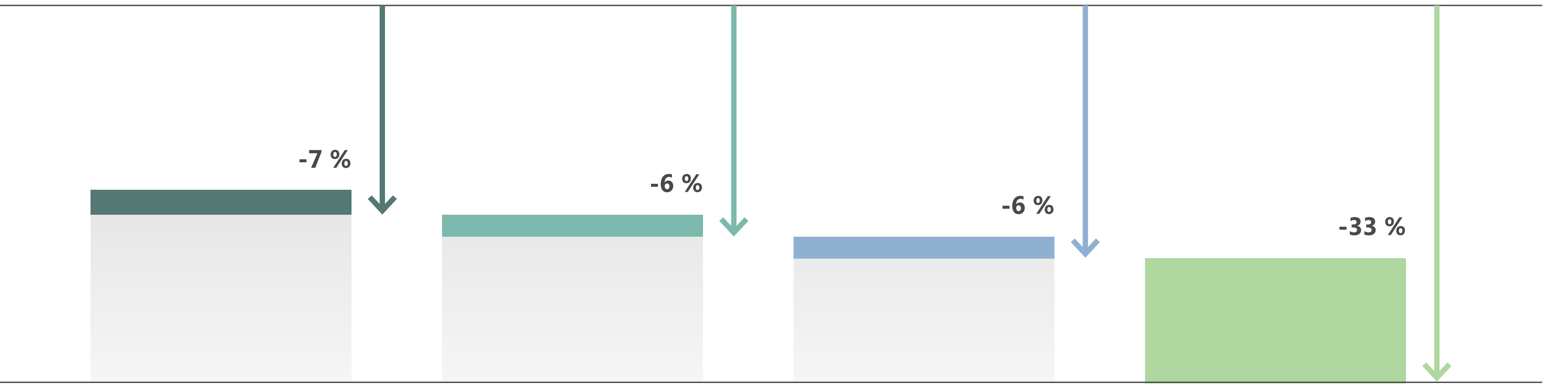
- Increasing the use of alternative fuels to replace coal and gas to heat the cement kiln.
- Using alternative fuels in cement kilns will also be beneficial for lowering the emissions from landfills, although transport costs can be a barrier to the uptake of alternative fuels.
- Applying the required preprocessing technolo-gies.
- Utilising green hydrogen as fuel to lower the amount of fossil fuels in clinker production – sub-stitution rates greater than 10% will require further research.

Account for concrete to uptake CO_2

- The International Panel on Climate Change (IPCC) Draft Report (2021) notes that concrete absorbs CO_2 emissions from the production of cement and concrete.
- Recarbonation occurs during the lifetime of the concrete structure and after the end of its life.

Capture remaining CO_2

- Proposed mitigation measure for CO_2 emissions that cannot be mitigated by conventional means.
- Several technologies are currently in pilot and demonstration phase.
- Australia provides good conditions for CCS and CCUS.



7. Measuring success and next steps

This report provides an overview of the key pathways that can be used to decarbonise the Australian cement and concrete sector. Taking into account that each pathway is not mutually exclusive, VDZ recommends that engagement plans be developed by the CIF and CCAA with relevant stakeholders along the value chain. The CIF and CCAA (with their members) will continue to engage with government and relevant organisations to advance underlying research requirements and other relevant decarbonisation initiatives.

A list of key research priorities has been identified as part of this project and can be found on page 11.

8. Key innovation areas recommended for consideration

Australia is well positioned to support future research based on the findings of this report. This includes scaling up measures which are mature enough to be tested at industrial scale. Cooperative research will also help to support the adaptation of the standards and building codes which are needed to market low emission cements and concretes in the market. Whilst the proposed CIF and CCAA engagement plans will include more detailed information on key innovation areas, VDZ recommends that the following innovation areas be considered – see Table 1.

Table 1: Innovation areas which can be addressed

Innovation area	Aim of the research projects
Alternative fuels with biomass (and other waste materials)	■ Demonstrate the potential of cement plants to contribute to local waste management – utilising waste (waste to energy) that would otherwise end up as landfill waste ■ Provide an environment for the development and implementation for use of future fuel concepts based on defined waste streams
Energy productivity	■ Demonstrate the Industry 4.0 / smart manufacturing approach to further increase electrical and thermal efficiency of the cement manufacturing process ■ Show the potential to integrate smart sensors and artificial intelligence for combustion and process optimisation
Carbon capture	■ Integrate capture in cement production into national CCUS plan ■ Produce the first CO_2-free clinker in Australia ■ Show costs and impact on competitiveness
Green hydrogen as a fuel and for CO_2 utilisation	■ Enable H_2 as a fuel in the clinker burning process aiming at thermal substitution rates higher than 10 per cent ■ Show synergies between H_2, O_2 and CO_2 generation
Specification of concrete durability by performance	■ Specify durability of decarbonised and resource-efficient concrete structures through performance-based specifications ■ Establish a set of performance tests / procedures for relevant applications accepted by all stakeholders
Database on the properties of low-carbon cement and concrete	■ Develop a comprehensive database on the properties of low-carbon cement and concrete ■ Use it as a tool to develop trust and confidence in low-carbon products from all stakeholders
Beneficiation of fly ash	■ Make stockpiled fly ash available in high amounts as an SCMs in cement and/or concrete ■ Show the potential (volume- and quality-wise) of Australian coal combustion products which are stockpiled and could be treated to become a usable product ■ Apply methods of beneficiation, also to ensure a sufficent low chloride content of the fly ashes, and check its technical and economical relevance
Additive manufacturing and digitalisation	■ Greater use of digital production techniques in concrete construction that could lead to a positive contribution to decarbonisation and resource efficiency ■ Identify future areas of application
Resource efficient Design principles	■ Create the basis for the broad introduction of resource-efficient design methods ■ Avoid material that is not required
Recarbonation	■ Demonstrate the potential of fresh concrete to uptake CO_2 and the potential impact on cement content in concrete ■ Show the impact of carbonation when curing concrete element in a CO_2 enriched atmosphere ■ Calculate CO_2 uptake of mortar and concrete during and after their service life for the Australian situation

This report can be accessed at
www.cement.org.au

The primary financial and in-kind contributors to this report are:

The Cement Industry Federation
www.cement.org.au

Cement Concrete and Aggregates Australia
www.ccaa.com.au

SmartCrete CRC
www.smartcretecrc.com.au

RACE for 2030 CRC
www.racefor2030.com.au

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Photos
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