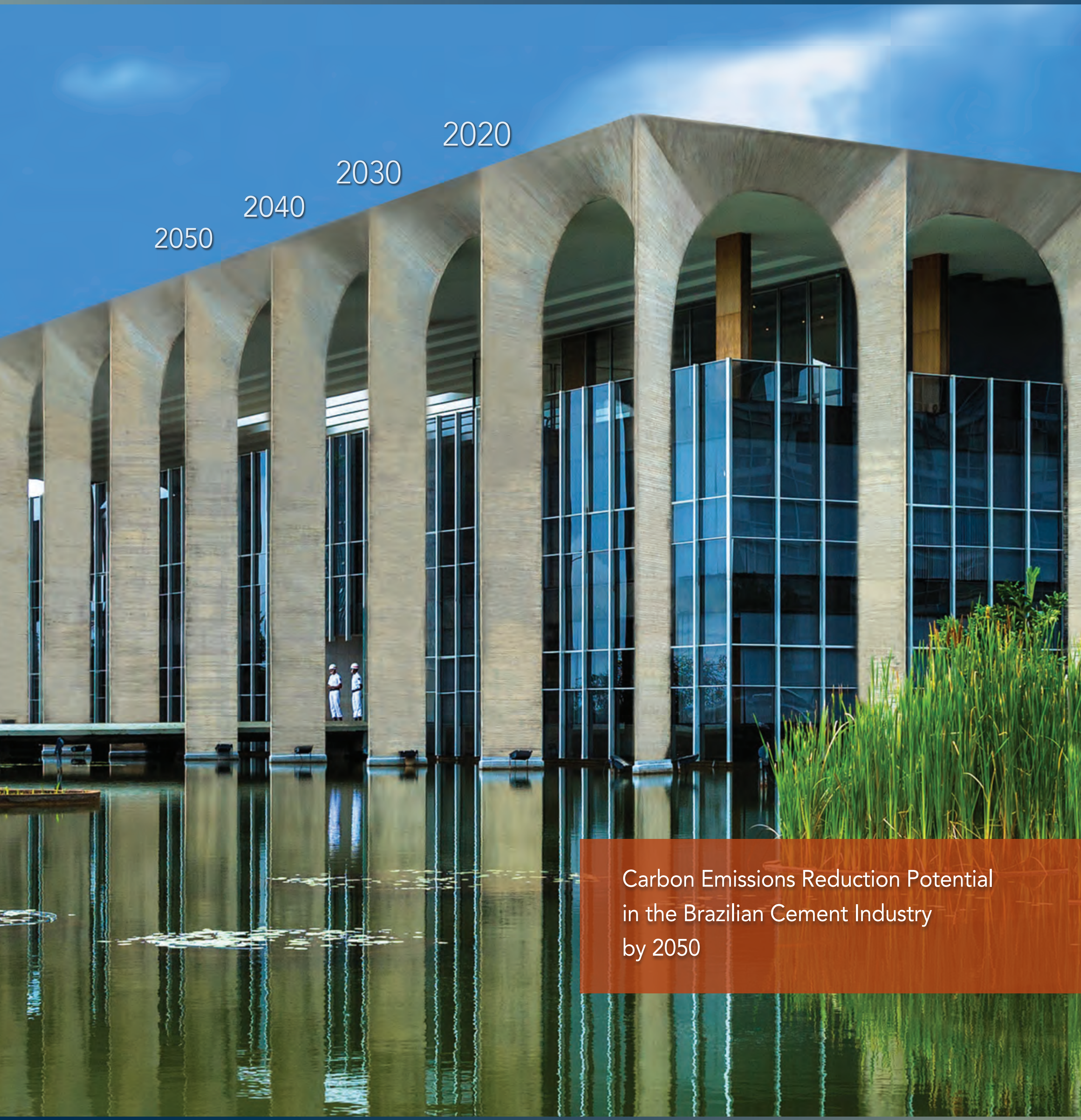
CEMENT TECHNOLOGY ROADMAP



Carbon Emissions Reduction Potential in the Brazilian Cement Industry by 2050

CEMENT TECHNOLOGY ROADMAP

Carbon Emissions Reduction Potential
in the Brazilian Cement Industry
by 2050

Disclaimer

This report is the result of the compilation of scientific research, data collection and mathematical models. Therefore, those involved in its development and elaboration assume no responsibility for any inaccuracies or even the inappropriate use of any information contained therein. The authors are not responsible for any damages or losses to persons or institutions originated by the use of this information. Users of this report should make their own business decisions, assessing the significance and limitations of the information presented therein. No specific commitment has been made to the implementation of any technologies presented in this report.

Copyright

International Cataloging Data on Publication (CIP)

Cement Technology Roadmap - Carbon Emissions Reduction Potential in the Brazilian Cement Industry by 2050/ coordinated by Gonzalo Visedo and Marcelo Pecchio. Rio de Janeiro: SNIC, 2019
64 p.

1. Cement - Manufacturing 2. CO2 3. Sustainability 4. Climate Change 4. Energy efficiency 5. Alternative fuels 6. Cement - Addition I. Visedo, Gonzalo, coord. II.Pecchio, Marcelo, coord. III. NATIONAL CEMENT INDUSTRY ASSOCIATION IV. BRAZILIAN PORTLAND CEMENT ASSOCIATION V. Title.
CDD – 23.e. – 666.94

Prepared by Maria Gisele Fonseca de Oliveira CRB-8/4097

Foreword

Brazil has numerous deficiencies and its housing and infrastructure gaps are two of the main shortfalls that impact its people´s wellbeing and quality of life. To change this scenario, it is paramount that the country invests in infrastructure works which means using an input necessary from start to finish in any civil work: cement. It is no wonder it is the most widely used man-made product on the planet.

Behind such an essential product there is a highly complex industry, both labour and capital intensive and firmly committed to mitigating environmental impacts, naturally inherent to similar sized operations.

Thanks to efforts made over the years, the Brazilian cement industry currently demonstrates one of the lowest global CO_2 levels per tonne of cement produced. It can, though – and will – advance further down this path.

The Paris Agreement, negotiated in 2015 under the Conference of the United Nations Framework Convention on Climate Change (UNFCC) and ratified by Brazil in 2016, established guidelines and commitments as an attempt to limit global average temperature increase to lower than 2°C.

As a contribution to this global effort, the Brazilian cement industry, in collaboration with the International Energy Agency (IEA), the World Business Council for Sustainable Development's (WBCSD) Cement Sustainability Initiative (CSI), the World Bank's International Finance Corporation (IFC) and a select group of experts from the most renowned Brazilian Universities and research centres, under the coordination of the emeritus professor and former Brazilian Minister José Goldemberg, elaborated this technology roadmap which evaluates a series of measures that might accelerate the transition to a low carbon economy.

The aim of this work is to contribute to a 33% reduction in the industry´s carbon intensity by 2050, based on current figures. For this purpose, the main measures were grouped into four main categories: (i) additions and clinker substitutes – clinker being the semi-finished cement obtained -, by adding by-products from other industrial activities; (ii) alternative fuels, by using biomass and waste with a high calorific power as a substitute to fossil fuels; (iii) energy efficiency by investing in machinery and technology that consume less power and/or thermal energy; (iv) innovative and emerging technologies - through the research and development of disruptive technologies, such as carbon capture.

The measures presented here are realistic and viable. The goals are ambitious. The cement industry's transition suggested in this roadmap can only be achieved with a supportive regulatory structure. The report maps out required public policies, evaluates promoting and development mechanisms and lists technical challenges to meet the proposed objectives.

This Technology Roadmap reiterates the cement industry age-old commitment to progress.

Paulo Camillo V. Penna
President of National Cement Industry Association
President of Brazilian Portland Cement Association

Index

List of Figures

List of Tables

List of Annexes

Key findings

- The Brazilian cement industry has one of the lowest levels of specific CO_2 emissions in the world, thanks to mitigating actions implemented by the sector over recent decades. While cement production increased by 273% between 1990 and 2014 (from 26 million to 71 million tons), total emissions grew by 223% over the period, due to the 18% reduction in emissions intensity (from 700 kg CO_2/t cement to 564 kg CO_2/t cement).
- In the same period, thermal intensity had a reduction of 17%, the use of alternative fuels increased from 5% to 19% and the use of clinker substitutes increased from 20% to 33%.
- The low per capita cement consumption in Brazil (260 kg/person/year) when compared to the worldwide average (553 kg/person/year), and coupled with the high housing deficit, the country's infrastructure and the expected population growth, indicates a resumption of production in the medium to long term, increasing between 60% and 120% by 2050 compared to 2014 (in the variants of low and high demand respectively).
- Regarding mitigating its CO_2 emissions, the main alternative and the biggest challenge to the sector is to further increase the use of clinker substitutes (Brazil is among the countries that use them the most). By reducing the clinker/cement ratio from 67% in 2014 to 52% in 2050, it would be possible to achieve a cumulative reduction of 290Mt in CO_2 emissions. This would represent 69% of the CO_2 emissions reduction in the sector by 2050. The expected scarcity of both blast furnace slag and fly ash in the long-term would increase pressure on the industry to identify other clinker substitutes, such as increasing the use of limestone filler and calcined clay.
- The use of alternative fuels, substituting fossil fuels, such as petroleum coke, represents the second largest carbon emissions mitigation strategy for the sector. The increase in thermal substitution rate from 15% in 2014 to 55% in 2050 would result in a cumulative reduction of 55Mt in CO_2 emissions. This would signify around 13% of the CO_2 emissions reduction. The use of Municipal Solid Waste (17% of thermal substitution) and Non-Hazardous Solid Waste (other 17%), both with a high content of biomass, represent the greatest potential.
- Brazil has a modern and efficient industrial complex, with an average thermal consumption of 3.5 GJ/t of clinker and electricity consumption of 113 kWh/t of cement. Therefore, major changes in energy intensity of cement production are not expected before 2030, when the gradual replacement of the more obsolete units and equipment with new lines using the best available technologies (BAT) will start taking place. It will then be possible to achieve values of 3.2 GJ/t of clinker and 91 kWh/t cement by 2050 and a cumulative reduction of 38Mt of CO_2 by 2050, representing around 9% of the sector's mitigation effort. Process control and optimization, recovery of heat in the coolers, vertical mills and waste heat recovery (WHR) equipment for generating electricity will each have a pivotal role in this reduction.
- In order to achieve emissions reduction compatible with the global commitments of minimum climate impact, it is necessary to search for innovative and disruptive solutions, such as Carbon Capture and Utilization or Storage (CCUS). By doing so, it would be possible, from 2040, to achieve a cumulative reduction of 38 Mt CO_2, representing about 9% of the sector's mitigation by 2050.
- The different measures for carbon emissions reduction are not distributed evenly around the country. Considering Brazil's continental dimensions, and its many different regions, it is fundamental to understand that the various actions recommended in this Roadmap, as well as their potential for penetration and reduction of CO_2, cannot be replicated with the same intensity in all regions of the country.

Key actions to 2030

The implementation of tangible actions by all stakeholders is fundamental to achieve the scenario for CO_2 reduction presented in this Roadmap. To reach the levels of improvement in the different key performance indicators (KPIs) and the subsequent reductions in carbon emissions, government, industry and civil society in general must create a joint agenda of structural actions, in order to accelerate the sustainable transition of the Brazilian cement industry. The major priority actions, in a short to medium term view (2030) are the following:

- Reinforce national and international cooperation for gathering and publishing reliable emission data, as well as performance indicators referring to energy efficiency, use of alternative fuels and clinker substitutes, such as those from the Cement Sustainability Initiative (CSI) database Getting the Numbers Right.
- Promote the development of new standards for cement, allowing the use of greater content of clinker substitutes, without compromising the durability of concrete and in accordance with standards already in use at a global level. Develop awareness campaigns in the whole cement value chain in order to inform consumers and facilitate the acceptance of cement with a higher content of clinker substitutes, showing their benefits in reducing the sector's emissions.
- Enhance energy recovery from waste, following the National Policy for Solid Waste (PNRS); update existing legislation in order to streamline licensing of alternative fuels and encourage their use; create specific legislation establishing directives on co-processing of fuels derived from municipal solid waste (MSW) in cement kilns; develop every type of waste management/treatment, promoting competitive conditions between the different alternatives.
- Share best practices at a national and international level to promote energy efficiency in the cement industry; encourage the adoption of public policies that result in less consumption of energy and generation of less waste; identify available public and private national and international financing mechanisms for equipment and technology that result in an increase of energy efficiency and a reduction in emissions.
- Promote R&D in emerging and innovative technology for mitigation of greenhouse gas emissions, including CCUS, through cooperation with research institutes; identify and/or create mechanisms for encouraging pre-commercial research, projects on a laboratory scale and pilot-projects for demonstration of technology.

Table 1: Key indicators for the Brazilian cement industry by 2030 in "2°C Scenario"

	2014	2030
Clinker Factor (ratio clinker/cement)	0.67	0.59
Thermal consumption [GJ/t clinker]	3.50	3.47
Electrical Consumption [kWh/t cement]	113	106
Alternative Fuels [% of thermal substitution]	15%	35%
Total CO_2 Emissions [Mt CO_2/year]	40	42
CO_2 Emissions Intensity [t CO_2/t cement]	0.56	0.48

Source: IEA modelling developed for this project. © OECD/IEA, 2016

INTRODUCTION

Cable-stayed bridge overRio Paraná, between São Paulo and Mato Grosso do Sul

Cement is the fundamental raw material for the construction industry, being the basic component for concrete and mortar, and concrete is the single most widely used material in the world.

It is also the most crucial element in the country's current infrastructure deficit. Cement is basic to the construction of houses, schools, hospitals, roads, railways, ports, airports, sanitation and electrical grids, among many other works that provide health and wellbeing to the population and fulfill the demands of modern life.

As a developing country, Brazil has an important infrastructure program to be implemented, and the increase in population, together with the growth of urbanization, will drive the demand for cement for future decades.

In cement production, however, carbon emission is intense. Globally, the cement industry accounts for around 7% of all anthropogenic CO_2 emissions.

Brazil is one of the countries with a lower quantity of CO_2 per ton of cement produced. This prominent position, while on one hand being a recognition of the efforts of the sector to combat climate change, represents an enormous challenge: to produce the cement needed for the development of the country, while at the same time finding methods to further reduce its CO_2 emissions.

Roadmap objetives

The International Energy Agency (IEA) worked together with the Cement Sustainability Initiative (CSI) of the World Business Council for Sustainable Development (WBCSD) to publish a global strategy entitled Technology Roadmap - Low-Carbon Transition in the Cement Industry (2009)[1]. This global roadmap described a series of pathways, including political support and required funding, to reduce CO_2 emissions in the cement manufacturing process up until 2050. Updated in 2018, this was the first IEA roadmap that focused on a specific industrial sector.

Being aware of the roadmap's potential for identifying and initiating the reduction of emissions in the medium to long term, in 2013, again with the participation of the IEA and CSI, as well as International Finance Corporation (IFC) of the World Bank Group, the Indian cement industry prepared a Cement Technology Roadmap specific to the country, presenting and discussing local peculiarities and projecting future potential for mitigation. Resource efficiency studies were also conducted at selected cement manufacturing facilities, which identified various emissions reduction opportunities.

Aware of the need to embrace the challenge of further reducing its CO_2 emissions, the Brazilian cement industry repeated the collaboration with IEA and CSI to develop its own Cement Technology Roadmap – Brazil, with technical support and co-financing from IFC.

This study maps the current status and future trends regarding the Brazilian cement industry. If its growth path and technological development were to continue business as usual, in the baseline scenario, the absolute emissions arising from cement production in Brazil would reach around 66 Mt CO_2 in 2050, a 64% increase compared to 2014 levels (40 Mt CO_2). Based on this scenario, the Roadmap proposes different technical alternatives capable of reducing these emissions to levels conducive to a lower climatic impact, limiting global warming to 2°C in the long term.

This would imply reducing the current carbon intensity in cement from 0.56 tons of CO_2/t of cement to 0.38t CO_2/t of cement by 2050, meaning that the total emissions would remain virtually steady, despite the increase in cement production estimated for the period.

The study also points out barriers that limit the deployment of identified measures, and proposes a series of recommendations for public policies, support mechanisms, regulatory and legal issues, among others, that are emissions reduction enablers in the short, medium and long term.

Partners and Collaborators

This Roadmap represents the joint efforts of both several national and international collaborators, plus the views and contributions of numerous subject matter experts and local specialists.

The overall coordination of the project was the responsibility of SNIC and ABCP. Besides its industry associations, the Brazilian cement sector was represented by the manufacturing groups Cimentos Liz, Ciplan, InterCement, Itambé, LafargeHolcim and Votorantim Cimentos, comprising more than 80% of national production. Industry specialists provided technical knowledge from their own experience, as well as data and numbers from the sector.

Under the coordination of the research scientist and former Brazil´s Minister of Education José Goldemberg, renowned specialists from Brazilian Universities and technological centers wrote a series of technical papers, indicating different alternatives for reduction of emissions applicable to the industry, their obstacles and potential for market penetration in the future.

The IEA provided guidance on the data collection processes and analysis, and performed the modeling exercise to understand the impact of the various technological alternatives. It also contributed to the structuring of the Project as

---

[1] *The global Cement Technology Roadmap (2009; 2018)* and that of India (2013) are available at: https://www.wbcsdcement.org/index.php/key-issues/climate-protection/technology-roadmap

a whole, based on its experience in the development of technology roadmaps.

The CSI provided technical expertise in the different stages of the process, with its global knowledge of the cement industry, and with its comprehensive emissions database.

The IFC gave technical and financial support to the chapters on Alternative Fuels and Energy Efficiency, by hiring national and international consultants.

Finally, more than 200 specialists from the industry, government and academia, among others, contributed through four technical workshops and various work meetings.

Roadmap drafting

This Roadmap is based on a group of over 40 measures for reduction of emissions applicable to the Brazilian cement industry. These measures were concentrated in four technical papers[2] developed by academics from the most renowned universities and research centers in the country. The papers described the current status of each measure, its impact on the reduction of CO_2, and the main barriers and constraints to its implementation and the potential for market penetration over time. In addition to the four technical papers, the modeling process included two other qualitative papers[3] which were not originally included in the projection model.

These technical papers are based on the vast amount of information available on the sector in Brazil referring to CO_2 emissions, power consumption, profile of fuels and use of clinker substitutes, among other indicators, obtained from the CSI[4] database. In addition, information was collected from the industry referring to the current technological profile of the industry – types of kilns, types of clinker coolers, types of cement, petcoke and raw material mills, average age of plants, life span and others. Altogether, data corresponding to regarding 80% of Brazil's cement industry was collected and extrapolated for total national production, thus becoming highly representative of the Brazilian reality.

All these materials were used by IEA to supplement and calibrate its modeling inputs and results on the impact of the different alternatives for the reduction of CO_2 emissions, consistent with its global 2°C Scenario, with variants for low and high demand (Box 1).

Finally, based on these scenarios, industry, academia, government agencies and development institutions discussed a series of recommendations to a diverse group of stakeholders capable of overcoming existing barriers and potentially accomplishing the different technical solutions proposed in this document, thus contributing to the mitigation of the industry's emissions.

Scope and boundary

This study concentrates on the strategies for mitigation of carbon generated in the manufacture of cement, focusing on the direct emissions arising from the production process, on the consumption of energy and on indirect emissions from electricity generation. It also recognizes the importance of considering the reduction of emissions in the broader context of the whole life cycle of cement, of concrete and the construction environment. While this broader context is outside the process of cement manufacturing, and therefor was not included in the modeling exercise, it is discussed in a specific section in this report.

At the same time, although the study presents a national-level vision, it is important to consider that Brazil's continental dimensions and its marked regional differences, in geography, economy and development, create potential limitations on the different emissions reduction alternatives proposed, mainly in relation to clinker substitutes and alternative fuels. The authors note that the potentials suggested in this Roadmap are not necessarily distributed evenly over the whole country, and an analysis of local peculiarities is fundamental when evaluating the potentials on a regional/state basis.

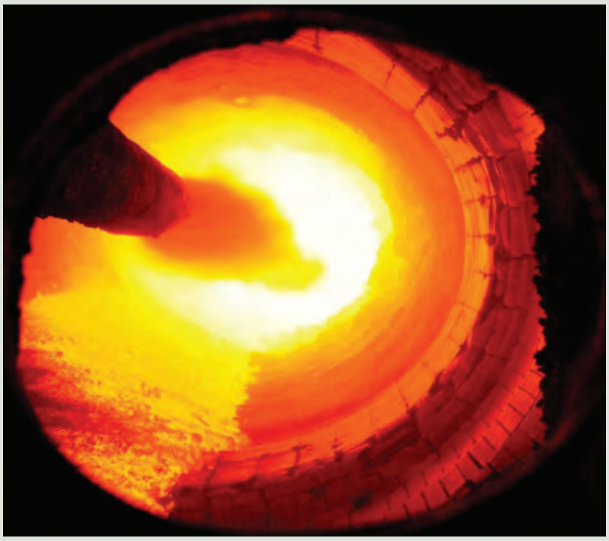
---

[2] 1. Clinker substitutes; 2. Alternative fuels; 3. Energy efficiency; 4. Carbon capture and utilization or storage.

[3] 1. Potential mitigation in the construction chain; 2. Regional differences.

[4] On the occasion of the publication of this report, the database *Getting the Numbers Right (GNR)*, the *Cement Sustainability Initiative (CSI)* as well as its other activities, were absorbed by the newly created *Global Cement and Concrete Association (GCCA)* and are available in https://www.wbcsdcement.org.

Box 1. Scenarios used in this *Roadmap*



The IEA uses extensive modeling to examine possible scenarios for the future global energy system. The "6°C Scenario", which serves as the reference scenario for this Roadmap, is an extension of current trends, without an effort by government, industry or the general public to reduce emissions. In 2050, global use of energy in the "6°C Scenario" almost doubles (in comparison to 2014) and total emissions increase even more. In the absence of efforts to stabilize atmospheric concentration of greenhouse gases, the average increase in global temperature will be at least 6°C in the long term. In this scenario, global emissions of CO_2 from all industries would be 45% to 65% higher in 2050 than in 2014.

On the other hand, the "2°C Scenario" is target-oriented: starting with the objective of limiting the increase in average global temperature to 2°C and examining means of achieving cuts in emissions sufficiently profound to reduce to at least half the global emissions by 2050. This does not mean that industry needs to reduce its emissions by more than 50%; rather that to achieve this objective in a more economical way each economic sector in each country must contribute based on its best specific costs of reduction. In this scenario, annual global industrial emissions would be around 20% less in 2050 than at present.

A detailed analysis is made periodically by IEA for the global cement industry, and in this particular project, the Brazilian cement industry received specific attention.

The model was developed on two variants within each scenario: low and high demand for cement. Given the recent national economic crisis and the uncertainties in projecting growth in cement consumption in the long term, this study concentrated mainly on the low demand variant.

The scenarios are based on existing technology in the short-term, but assume a more optimistic view of development of additional technology in the long term, and consider that new technology is adopted if it is competitive in terms of cost in the scenario's energy price context. IEA scenarios also presume that non-technical obstacles are overcome, including, among others, social acceptance, adequate regulations and information deficits. The analysis does not evaluate the probability of compliance with these assumptions, but obviously profound reductions of CO_2 can only be achieved if all parts of society (industry, government, community) contribute collectively.

These scenarios are not predictions. They are internally consistent analyses of methods that can be available to achieve objectives of energy and climate policies, given a certain set of technological assumptions.

AN OVERVIEW OF THE CEMENT INDUSTRY

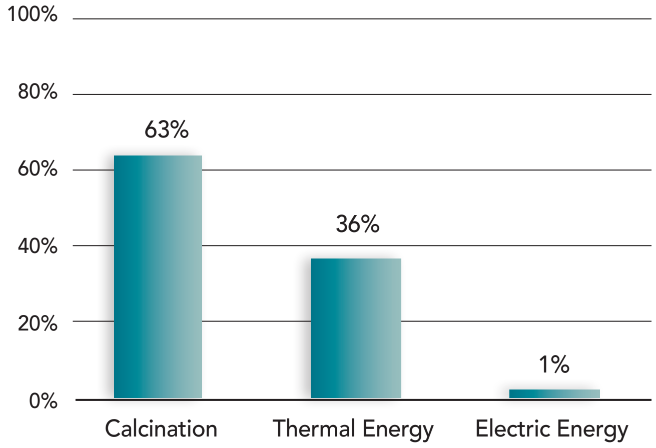
Night view of a cement plant

Manufacturing process and formation of CO_2 emissions

Cement manufacturing can be considered as a two-step main process. It starts with clinker production in high temperature kilns and it is at this stage that direct CO_2 emissions occur. Typically, 30% to 40% of the direct CO_2 emissions come from the burning of fuels and the remaining 60% to 70% are inherent to the process and come from the chemical reaction involved in the conversion of limestone to calcium oxide (calcination), in the formation of clinker. Another 5% of CO_2 emissions occur indirectly as a result of electrical consumption by the industrial plant.

In Brazil, the burning of fuels represents 36% of total emissions, while the emissions from calcination contribute another 63%. Contribution from electrical energy is approximately 1%, due to 74% of the country's electric supply being renewable.

Figure 1: CO_2 emissions from cement production in Brazil



Key-message: Almost 2/3 of the sector's emissions are inherent to the process and happen during the calcination of raw material.

Source: CSI; SNIC, 2014

To produce cement, clinker is ground together with calcium sulfate, or gypsum. Depending on the technical properties required of the finished product, other components, such as fly ash, blast furnace slag and limestone filler can also be ground together or mixed at a later stage. The cement can be produced in integrated units, with the clinker kiln and grinder in the same place, or in separate grinding mills or mixing plants, which receive the clinker from integrated units.

The two basic processes for the production of clinker are the wet process and the dry process, depending on the technology used for homogenization of the raw materials. The wet process consumes double the energy, as all the water added for mixing the raw materials (known as paste), needs to be evaporated. This process practically no longer exists in this country (less than 1% of capacity). There are also different configurations of kilns.

The cement manufacturing process is complex. It demands close control of the chemical formulation and involves various stages, requiring specialized equipment.

1. Quarrying of raw materials

Natural carbonate deposits, such as limestone, provide calcium carbonate ($CaCO_3$), an essential raw material for cement. These are quarried by heavy machinery, often located near to the cement plant. Small quantities of "corrective" materials, such as iron ore, bauxite, shale, clay or sand, which are also extracted from mines, may be necessary to provide extra content of iron oxide ($Fe2O_3$), aluminum ($Al2O_3$) and silicon (SiO_2), to adjust the chemical composition of the raw meal needed for the manufacturing process and the requirements of the product.

2. Crushing

Raw materials are crushed into fragments (< 10 cm) and transported to the cement plant by conveyor belts, trucks or trains.

3. Preparation of raw meal

The different raw materials are mixed to maintain the chemical composition necessary in a process known as "pre-homogenization". Material previously crushed will now be ground to produce the "raw meal". To guarantee the high quality of the cement, the chemical composition of the raw materials and the raw meal is carefully monitored and controlled.

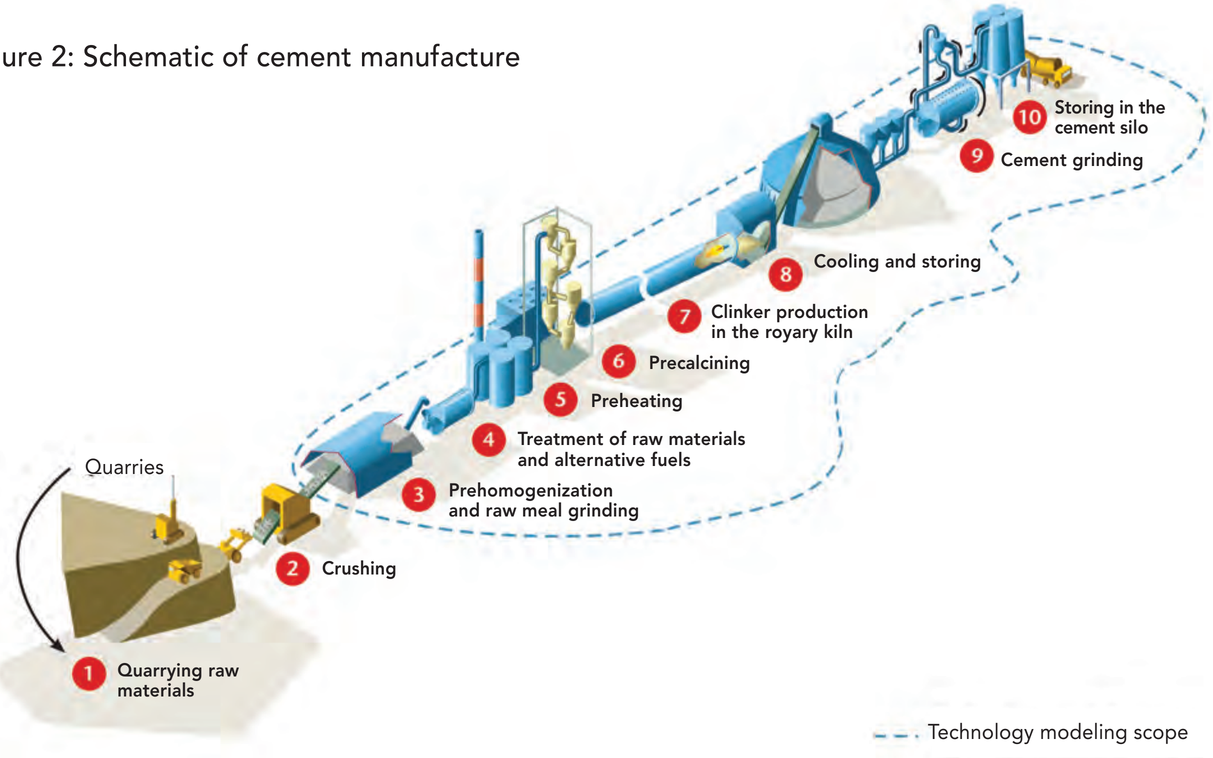
4. Treatment of raw material and alternative fuels

Cement production can co-process waste and byproducts derived from other industries or municipalities. They can substitute raw materials for the raw meal, or fuels used in the heating process, so long as they are prepared for this. Waste and byproducts vary widely in nature and often contain a high proportion of moisture. For this reason they need to be analyzed, classified, ground, separated granulometrically (graded), and in some cases submitted to moisture reduction processes before being introduced into the cement kiln.

5. Preheating

The pre-heater consists of a series of vertical cyclones through which the raw meal is passed, entering in contact with swirling hot kiln exhaust gases moving in the opposite direction. In these cyclones, thermal energy is recovered from the hot flue gases and the raw meal is pre-heated before entering the rotary kiln. In this way part of the chemical reactions needed for the formation of clinker occur faster and more efficiently. Depending on the raw material moisture content, a kiln may have up to six cyclone stages, with increasing heat recovery in each extra stage.

Figure 2: Schematic of cement manufacture



Key-message: Manufacture of cement involves multiple stages.
Note: A kiln using the dry process with pre-calciner and pre-heaters of multiple stage cyclones, as shown above, is considered state of the art technology.
Source: IEA/WBCSD, 2009

6. Precalcining

Calcining is the decomposition of limestone to form lime (CaO). Part of this reaction occurs in the "pre-calciner", a combustion chamber situated in the lower part of the pre-heater and above the kiln, and part in the interior of the rotary kiln. The chemical decomposition of the limestone generally produces 60% to 70% of the total gas emissions. The burning of fuel generates the remainder (around 30% to 40%), 65% of which occurs in the pre-calciner.

7. Clinker production in the rotary kiln

The pre-calcined meal then enters the rotary kiln. The fuel burns inside the kiln, feeding a blow torch, and temperatures of up to 1.450°C are achieved. As the kiln rotates, at around three to five times per minute, the material slides and tumbles down through progressively hotter zones towards the flame. The intense heat causes chemical and physical reactions which partially melt the meal, turning it into Portland clinker. The chemical reaction includes calcination, which is the decomposition of the carbonate minerals in the limestone with a consequent emission of CO_2.

8. Cooling and storing

The hot clinker is then rapidly cooled, from temperatures above 1 000°C to around 100°C, by means of a cooler that blows cold air into the kiln. This air will be re-used in the burning of the fuel. The air blowers are electrical, and on exchanging the heat of the clinker, the circulation of hot air improves the thermal efficiency of the kiln. A typical cement plant normally stores the clinker before the grinding of the cement. Clinker can be ground in the integrated unit, or transferred to specific grinding units.

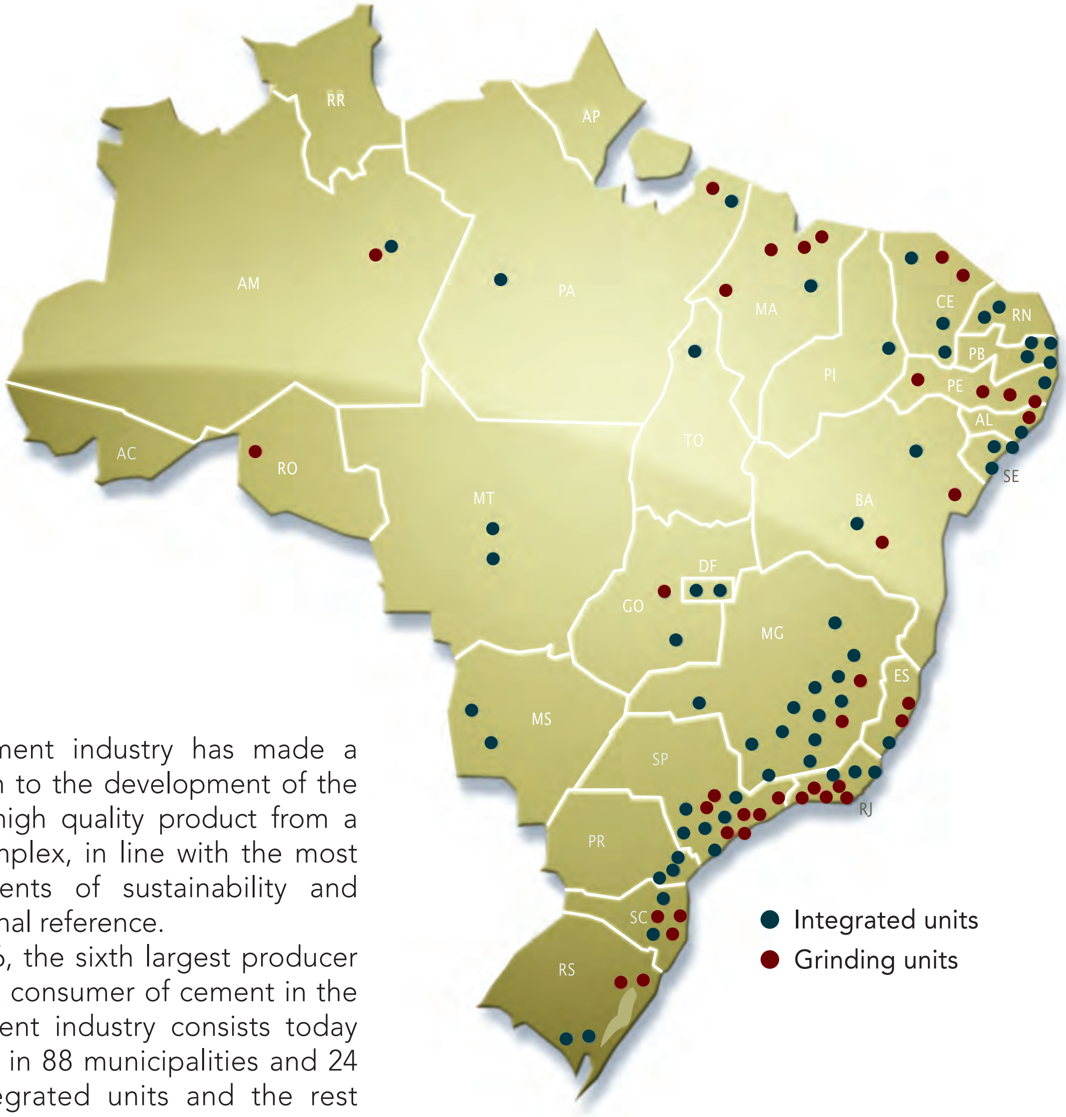
9. Cement grinding

The clinker, cooled and mixed with gypsum, is ground until it becomes a grey powder, known as common Portland cement. All types of cement contain around 3% to 4% of gypsum to control the setting time of the product. When other clinker substitutes are present in the cement, it can assume other names and acquire special properties. The grinding of these clinker substitutes can be done together with the clinker or separately. Traditionally ball mills were used for the cement grinding. However, in many modern plants more efficient technology is used – roller presses and vertical roller mills.

10. Storing in silos for packing and dispatching

The end product is homogenized and stored in cement silos for later delivery to the customer. For transport, the cement is packed in bags or in big bags, which can be palletized, or also bulk loaded in trucks.

The cement industry from a Brazilian perspective



The Brazilian cement industry has made a significant contribution to the development of the country, supplying a high quality product from a modern industrial complex, in line with the most demanding requirements of sustainability and making it an international reference.

Brazil was, in 2016, the sixth largest producer and the eighth largest consumer of cement in the world. The total cement industry consists today of 100 plants, located in 88 municipalities and 24 states, 62 being integrated units and the rest grinding mills. The majority of the plants are located in coastal regions of the country, accompanying the greater population density and the consumer market.

From 2003 to 2014, Brazil's annual consumption of cement practically doubled, due to income and job growth, strong expansion of mortgage lending, a fall in interest rates and inflation, and investments in infrastructure programs, reaching a record consumption of 72 million tons in the last year. During this same period, there were significant investments in expansion of installed capacity, reaching currently around 100 million tons per year.

Since 2015 the country has been facing a serious political-economic crisis, which resulted in the reduction of investment in infrastructure and an increase in unemployment. The increase in interest rates and salary losses reflected heavily on the real estate market, civil construction consequently suffering a strong downturn, culminating in the worst crisis that the Brazilian cement industry has ever faced, with a cumulative drop in production of 25% in the last three years.

Brazilian per capita consumption is currently 260 kg/person, less than half the world average (553 kg/person/year)[5] and well below countries in full development or already developed. The high housing deficit and the precarious infrastructure base demand implementation of important investment programs in Brazil. Considering the increase in population, with growth predicted up to mid-2040, and cement being the indispensable basis for the construction of infrastructure, an increase in the production of the product is predicted for the next decades. To reconcile this growth with a reduction in its carbon emissions is a priority for the sector.

---

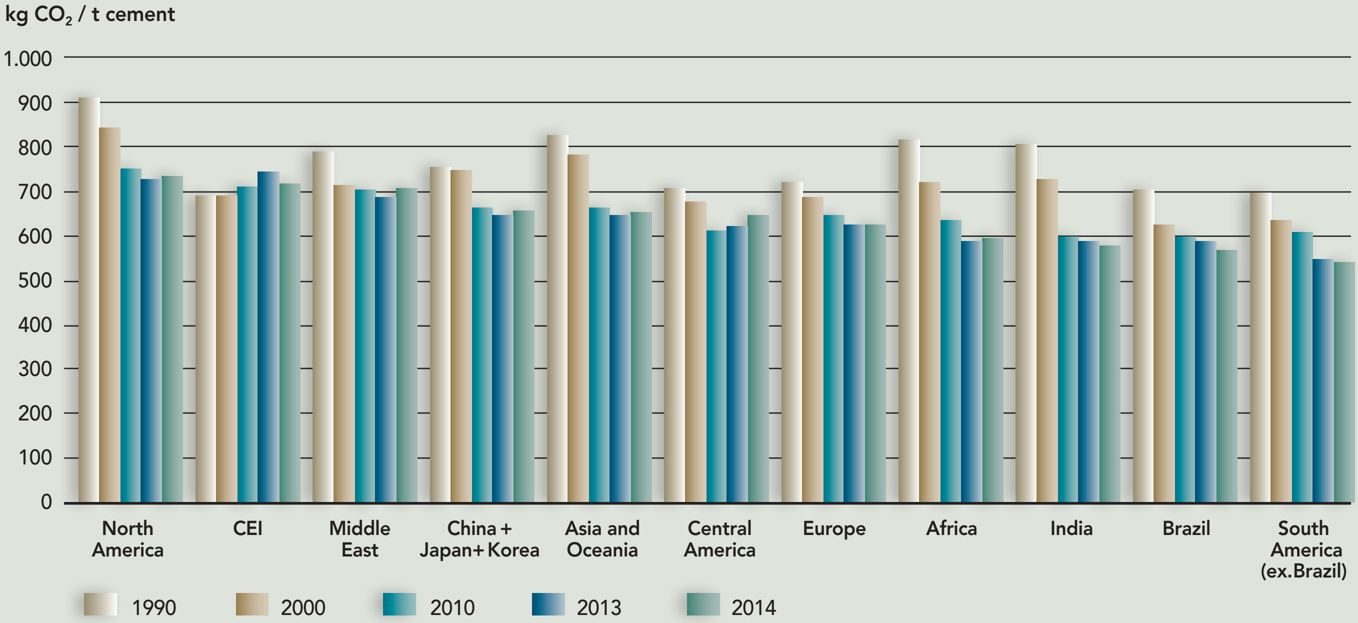
[5] Sources: World cement consumption: databasedanalysis.com; World population: UN. 2015 data.

Actions taken to reduce emissions in Brazil

Globally, the cement industry's CO_2 emissions represent around 7% of total CO_2 emissions produced by man. In Brazil, due to actions being implemented for years, this participation is practically one third of the world average, or 2.6%, according to the National Inventory of Greenhouse Gases[6].

The efforts of the Brazilian cement industry to reduce its carbon footprint, by adopting better practices available today, are reflected in its carbon intensity indicators. Since the first records of CO_2 emissions in the sector, in 1990, until today, Brazil has taken a leading position among the countries/ regions with lower specific emission per ton of cement produced in the world.

Figure 3: Emission intensity in cement production



Key-message: Due to actions implemented throughout the decades, Brazil has one of the lowest indices of specific emissions in the world, since the start of historical records.

Source: Cement Sustainability Initiative (CSI), 2014

---

[6] Brazil's 3rd National Communication to the Convention - The United Nations Framework Convention on Climate Change (UNFCCC) – MCTI 2016

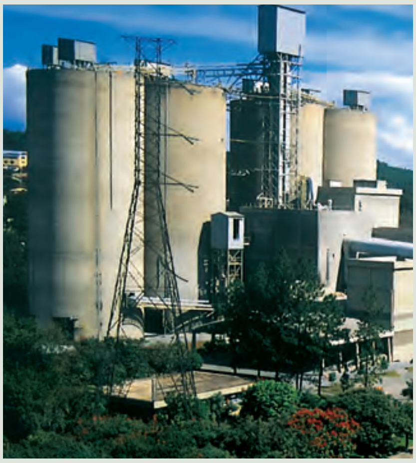
From 1990 to 2014, the sector's specific emissions diminished by 18%, from 700 kg CO_2/t cement to 564 kg CO_2/t cement[7]. During this same period, cement production grew by 277%, from 26 million to 72 million tons. The reduction in the industry's emissions was due to actions that can be illustrated in three main groups as follows:

Clinker substitutes

The national cement industry has a tradition in the use of clinker substitutes. Byproducts from other activities and alternative raw materials have been used in Brazil for more than 50 years.

Cement production with clinker substitutes, such as blast furnace slag, fly ash, calcined clay and limestone filler, besides diversifying applications and specific characteristics of the cement, represent an environmentally friendly solution for byproducts and other productive processes and for the preservation of non-renewable natural resources, while complying with the specifications of the Brazilian Association of Technical Standards (ABNT).

Between 1990 and 2014, the clinker to cement ratio was reduced from 80% to 67%, achieving one of the lowest ratio in the world.



Alternative fuels

Besides the traditional fossil fuels used by the cement industry, mainly petroleum coke in Brazil (85% of current thermal energy consumption), the use of alternative fuels is growing in the country, through co-processing of waste and the use of biomass.

The search for fuels with lower factors of emission than conventional fuels has been an important tool in the sector for reduction of its CO_2 emissions, especially from the beginning of the 21st century. This energy transition required investments in adaptation and adjustment of the production process, in addition to improvements in monitoring and control.

In the period 2000 to 2014, the industry managed to increase the share of alternative fuels in its energy mix from 9% to 15%, reducing its emissions while reducing the environmental liability represented by waste.

Thermal and electrical efficiency

Brazil's cement industry has a modern and efficient industrial complex, constantly being modernized. The almost total substitution of wet kilns for dry kilns between the 1970s and 80s (today more than 99% are dry process), the significant increase in capacity in the last ten years, with plants operating with the best available technology (BAT), and the constant investments in retrofits and equipment modernization, result in the sector's energy consumption being today below that practiced by the majority of countries[8].

Between 1990 and 2014, the sector achieved a reduction in its thermal intensity of 17%, from 4.2 GJ/t of clinker to 3.5 GJ/t of clinker. In terms of electrical intensity, the advances were less marked in this period, since the value of 113 kWh/t of cement was already close to the benchmark.

---

[7] Values obtained from GNR database – CSI, 2014

CARBON EMISSIONS REDUCTION MEASURES

View of the preheaters and precalciner tower

There are numerous studies that recommend a series of alternatives or technologies with the potential to reduce the industry's CO_2 emissions. This study analyzed more than 70 different measures mentioned in the Technical Papers of the 2009/2018 Global Cement Technology Roadmap, and the 2013 Indian Cement Technology Roadmap, as well as other international references, evaluating their applicability to the Brazilian industry. As a result, around 40 measures were identified and concentrated into four principal sets of actions or pillars.

Each of these pillars is described as follows, as well as their technical potential for implementation in Brazil during the next decades.

Note: There are frequent cases of one individual alternative for reducing emissions having influence on the potential of another alternative. For example, the use of alternative fuels generally increases the specific consumption of energy, due to its higher levels of moisture. In the same way, the process of carbon capture and storage also increases the total electrical consumption. However, to simply add the potentials for reduction of each alternative to calculate the total potential for reduction is not technically correct (see Box 2).

Clinker substitutes

An increase in the use of clinker substitutes would reduce around 290 Mt of CO_2 or 69% of the cumulative mitigation of CO_2 emissions by 2050 in the "2°C Scenario", when compared to the "6°C Scenario".

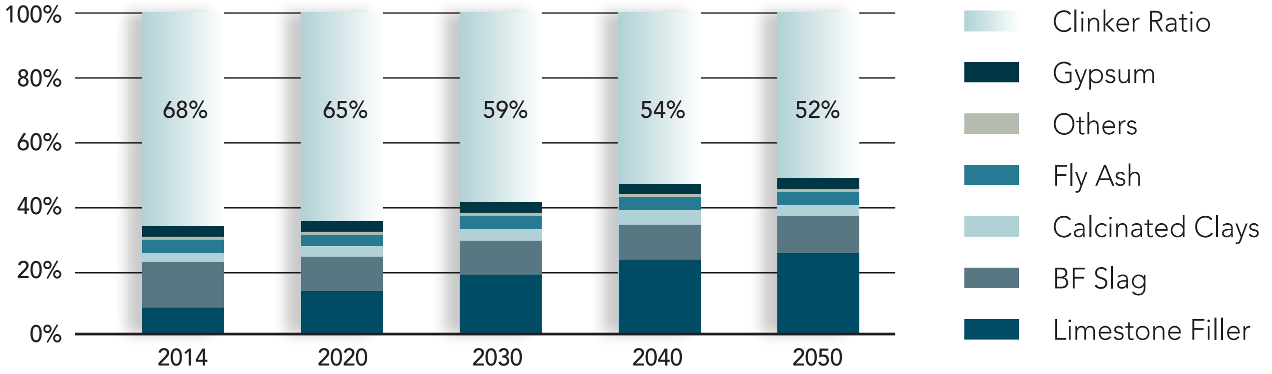
Clinker is the intermediate product in the manufacture of cement, composed of silica, aluminum and iron. It is obtained by burning limestone and clays at high temperatures in rotary kilns. When ground finely with gypsum, in proportions of 3% to 4%, it forms Portland cement, a hydraulic binder which on reacting with water becomes hard and resistant, preserving this property even when submersed. There are other materials with hydraulic properties that can partially substitute the clinker in the manufacturing cement process, creating many types of cement with distinctive characteristics and properties.

The most traditional materials used as substitutes for clinker are granulated blast furnace slag (a by-product from pig iron production), fly ash (residue from thermoelectric plants fueled by coal) and certain natural materials, calcined or not, among others. The production of Portland cement with clinker substitutes results in reduction of CO_2 emissions, since the consumption of clinker per ton of cement is reduced, and consequently the burning of fuels and the emission by calcination/decarbonation, apart from contributing to the preservation of quarries/mines.

The use of clinker substitutes in cement diversifies the applications and specific characteristics and frequently provides advantages related to greater durability and useful life of concrete structures (low permeability, resistance to attack by chlorides and sulfates, prevention of alkali-aggregated reaction, high strength in more advanced ages).

For the period 2030 and 2050, in a "2°C Scenario", the volume of clinker substitutes should grow, reducing the clinker factor from current levels (around 67%) to 59% in 2030 and 52% in 2050. Due to regional character of distribution of some of these clinker substitutes, and the prediction of lower availability in the future of traditional clinker substitutes, slag and fly ash, related to the evolution of technological processes, an increase of the limestone filler content is one of the more promising alternatives in the mitigation of CO_2 emissions.

Figure 4: Evolution of the use of clinker substitutes in "2°C Scenario"



Key-message: If the availability of slag and fly ash is reduced, the major potential for further reduction of the clinker proportion is in greater use of limestone filler.

Source: IEA modelling developed for this project. © OECD/IEA, 2016

Blast furnace slag as an additive to Portland cement has been used in Brazil for nearly 70 years, and technical obstacles have been studied and overcome by the industry and by academia. In 2014, more than 95% of granulated blast furnace slag produced in the country was consumed by the cement industry. The obstacle to the increase in use of slag by the cement industry is, in the short and medium term, the lower growth in supply in relation to the increase in cement production, due to the rising global competition faced by the national steel industry; and in the long term by the evolution of technological processes, with a lower production of slag per ton of pig iron produced, and a shift away from pig iron at all. It can be estimated that the production of slag, in 2050, could be 14.8 Mt. The average content of slag in cement would go from 14% in 2014 to 11% in 2050 – less therefore than the average content currently.

Data indicates a similar trend with the use of **fly ash**, which from the perspective of lower investments in coal-burning thermoelectric plants and from the tendency to decarbonize the electric grid, in a more favorable scenario for clean energy sources, such as wind power and solar energy, will be unable to attend to the demand resulting from the growth of cement production. The maximum annual production capacity of ash today is around 4.4 Mt. However, this number is much influenced by the utilization factor of thermoelectric plants, which in 2013 was around 50%, producing only 2.2 Mt of ash. In 2050, it is estimated that the annual production of fly ash will reach values near to 3.3 Mt, representing a rate of substitution of 2% to 2.5% in cement[8].

Two types of clinker substitutes tend to be responsible, in the long term, for the decrease in the clinker-to-cement ratio: limestone filler, and on a smaller scale, calcined clays.

The use of **limestone filler** does not demand large investments, does not require calcination and is easily available to all plants that opt for its use. However this option requires a gradual increase in its content in the cement to overcome eventual operational difficulties and guarantee its performance, to achieve the consumer acceptance. Among all the clinker substitutes, limestone filler offers the greatest potential in mitigation of CO_2 and its use demands that the regulatory base be adapted to this scenario of producing cements with a lower intensity of carbon, backed by requirements and performance criteria that provide the technical basis for quality control and specification.

The change in the standards, which takes into account the existing synergies between calcined clays and limestone filler, will facilitate increasing the use of the latter in cement manufacturing. However, the cement end application/end use should be considered – being it in structural works with higher technical requirements or general use cements with less structural requirements that can be fit for purpose for an informal market of self-builders which, by 2050, will still have a high share.

Brazil already has reasonable experience in the use of **calcined clays**, which have almost unrestricted distribution all over the country. Its isolated use as clinker substitute already has a regulatory basis. Its manufacture, however, has less potential for CO_2 mitigation, since contrary to other clinker substitutes, calcination of these clays will demand fuel consumption, consequently resulting in CO_2, although less than a quarter the emissions of clinker[9]. Additionally, it demands investment in machines and calcination.

So the calcined clay´s average rate of clinker substitution should be lower than that of limestone filler, but its use together with limestone filler can be stimulated, mitigating its undesirable effects on the rheology of concrete. For this, a new regulatory base should be created, similar to that already existing in Europe with other pozzolanic materials.

On a lower scale and with growth potential difficult to predict, **acid slag and steel slag** should be considered. The increase in their use in cement will depend on the steel industry and the pressure of environmental legislation, with investments to transform them into materials usable by the cement industry.

Finally, regional experiments, such as the use of copper, nickel, manganese slag and other materials such as natural pozzolans, that effectively prove pozzolanicity or hydraulicity, should be continued, as they could provide specific solutions for the mitigation of CO_2.

---

[8] Although an increase in absolute production of ash is expected, the participation of thermal plants in the national grid, which is already at a minimum, will fall even further.

[9] Calcined clays require about 70% of the energy required for clinker calcination (or about 2.5 MJ/t). Thus, although process emissions (decarbonation) are avoided, the emissions related to fuel combustion still occur, but to a lesser extent.

Figure 5: Characteristics of clinker substitutes in Brazil

Clinker Substitutes	Souce	General characteristics of blended cements compared to ordinary cements		Estimated level of production and consumption
		Positive	Limiting	
Blast furnace granulated slag	Production of pig iron	High mechanical strength at long ages and better durability	Higher power consumption of the grinding and lower mechanical strength; regionalization of supply	Production: 7.4Mt in 2014, 11.1 Mt in 2030 and 14.9 Mt in 2050 Consumption: 7.1Mt in 2014, 10.0 Mt in 2030 and 14.7 Mt in 2050
Fly ash	Coal fired thermo-electric plants	Low demand for water, improvements in workability, greater mechanical strength at long ages, improved durability	Less relative mechanical resistance, principally at early ages, regionalization of supply	Production: 2.2Mt in 2014, 3.0 Mt in 2030 and 3.3Mt in 2050 Consumption: 1.4Mt in 2014, 2.7 Mt in 2030 and 3.1 Mt in 2050
Calcinated clays	Specifically produced from clay mines	Improved durability and unrestricted distribution	Lower relative mechanical strength, especially at early ages and larger counterparts to ensure the rheology	Great availability of clay reserves. Consumption: 1.5Mt in 2014, 3.4 Mt in 2030 and 5.4 Mt in 2050
Limestone fíller	Limestone mines	Improved workability and synergetic effect when associated with calcined clays	Cement content limitation, as it does not perform as traditional additions	Great availability of limestone reserves. Consumption: 4,0Mt in 2014, 16.4Mt in 2030 and 33.5Mt in 2050
Blast furnace acid slag	Production of pig iron using coal	Improved durability, greater response to thermal cure	Lower relative mechanical strength, especially in early ages	Production: 1.22 Mt in 2030 and 1.64 Mt in 2050 Consumption: 0.24 Mt in 2030 and 0.49 Mt in 2050
Steel slag	Steel production	Reduction in clinker-to cement ratio, synergetic effect with blast furnace slag	Lower relative mechanical strength, especially in early ages	Production: 5.6 Mt in 2030 and 7.5 Mt in 2050 Consumption: 1.1 Mt in 2030 and 2.2 Mt in 2050

Challenges to implementation

Some limiting factors for the adoption of cements with a high clinker substitute's content are as follows:

- Uncertainties related to the availability of blast furnace slag given the lower supply growth in relation to the increase in cement production.
- Due to the absence of investment in coal-fired thermoelectric plants, and the tendency toward greater decarbonization of the power grid, there will be no significant increase in the fly ash availability, limiting it to a little more than that used today due to the low rate of use of thermoelectric plants (currently 50%).
- The regionalized availability of granulated slag in the Southeast region and of fly ash in the Southern region prevents its use in other regions of the country.
- The lack of partnership with the steel industry in the sense of pooling efforts in the activation of non-granulated slag, or even to encourage greater use of non-traditional slag (manganese, nickel, copper and others). This failure impacts the availability of clinker substitutes, and the advantages of having an environmental destination for this waste.
- Brazilian standards limit the use of limestone filler to a maximum of 10%, and a new standard is needed, permitting its use with other pozzolanic materials and the development of other types of cement.
- The need for research programs for the development of new products (quaternary cements) with higher clinker substitutes (filer limestone and calcined clays), as well as new materials to be used as alternative cement constituents.
- Disinformation of the informal consumer ("self-builder") regarding best practices in the use of cement.

Alternative fuels

The increase in the use of alternative fuels would reduce around 55 Mt of CO_2 or 13% of cumulative mitigation of CO_2 emissions by 2050 in the "2°C Scenario", when compared with the "6°C scenario".

The energy needed for the manufacturing process makes the cement industry one of the five sectors in the world with the largest energy consumption. For this reason it is constantly diversifying the range of fuels used.

Around 85% of fuels used by the sector in Brazil are of fossil origin, almost exclusively petroleum coke, or petcoke. The other 15% are classified as alternative fuels, and are subdivided, essentially, into waste and biomass.

The use of alternative fuels in the production process reduces the amount of fossil fuels needed, contributing to the reduction of greenhouse gases by having a lower CO_2 emission factor, i.e. they emit less carbon in generating the same amount of energy.

Cement kilns have characteristics favorable to the burning of waste, such as high temperatures, a long time at temperatures above 1,450°C, oxidizing atmosphere, total destruction of organic components and zero ash, among others.

The combined operation of manufacturing cement together with the burning of waste is known as co-processing. Besides re-using the energy value and the mineral fraction of the waste, substituting non-renewable fossil fuels, co-processing diminishes the environmental impact caused by inadequate disposal of waste in nature.

Even when technical problems limit the use of certain waste or co-processing, the range of adequate matter is very large[10].

Table 2: Principal types of waste used by the cement industry

- Waste oil
- Solvents
- Greases
- Textile waste
- Plastic waste
- Sawdust
- Waste from paper factories
- Scrap tires
- Waste from rubber factories
- Sludge from chemical processes
- Distillation bottoms
- Sludge from municipal sewers
- Animal bones and bone meal
- Expired grains

---

[10] Besides those not used due to process limitations, some waste is forbidden by Brazilian legislation, such as radioactive, explosive and those from the health system.

Different types of waste have been used as alternative fuels in cement kilns in Europe, Japan, USA, Canada and Australia since the start of the 1970s.

In Brazil, co-processing of industrial waste started in the 90s, in states in the South and Southeast. However, experimental use of alternative fuels by the cement industry even earlier, such as the use of rice straw during the 1980s, charcoal from the steel industry, babaçu nut shells, sugarcane bagasse, among others.

In 1999, the National Environmental Council (CONAMA), of the Ministry for the Environment, published a resolution defining directives for the licensing of co-processing, an initiative complemented later by another resolution establishing limits of emission for dioxins and furans.

Since then, the use of clinker kilns as a tool for waste management has become more and more important in the national scenario.

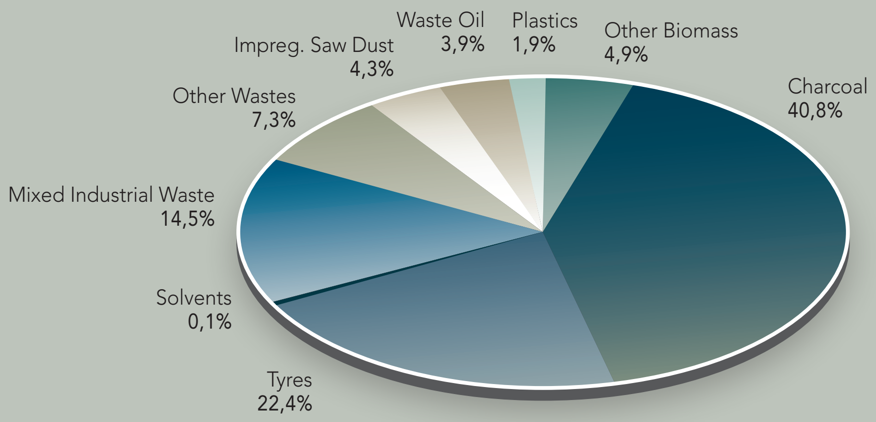
In 2010, Law No. 12.305, which institutes the National Policy for Solid Waste (PNRS), established a hierarchy in waste management and prioritized use for energy rather than disposal in landfills, which strengthened, on a legal level, the option for co-processing of waste.

Currently around 60% of integrated plants have kilns licensed by environmental agency to co-process waste.

The consumption of alternative fuels by the sector in Brazil has grown considerably. However, when the current level of thermal substitution (15%) is compared to that of other countries, it is clear that there exists major potential for an increase in the use of waste and biomass for energy generation, including municipal solid waste.

In 2014, the Brazilian cement industry utilized 1.5 million tons of waste and biomass, representing 15% of the total energy consumed, 8% coming from waste and 7% from biomass.

Figure 6: Mix of alternative fuels used by the Brazilian industry



Key-message: With a total shortage of charcoal predicted for 2030, the cement industry should procure other sources of biomass.

Source: CSI, 2014; ABCP, 2016

To achieve the "2°C scenario" in the future, the sector intends to increase thermal substitution to 35% by 2030 and 55% by 2050. With this objective, based on international trends and also on the Brazilian reality and conditions, a possible evolution of the principal types of alternative fuels was evaluated, and their respective potential for use by the Brazilian cement industry.

These fuels were identified in seven distinct types, four already being widely used by the industry: scrap tires, hazardous industrial waste (blend[11]), non-hazardous industrial waste and charcoal; and another three with major potential for use, and principally with a lower emission factor[12]: fuel derived from Municipal Solid Waste (MSW), sludge from sewage treatment, and agricultural waste.

In the case of **scrap tires**, which are currently the waste most used by the industry, the tendency is towards less availability in the future market due to the emergence of new solutions for recycling and use in civil works. For this reason, despite an expected increase in the vehicle fleet, the percentage use of tires by the cement industry should not experience significant alterations in the future[13].

---

[11] Oils, solvents, paints and others.

[12] The pure biomasses, such as sewage sludge and agricultural waste, are considered as neutral in carbon, with an emission factor of zero. In the case of SRFs (solid recovered fuels), a fraction of biomass of around 30% is considered for the Brazilian context.

[13] Currently around 70% of scrap tires in the country are destroyed by co-processing.

The blends of **hazardous industrial waste** prepared by the blending platforms will possibly be limited by a reduction in their production and the cost of preparation. For this reason a significant variation in the percentages of waste-fuel blends is also not expected in the coming decades.

The most promising materials are the solid recovered fuels (SRF) produced from non-hazardous waste and municipal solid waste (MSW).

The availability of **non-hazardous industrial waste** should increase in the future with the limitations to disposal in landfills imposed by the National Policy for Solid Waste.

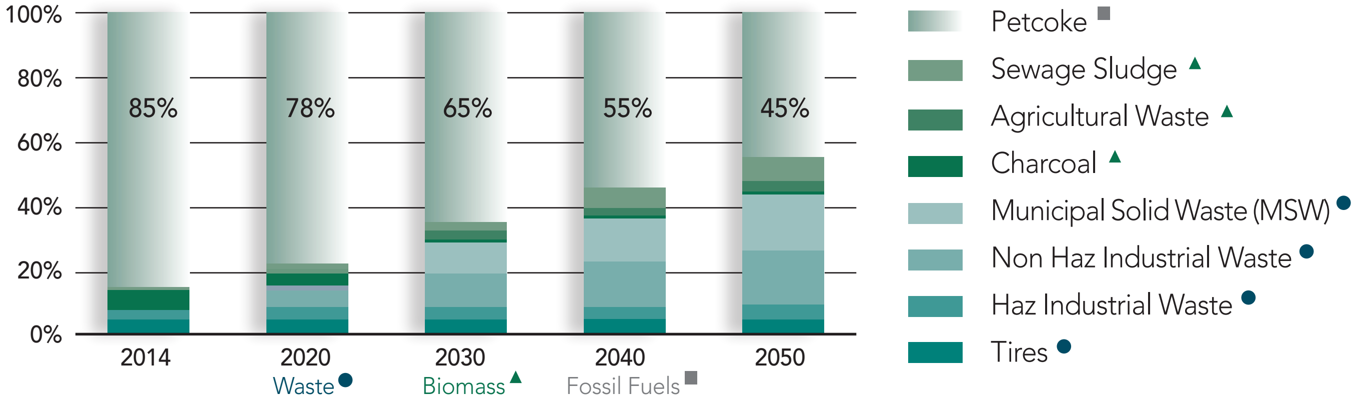
Solid recovered fuels from **municipal solid waste (MSW)** shows enormous potential, in light of environmental pressure to reduce or eliminate landfills in the near future. However, limiting factors to this alternative could be: the need for a mature selective collection system and sorting of the materials; distance from the plants in relation to large urban centers; difficulty of establishing contracts that guarantee the supply of waste; technical questions related to excess of chlorine; and the need to process the trash to convert it to fuel[14].

In relation to biomass, the main source used currently is **residue from charcoal**, which comes from small pig-iron plants. In light of the contraction of this sector and the forecast of technological changes in the future, total scarcity of this fuel is expected as early as 2030. The sector will have to seek alternative sources of biomass.

One potential alternative is **agricultural waste**. However, as Brazil is a country of continental dimensions, locations of agricultural production, volume, seasonality, costs of collection, transport etc. must be considered by region.

Sewage sludge, produced from municipal effluent treatment plants, could also have potential for co-processing in the near future, but with limited impact on thermal substitution due to the low calorific power and the need to remove the moisture.

Figure 7: Evolution of the use of alternative fuels in the "2°C Scenario"



Key Message: The contribution of non-renewable fossil fuels in cement production should diminish from 85% to 45% in the "2°C Scenario", due to the growing use of waste and biomass.

Source: IEA modelling developed for this project. © OECD/IEA, 2016.

---

[14] To transform trash (Municipal Solid Waste – MSW) into fuel it needs to undergo a long process of preparation and treatment to separate the recyclable portion.

Challenges for implementation

- **Technical:**

  Although thermal substitution is possible with 100% of alternative fuels, technical challenges could arise due to the significant differences in relation to traditional fuels, for example the low calorific power, a high concentration of chlorine, sulfur or moisture, or the presence of other substances detrimental to the process. Regarding biomasses, the difficulties of handling and storage due to their low density as well as their availability, related to the regionalization of the various crops and to the seasonality, should be considered as they would only be available during the harvesting periods.

- **Economic:**
  - The low cost of disposal in landfills and dumps affect competitiveness with other treatment technologies, such as SRF production.
  - Proximity of the cement plants to urban centers and / or sources of waste and biomass.
  - Competition with other alternatives for energy recovery or materials.
  - Logistical difficulties and costs

- **Legislation:**
  - Long and bureaucratic licensing procedures.
  - Laws that encumber or forbid energy recovery from solid waste.
  - The possibility of state environmental agencies resolutions that impede or limit the deposit, storage and processing of hazardous waste generated outside the state.
  - Non-compliance with local and federal legislation that restricts disposal in landfills or dedicated incineration.
  - Failure to observe the hierarchy of waste management established by the National Policy for Solid Waste, which prioritizes energy recovery as against disposal in landfills.
  - Difficulty in establishing long term contracts for supply of municipal solid waste with public agents.

- **Relations with local communities:**

  The co-processing of waste can strongly affect relations with surrounding communities. Due to lack of information, people frequently associate the use of waste with the increase in harmful emissions, when in reality the contrary is true[15].

---

[15] Process controls and emission standards for units coprocessing wastes are even more restrictive than for those using conventional fuels.

Thermal and electrical efficiency

Improvements to the energy efficiency would reduce around 38 Mt of CO_2 or 9% of cumulative mitigation of CO_2 emissions by 2050 in the “2°C Scenario”, in comparison to the “6°C Scenario”.

Cement production is an energy-intensive activity throughout the whole process, from the preparation of the raw materials to the grinding of the final product, via clinker production at temperatures that reach 1,450°C.

The Brazilian cement industry has been making improvements to its energy efficiency for many years. In the 1970s and 80s, after the two main petroleum crises, various companies took measures to reduce energy in their manufacturing processes, from simple operational adjustments to more complex and intensive changes in investment, processes and equipment. One example was the rapid substitution of the wet process by the dry process in the production of cement. The wet process, energy intensive and representing around 80% of production in the early 1970s, was transformed into the dry process, reaching almost 90% of production already in the first half of the 80s. Currently, 99% of Brazilian cement production uses the dry process.

In the last ten years, in response to a growing demand from the construction sector, the industry has doubled cement production and increased its installed capacity by 50%, reaching 71 million and 100 million tons/year, respectively. To achieve this the best available technology was used (BAT)[16].

Today, around 40% of the industrial complex is less than 15 years old, and more than 70% of its kilns are equipped with 4 to 6 stage pre-heating towers and pre-calciners. Modern grate coolers equip 80% of Brazilian kilns and approximately 46% of the raw material mills are vertical, considered to have lower electrical consumption.

Consequently, the sector achieves an average thermal consumption of 3.5 GJ/t of clinker (836 kcal/kg clinker) and an average electrical demand of 113 kWh/t of cement[17].

Given this modern and efficient profile, significant changes in thermal consumption are expected from 2030, when older units - over 40 years old - will be replaced by units that will use the best available technology at the time. One should consider the effect of increased cement production after 2030, which opens up the potential for integrating BATs as new production capacity enters the industry.

Apart from this, a series of measures to improve energy efficiency will be adopted, not only reducing emissions, but also aiming at general improvements in operations. Among these, the most effective are the increase in thermal efficiency of the plants: process controls and production optimization, improved burnability using mineralizers and optimization of heat recovery in cooling the clinker.

Due to its low cost and easy implementation, the improvement of **process controls and production optimization** is one of the most promising measures. This is the best option for the Brazilian industry in coming years, also because automatic process monitoring systems are available and tend to be ever more efficient, due to the increase in capacity of data processing and continual improvements of algorithms for information treatment.

Improvements in the raw meal burnability, using **mineralizers**, despite its potential for emissions reduction, face difficulties in implementation in the country due to the scarcity of fluorite deposits, one of the primary mineralizers. Besides this, the solution requires improvements to specific technology.

In relation to measures for electrical efficiency, due to the predominantly renewable electric power grid in this country, the participation of electrical consumption in the sector’s emissions is significantly less than the worldwide average (only 1%, against 5%). Among measures studied that showed greatest potential is **waste heat recovery** (WHR) for electricity production. The potential of this technology for electrical economy is significant, with around 20% to 30% reduction in the plant’s total imported electricity. This alternative alone has the impact on electrical consumption equal to the sum of all other options for electrical economy mentioned here. It is estimated that this technology could be adopted by around 35% of Brazilian clinker producing capacity in the medium term (2030).

---

[16] Best available technologies

[17] Values obtained from the database Getting the Numbers Right, from the Cement Sustainability Initiative - CSI, 2014

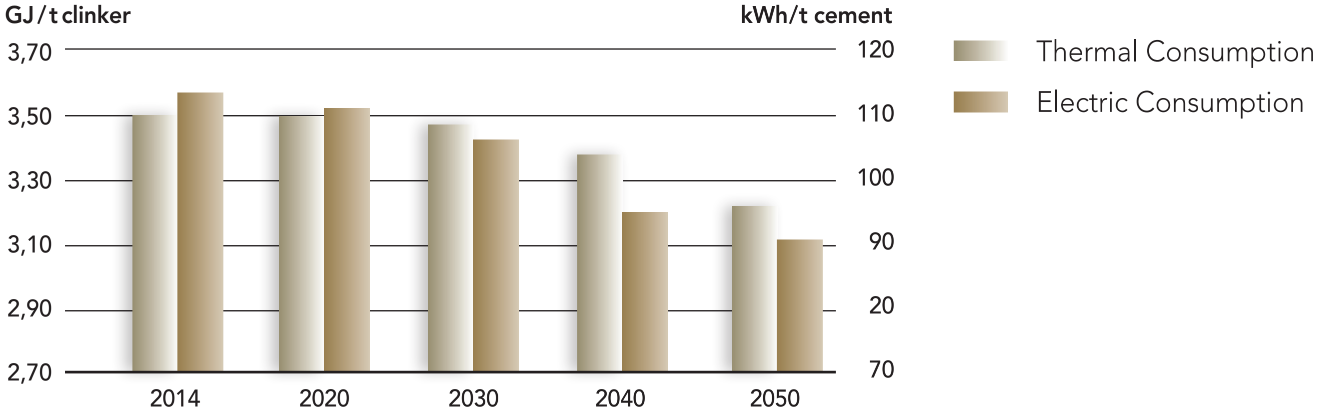
Despite the modest contribution of this technology in terms of reduction of CO_2 emissions, the following should also be considered: substitution of ball mills by **vertical roller mills, HPGR or horizontal mills**; use of **high efficiency separators; optimization of cement grinder operations**; and other **general measures** (use of high efficiency motors, use of Variable Speed Drive (VSD), preventive maintenance and minimization of air leaks).

If implemented, it would be possible to reach values approaching 3.22 GJ/t of clinker and 91 kWh/t of cement by 2050 (87 kWh/t of cement, excluding CCUS[18]).

Based on these numbers, in a "2°C Scenario", if all the other variables remain constant, it is estimated that the reduction in thermal consumption would be around 137 PJ and electrical savings greater than 3,000 GWh, in relation to the "6°C Scenario".

In terms of carbon mitigation, these energy savings estimates would result in a reduction of emissions in the region of 38 Mt CO_2 between 2014 and 2050.

Figure 8: Thermal and electrical intensity in cement production in the "2°C Scenario"

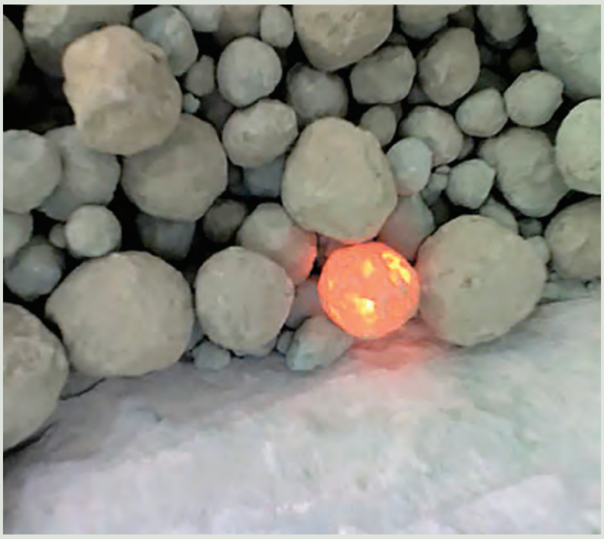


Key message: More significant advances in thermal and electrical efficiency will be observed after 2030, with the substitution of the more obsolete units and equipment by new plants operating with best available technology (BAT).

Source: IEA modelling results for the evolution of the share of alternative fuels.

Box 2: The importance of integrated scenarios

It is important to point out that the different alternatives for reduction cannot be treated in isolation. It is necessary to consider the impact that some measures have on others. The search for more reactive clinker to permit a higher level of clinker substitutes and the switch of fossil fuels for alternative fuels, with a greater content of moisture and chlorine, has a negative impact on the thermal consumption of the kiln. In the same way, CCUS measures also increase the electrical consumption of the unit. In an integrated analysis of the different scenarios and alternatives for reduction, it becomes a challenge to achieve state of the art in terms of thermal consumption (2,9 GJ/t clinker) and electrical (80 kWh/t cement).



---

[18] Carbon Capture and Utilization or Storage

Challenges for implementation

The specific thermal and electrical consumption depends on various factors, such as the thermal efficiency of the equipment, the way the materials are transferred during the process, and the level of automation and the quality of raw materials and fuels.

Some obstacles that prevent the industry from achieving lower levels of energy consumption are as follows:

- Investments: Reduction in specific consumption in older plants requires major retrofits, which normally demand large investments and are only justified economically if there is a need for an increase in production.
- Credit: Economic and financial obstacles are possibly the most important, due to the major investment demanded by some measures. Common impediments are: difficult access to capital, high cost of developing opportunities, high economic risk and the existence of unidentified initial costs. Another important obstacle is the high cost of importing equipment, created by the combination of high import dues in Brazil and unfavorable exchange rates.
- Environmental requirements: Public policies for mitigation of environmental impacts by the industry have become more and more restrictive, resulting in growth in specific energy consumption. For example, installation of bag filters instead of electrostatic precipitation; adoption of mechanized systems for loading and unloading, in order to avoid emission of escaping dust; and installation of new controls for gas emissions (NOx, SO$_X$ and others).
- Increase in use of alternative fuels: These fuels require more air, preparation and injection systems, and also have a larger content of moisture and granulometry. On the other hand, their lower emission factors effectively counter the disadvantages caused by the increase in energy consumption.

Innovative and emerging technology

The viability of innovative and emerging technology would reduce around 38 Mt of CO_2 or 9% of cumulative mitigation of CO_2 emissions by 2050 in the "2°C Scenario", in comparison with the "6°C Scenario".

The alternatives traditionally used in the sector for mitigation of emissions have a technological and operational limit. As the industry approaches this barrier, long term innovative solutions must be sought, which permit it to go further towards a less carbon intensive process and which is consistent with the "2°C Scenario".

Among the innovative and emerging alternatives, CCUS – *Carbon Capture and Utilization or Storage* appears as one of the main potential technological solutions for large sources of emissions, as in the case of the cement sector.

In the CCUS process chain, there are usually three basic stages: (i) capture and separation of CO_2 in the source of emission, (ii) transport (iii) use in other production processes, such as the algae growth (biomass for use as fuel) or even permanent storage in geological reservoirs.

Carbon Capture

CO_2 capture for application in the clinker production is the same as that considered in the energy generation of other industrial sectors: pre-combustion, post-combustion and oxy-combustion.

Among these three choices, pre-combustion is the least viable for application in the cement industry. Its applicability would depend on the viability of adapting the clinker production process to use hydrogen as the primary fuel in the kiln. Even so, CO_2 emissions generated by calcination would still not be avoided, as a post-combustion process would be needed for this. Thus the potential for reduction of CO_2 is estimated at less than 40% of the total emitted (ECRA, 2009/2017).

Post-combustion techniques are capture mechanisms that do not require significant changes in the production process and permit the retrofit of units already in operation, depending on any restrictions in physical space. Among the options for post-combustion are the following:

- **Chemical absorption:** Method of separating CO_2 from the other effluent gases by means of chemical solutions, such as amines. This process is the most advanced, and is already used commercially in other sectors, and can achieve high rates of capture. In the cement sector, there are pilot tests that indicate a potential reduction of CO_2 of up to 95%, demanding however additional thermal and electrical consumption (Ketzer et al, 2016; ECRA, 2009/2017).

- **Use of membranes:** This solution is interesting from the operational point of view. The membranes are small, require little monitoring and maintenance, do not need energy for regeneration and don't generate residue. However, it is still necessary to develop appropriate materials and cleaning techniques. Their potential for absorption is more than 80% of the CO_2 emitted (ECRA,2009/2017).

- **Calcium cycle:** This is a process of chemical absorption in which the calcium is brought into contact with the combustion gas containing CO_2, forming calcium carbonate. The technology is being considered as a potential option for retrofit of existing kilns, although it causes a significant rise in thermal consumption. Results on a laboratory scale indicate a potential for CO_2 reduction of up to 85% (Romano, M. C. et al, 2013).

The oxy-fuel technology (burning pure oxygen instead of air), although still very costly, is considered very promising for application in the cement industry.

Two possibilities are considered for implementing this type of process in the production of clinker:

- **Partial oxy-fuel (applied only in the calciner):** Existing plants could be adapted to use this technology, and around 60% to 75% of CO_2 emissions from the kiln could be captured (Ketzer et al, 2016; ECRA, 2017).

- **Full oxy-fuel (applied in the calciner and the rotary kiln):** The pre-heating tower needs no alterations. The kiln, however, should be adapted or remodeled to operate in oxy-fuel conditions. This process will provide CO_2 capture in the order of 90% to 99% (Ketzer et al, 2016 ; ECRA, 2017).

There have been experiments in clinker kilns in the USA and Europe in operations with oxygen enrichment to increase production capacity. The oxy-combustion technology has also been investigated in electric power plants, with results that can be transferred to cement kilns. Research is also being carried out in the cement industry that investigates the oxy-combustion process for the burning of clinker and the impact on product quality and costs (ECRA, 2017).

Carbon Storage

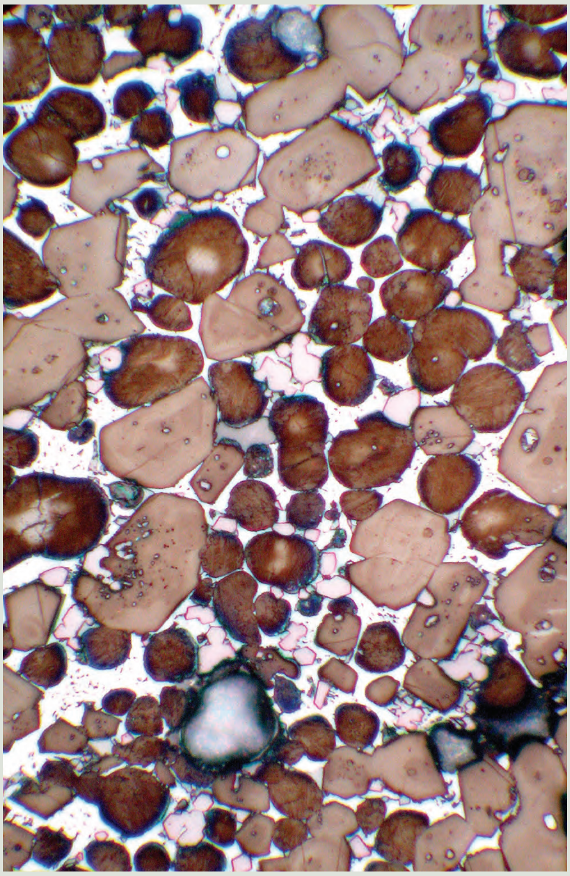
Once captured and separated from the other components of the effluent, CO_2 needs to be transported to the locality of use or storage. Options for the final destination of the CO_2 should take into consideration various factors and evaluated case by case. In particular, the volume generated and the degree of purity of the CO_2 obtained will determine if it can be used or permanently stored.

Costs relating to CCS - *Carbon Capture and Storage* include, apart from capture and separation, the transport, geological storage and environmental monitoring.

The reservoirs considered ideal for storage of CO_2 are rock formations created by the deposits of sediment accumulated in sedimentary basins. These reservoirs must have sufficiently high porosity and permeability, have formations that impede the return of the CO_2 to the surface, and be situated at a depth sufficient for storage of large quantities in small volumes, among other features.

Carbon Utilization

Alternatively to the permanent storage of carbon, CO_2 can be re-used in various processes and industries. Although its potential is limited due to the large volume of CO_2 emitted by the cement industry, CCU - *Carbon Capture and Utilization* is a more promising solution for the sector than CCS, due to its cost. Currently there are various projects and studies being made on the utilization of CO_2.



Photomicrography of clinker observed under a light microscope with the presence of calcium silicates.

Small volumes of CO_2 can be used in other industries, such as for example the food industry, though it must be of the highest purity. As volumes obtained are usually large, other options should be considered, such as its use in EOR – **Enhanced Oil Recovery**. In this process the CO_2 is injected into oil fields to increase the pressure and dissolve in the fluids of the reservoir, increasing the oil recovery factor. It shoud be considered that different types of applications have different characteristics regarding the duration of the CO_2 lock-in effect. While CO_2 used in the food and beverage industry will be released back to the atmosphere shortly after use, EOR applications can be characterized as CCUS where CO_2 is retained underground.

One option for the use of CO_2 is the **mineral carbonation** process, in which the gas captured reacts with minerals, generally calcium silicates or magnesium, and the products of the reaction (calcium carbonates and magnesium) can be used as construction material or stored.

Another process transforms CO_2 into **sodium bicarbonate** in three stages – treatment of the gas, absorption and electrochemical transformation - and each of these stages is already used by the industry. In 2014 a plant was inaugurated using this technology, associated to a cement plant with capacity for capturing 75,000t of CO_2 per year. The chief obstacle to its use is the saturation of the bicarbonate market. For these reasons, this technology can only be considered as part of a portfolio with other CO_2 capture technologies

The use of **algae to capture CO_2** is another option being studied by the industry. The technology produces biomass, which can be used as a source of energy, adding some income and providing potential for mitigation of greenhouse gas emissions. In this process, the photosynthetic efficiency of the algae is high, developing more rapidly than other biological options. Apart from this, the algae don't depend on areas of land and don't compete with food production. On the other hand, they do demand water. The major obstacle to expansion of their use in the cement industry is the current status of the technology. Both the efficiency of conversion and the costs are still not competitive, especially if compared with sugar cane ethanol and bioenergy, which also convert solar radiation into energy vectors.

There are other projects in progress studying the use of carbon. For example, capturing exhaust gases by use of micro-organisms that convert CO_2 and hydrogen into fuels and/or bioplastics; or, the conversion of CO_2 in methanol and formic acid, chemical products that can be used as fuels or in the production of hydrogen.

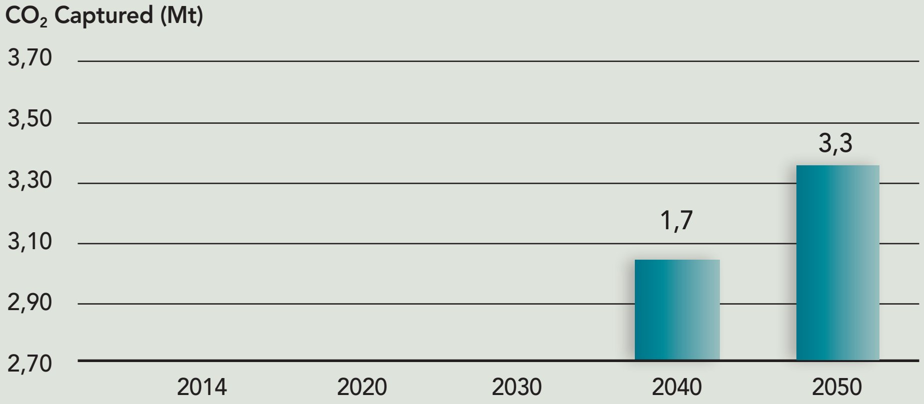
To the extent that limitations of CO_2 emissions become more rigorous and the usual alternatives approach their maximum technical potential, more costly strategies of carbon mitigation, that however provide greater reductions of CO_2, such as carbon capture, need to be implemented.

In the "2°C Scenario", carbon capture in the Brazilian cement industry gets deployed from 2040 onwards to meet the emissions reductions ambitions, as the clinker-to-cement ratio reduction is identified as a more economical carbon emissions mitigation option, which accounts for the bulk of the emissions reductions effort, reaching 3.3 Mt of CO_2 captured per year by 2050. However, it is fundamental to support research and development (R&D) of all types of emergent and innovative technology from now, in order to favor its technical and economic viability on a large scale in the medium and long term.

Finally, an aspect that still requires research is the question of re-carbonation of concrete, a chemical phenomenon that occurs both during the useful life of cement and during the recycling of construction and demolition rubble, after the end of the concrete's period of life. This phenomenon certainly occurs, but it needs to be quantified for the diverse applications and use of cement.

Note: This section includes several types of applications with different characteristics regarding the time of the carbon sequestration effect. Although CO_2 used in the food and beverage industry is released back into the atmosphere soon after use, other applications, such as EOR, where CO_2 is trapped underground, have a permanent effect.

Figure 9: Carbon captured by the cement industry in the "2°C Scenario"



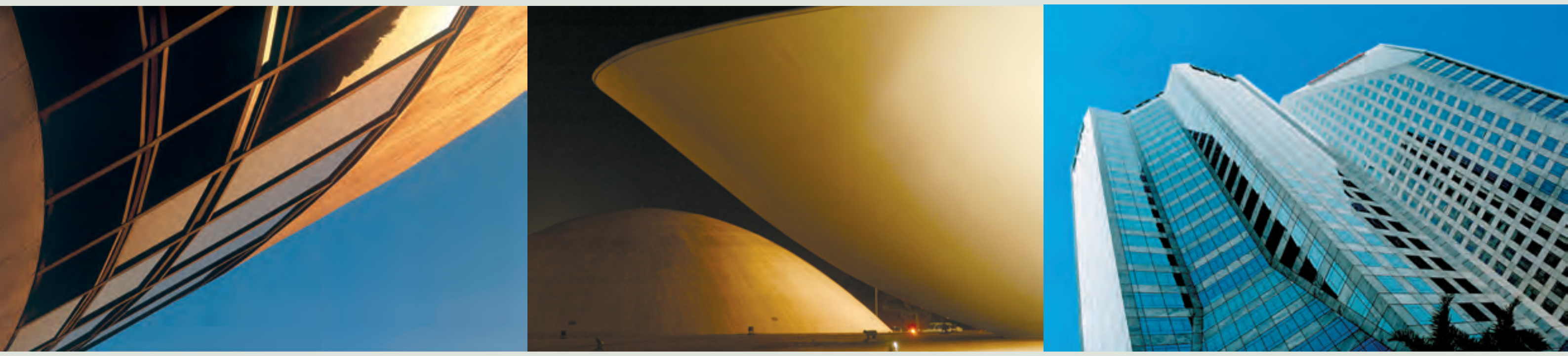
Key message: Carbon capture, an alternative still emerging for the mitigation of CO_2 emissions, would become viable for the Brazilian cement industry only after 2040.

Source: IEA modelling developed for this project. © OECD/IEA, 2016.

Challenges to implementation

The main obstacles to implementation of CCUS are:

- The high investments required and the operational costs, especially the increase of those related to electricity .
- Availability of transport infrastructure, access to suitable stocking localities, and public policies to regulate licensing the operation.
- Acceptance by society and environmental institutions relating to safety and effectiveness of a complex and costly technology such as the storage of carbon.
- Potentially high CO_2 transport costs, considering the size of the country, with the option to use consortia with other sources of emissions, such as ethylene, ethanol, thermoelectric plants, steel mills, refineries, ammonia, processing of natural gas and early oil recovery (EOR), that would dilute the costs of investment and operations (CAPEX and OPEX).
- The need for national articulation in favor of building a political agenda for CCUS, including themes such as taxation, fiscal incentives, clean development mechanisms, laws and others.
- The high cost of capture, separation, transport and storage of carbon dioxide, especially when considering the low added value of the product.



Mitigation potential in the construction chain

Each stage in the life cycle of a product presents relevant environmental impacts. Studies of emission and mitigation of CO_2 from cement have concentrated essentially on its stage of production. There exists, however, a potential for reduction of emissions in the stages of use and post-use of products based on cement, by means of gains in efficiency in the production of concretes, mortars and construction methods themselves, as well as through the carbonation of cement materials; that is, the capture and natural reincorporation of CO_2 by exposed buildings and an atmosphere ever more rich in carbon.

Although the opportunities for reduction of emissions beyond the stage of cement manufacture are not within the scope of this *Roadmap*, the adoption of a broader approach to the life cycle along the whole value chain of construction offers an important potential for additional mitigation that should not be disregarded. Some of these opportunities are described as follows.

Industrialization of the end use of cement

In Brazil, bagged cement represents 66% of sales and is almost totally used for the production of concrete and mortar in small works and building sites. In these conditions, where specialized equipment and know-how are essential for the control of variability and optimization of formulation but rarely exist, more cement is used than when these materials are produced in industrial installations. In this scenario, with incentives to industrialization of the cement value chain, there is potential for reduction of the demand for cement and greater mitigation of associated CO_2 emissions.

Ready-mix or industrialized concrete

Concretes mixed in construction works contain cement at a rate of around 350 kg/m³, while concretes produced in concrete plants, depending on the resistance needed and the type of use, can for example contain 285 kg/m³. This difference in consumption, by itself, represents an important contribution by industrialization for mitigation of CO_2 in the cement chain.

Furthermore, changes in fiscal policy and other incentives would permit the introduction of mixers in the concrete ready-mix, reducing the consumption of cement by another 10%, so the specific average consumption would reach 260 kg/m³. This gain in competitiveness would favor the use of ready mixed concrete in detriment to the concrete "mixed on site", providing a rate of growth of at least 50% above the current scenario without such incentives.

It is estimated that if an incentive for the production of ready-mix concrete were created – either using mixing trucks or dry mixing – there would be a potential for reduction of emissions in the order of 47 Mt of CO_2 from 2014 to 2050, corresponding to around 3.2% of emissions relating to cement production.

Industrialized mortars

The industrialization rendering mortars offers two potential advantages: (a) the incorporation of air, which increases the product yield typically by 20%; (b) use of less hydrated lime, which is intensive in CO_2.

On the other hand, industrialized mortar has no cost advantage when compared to mortar mixed on site, as it requires packaging and the use of dry sand, apart from the taxes associated to the industrial activity. For these reasons, its market growth has been very slow, consuming from 2% to 3% of the cement production. Without institutional changes the product will not gain significant market share in the near future.

The typical cement content in industrialized mortars is around 240 kg/m³, apart from 14 kg/m³ of lime. Mortars made on site should contain 260 kg/m³ of cement and 17 kg/m³ of lime.

It is estimated that an incentive for industrialization of mortars offers a potential reduction in emissions of approximately 29 Mt of CO_2 from 2014 to 2050, around 2% of the total cement emissions in the period.

Production of aggregates

It is believed that improvements in the grading and in the format of the grains in aggregates would permit a significant reduction in the average volume of the paste (cement, water, other fines), reducing emissions of CO_2 from the concrete. Literature indicates paste volume in concrete as 250 dm³/m³ in 2050, while in Brazil the typical volume of concrete paste is around 310 dm³/m³.

A consistent program of incentives to improve the production of aggregate has a potential for mitigation of around 15% to 20% of CO_2 emissions from the concrete. There are no equivalent data for mortars, but laboratory experiments indicate that the potential is similar to that of concrete.

More industrialized production of concrete and mortar increases the chances of success of this strategy, which is more complex than the others, as it implies technological development, investment in thousands of aggregate production units and a change in the operational practices of the manufacturers and their customers.

Rationalization in construction

A reduction of material losses has large mitigation potential, mainly for rendering mortars. In Brazil, 40% more mortar is used than planned, due to thicker layers, also associated to geometric imperfections in construction (misalignment, bad plumb lines, differences in level). A reduction of 40% in the rate of loss could result in a mitigation of around 10% of the emissions.

Articles in international literature state that consumption of concrete can vary between 0.2 and 0.6 m^3/m^2 of useful area, depending on the design. In Brazil, these figures are smaller, between 0.2 and 0.35 m^3/m^2, but equally dispersed. Considering all the opportunities, the gains in efficiency could have a potential reduction of around 20% to 25% of total emissions from cement production.

Re-carbonation: carbon capture by cementitious materials

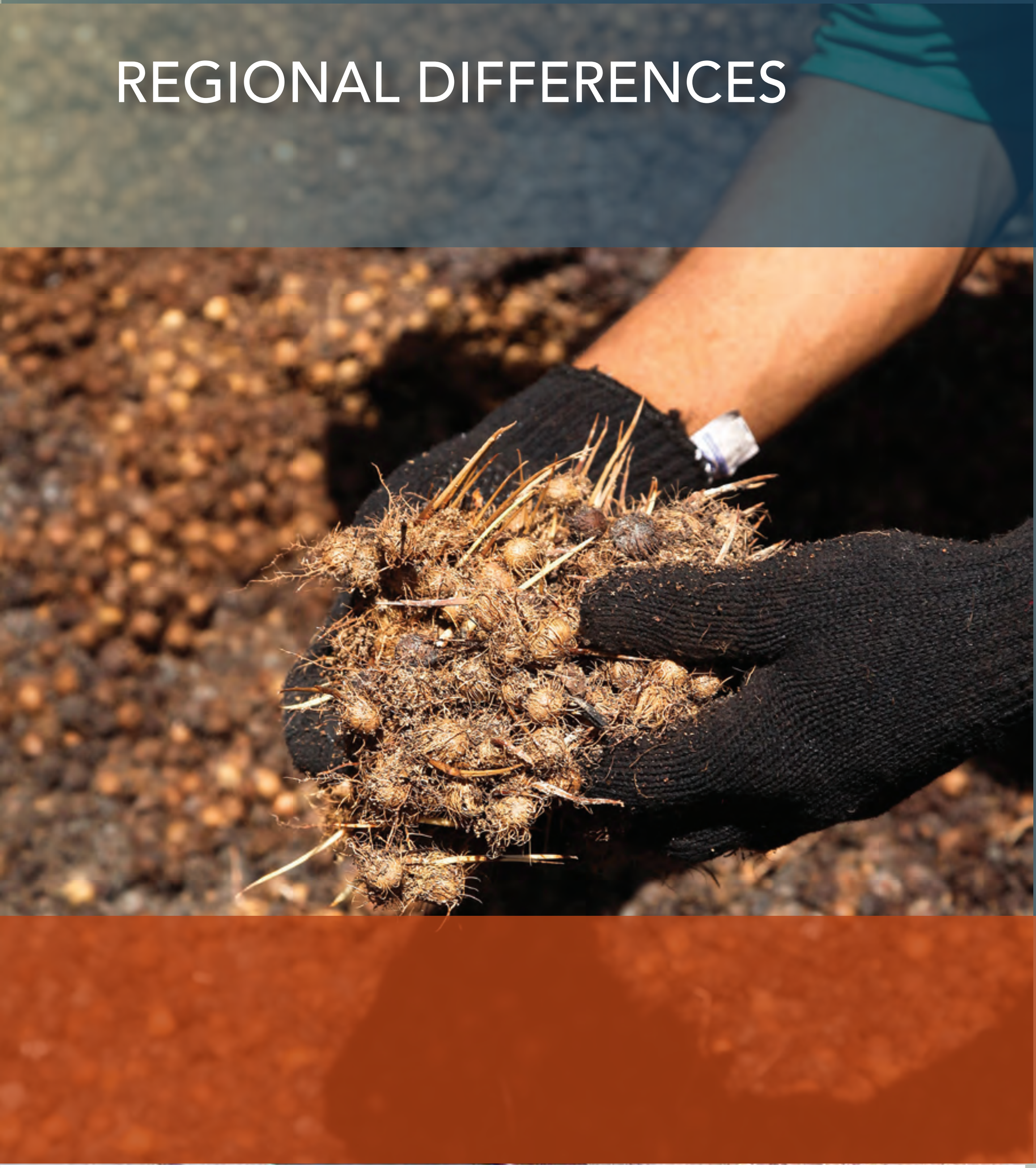
Cementitious materials, during the phase of use and post-use of construction, capture CO_2 from the atmosphere by re-carbonation. If the de-carbonation of raw material is inherent to the productive process of cement, its re-carbonation is inherent to the product over the years. However, its quantification is still little studied and there are only a few works that estimate the volume of carbon recaptured.

Based on the model published by *Nature Geoscience*[19], a conservative estimate would be that between 2014 and 2050 carbonation of mortars produced since 1950 could capture around 220 Mt CO_2, around 23% of CO_2 coming just from the calcination of the clinker, or 15% of the total emitted by cement manufacture in the period.

---

[19] Xi, F. *et al*. Substantial global carbon uptake by cement carbonation. *Nat. Geosci.* advance online publication, (2016).

REGIONAL DIFFERENCES



Açaí seeds used as alternative fuel for clinker production

Brazil is a country of continental dimensions, covering more than 8.5 million km², making it the fifth largest on the planet. It is subdivided into five geographic regions – North [N]; Northeast [NE]; Center-West [CW]; Southeast [SE] and South [S]– following criteria of similarity in physical, human, cultural, social and economic aspects.

In this context, cement production is distributed unevenly over the country. Thus in production of more than 71 Mt in 2014, the SE region represented more than 47% of the national production. The NE produced around 22%, followed by the South, with 15%, CW 12%, and N 5%. Among the determining factors for the location of cement industries is the availability of raw materials, above all limestone deposits, and the proximity of major urban consumer centers. Many of the different alternatives for reduction of emissions, however, also accompany the diverse distribution in various regions, meaning that not all installed plants in the country have the same potential for reduction.

Clinker substitutes

An important regional difference is the distribution of clinker substitutes, reflected in the major variation of the clinker-to-cement ratio in different Brazilian regions. The highest rates of substitution are registered in the SE region, reaching 40% in 2014. To a large extent this substitution is caused by the use of granulated blast furnace slag (26% to 28%) – followed by limestone filler (6.5% to 8.5%), and the fact that most pig-iron plants and steel industry in the country are installed in this region. However, substitution of clinker by fly ash is concentrated basically in the S region, where coal-burning thermoelectric plants are located. The rate of substitution in this region is approximately 32%, comprising fly ash (18% to 22%) and limestone filler (5% to 7%). In turn, the use of calcined clays and other pozzolans is concentrated in the Northern region (14% to 16%), CW (8% to 10%) and NE (4.5% to 6.5%), with a small usage in the regions SE and S. For the future a reduction in the content of granulated slag in cement in the SE region is expected, and an increase in the N and NE regions. In relation to fly ash, a small fall in content is expected by 2050, maintaining the concentration in the S region and a small usage in the N and NE regions.

Alternative fuels

The availability and use of low carbon fuels in the production of cement in Brazil also shows large regional differences, translating into percentages of thermal substitution practiced in each of the regions. The SE region has the highest rates of use of alternative fuels (21% to 23%), followed by the S region (14% to 16%), CW (12.5% to 14.5%) and N (11.5% to 13.5%). In the NE region the rates of substitution are less than 5%. This regionalization is much related to the availability of waste and its proximity to the cement plants. The generation of hazardous waste, for example, is concentrated in the SE region, followed by the CW and S regions, responsible respectively for around 44%, 29% and 22% of hazardous waste in Brazil. Non-hazardous waste is concentrated in the SE region (49%), followed again by regions S and CW (both 17%). The co-processing of scrap tires, is also strongly correlated with this distribution, being concentrated in the regions SE (28%), S (15%) and CW (9%).

The waste with the highest potential for thermal substitution in the future is solid recovered fuel from municipal solid waste (SRF). With the same tendency to accompany urban development, the first projects are expected to occur in regions SE and S, followed by regions CO, NE and N. Using quantity data collected and feasibility criteria for use of SRF in Brazil per region, the SE region would once again have the greatest potential for use of SRF (53% of waste collected in Brazil and around 38% of plants within the viable criteria for installation of SRF), followed by NE (22% of waste collected in Brazil and 19% of the plants within viable criteria), S (11% of waste collected and 19% of viable plants), CW (8% of waste collected and 19% of viable plants) and finally N (6% of waste collected and 5% of viable plants).

In relation to biomass, it is estimated that Brazil generates around 300 Mt of agricultural waste[20]. Some of it, such as sugar cane bagasse, produced in the SE and CW, is already used within the industries of sugar and alcohol. However, other agricultural biomass, found principally in the regions CW, N and SE, could be used by the cement industry as a source of energy.

The potential for exploiting the sludge from sewage treatment plants is also linked to the degree of urban and sanitary development, as well as the proximity of sources to the plants. In Brazil only 43% of sewage is treated[21]. The regions with the greatest indices of treatment being: CW, SE and S, with 50%, 47% and 41%, respectively. Currently, the destination of this residue for co-processing is irrelevant, as until now only a few tests have been made. It is hoped that this number will grow significantly, as already occurs in some countries of Europe, Japan and the USA. The use of this residue should concentrate in the regions SE and S in 2030, with greater participation of CW, NE and N in 2050.

---

[20] Survey made by the Instituto de Pesquisa Econômica Aplicada (IPEA), of the Federal Government.

[21] National Sanitation Information System (SNIS).

Emissions from raw material

Another major regional peculiarity refers to the types of limestone and their distribution in Brazil. Comparing national values of the calcination factor[22] with the default values in the Cement Sustainability Initiative (CSI) database, the national factors are greater than the world standard (average of 550 kg CO_2/t of Brazilian clinker against 525 kg CO_2/t of CSI), due to the high content of magnesium carbonate ($MgCO_3$) in the raw material. There also exists great disparity between the Brazilian values, oscillating between 540 and 573 kg CO_2/t of clinker depending on the geographic location of the deposits, and objectively, the variation in the magnesium content.

The Southern region has the highest percentages of Mg in the limestone, varying between 6.5% and 7.5%[23]. Consequently, the industrial units located there have higher emissions of carbon from raw materials. In comparison, in the CW region Mg values vary between 4% and 5%. In the SE region there is a large variation of magnesium content in raw materials, varying between 1.5% and 6% with an average of 3%, equal to the NE. Plants located in regions with higher Mg content in the limestone in fact show higher emission factors than those in other regions.

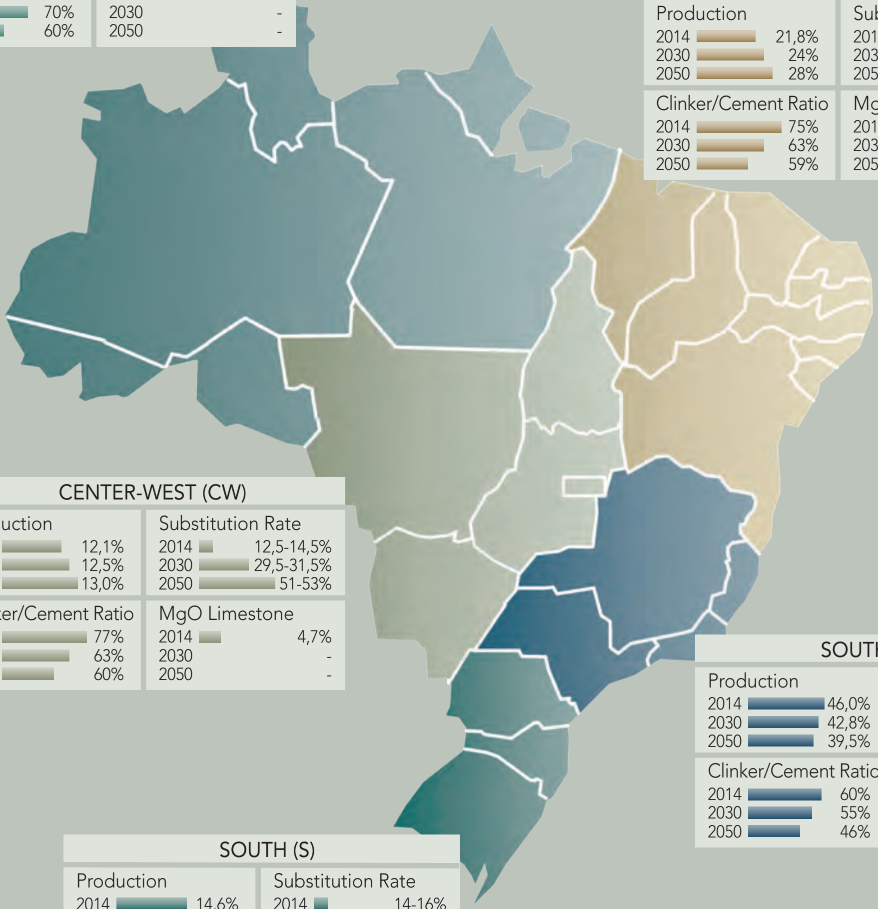
Due to all these variations, the true potential for reduction of carbon emissions in each of the Brazilian regions must be evaluated in the light of these peculiarities and limitations, to permit compatible and effective solutions and public policies. None of the future potentials suggested in this Roadmap, treated in a strictly national approach, should be replicated to the letter in regional/state context, at the risk of not considering the regional differences.

---

[22] Refers to emission from raw material, or the decarbonation of limestone for making clinker.

[23] Calculated from the percentage of magnesium oxide (MgO) contained in the clinker, arising from the decarbonation of magnesium carbonate ($MgCO_3$) in the limestone.

Figure 10: Regional differences in Brazil



NORTH (N)

	2014	2030	2050
Production	4,6%	6,5%	7,5%
Substitution Rate	11,5-13,5%	17-19%	32-34%
Clinker/Cement Ratio	73%	70%	60%
MgO Limestone	3%	-	-

NORTHEAST (NE)

	2014	2030	2050
Production	21,8%	24%	28%
Substitution Rate	2,54%	20-22%	34-36%
Clinker/Cement Ratio	75%	63%	59%
MgO Limestone	3,1%	-	-

CENTER-WEST (CW)

	2014	2030	2050
Production	12,1%	12,5%	13,0%
Substitution Rate	12,5-14,5%	29,5-31,5%	51-53%
Clinker/Cement Ratio	77%	63%	60%
MgO Limestone	4,7%	-	-

SOUTHEAST (SE)

	2014	2030	2050
Production	46,0%	42,8%	39,5%
Substitution Rate	21-23%	47-49%	75-77%
Clinker/Cement Ratio	60%	55%	46%
MgO Limestone	2,8%	-	-

SOUTH (S)

	2014	2030	2050
Production	14,6%	14,2%	14,0%
Substitution Rate	14-16%	38-40%	61-63%
Clinker/Cement Ratio	68%	57%	54%
MgO Limestone	6,9%	-	-

BRAZIL

	2014	2030	2050
Production	100%	100%	100%
Substitution Rate	14,8%	30-40%	50-60%
Clinker/Cement Ratio	67%	59%	52%

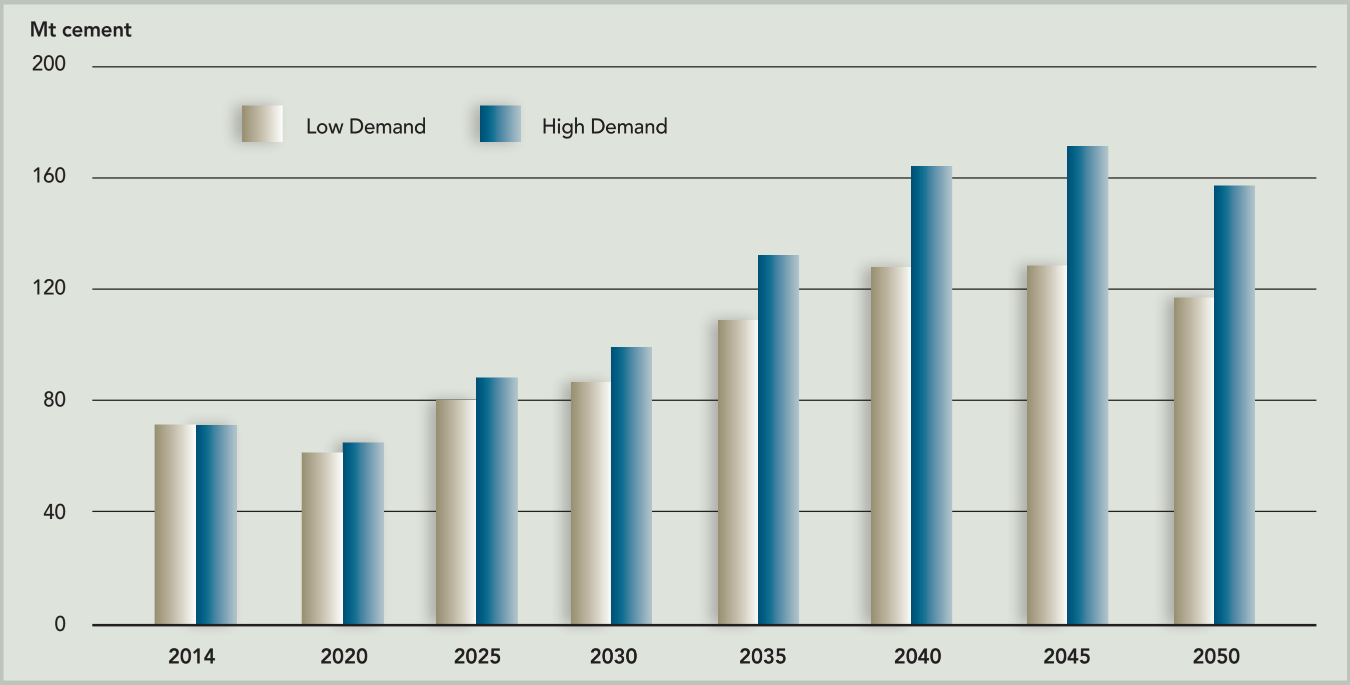
LONG TERM VIEW: REDUCTION POTENTIAL BY 2050

Overview of clinker rotary kiln with preheater tower at the back

The recovery of the Brazilian economy from its current recession, and subsequent GDP growth plus the infrastructure and housing deficit should drive up cement demand steadily from 2020 to 2040. From 2040 to 2050, a plateau and slight drop-off is expected in cement demand, driven by a reversal in population growth predicted by the Brazilian Institute of Geography and Statistics - IBGE. This trend occurs both in the low demand variant, that guided the indicators and potentials of this study, and in a high demand variant.

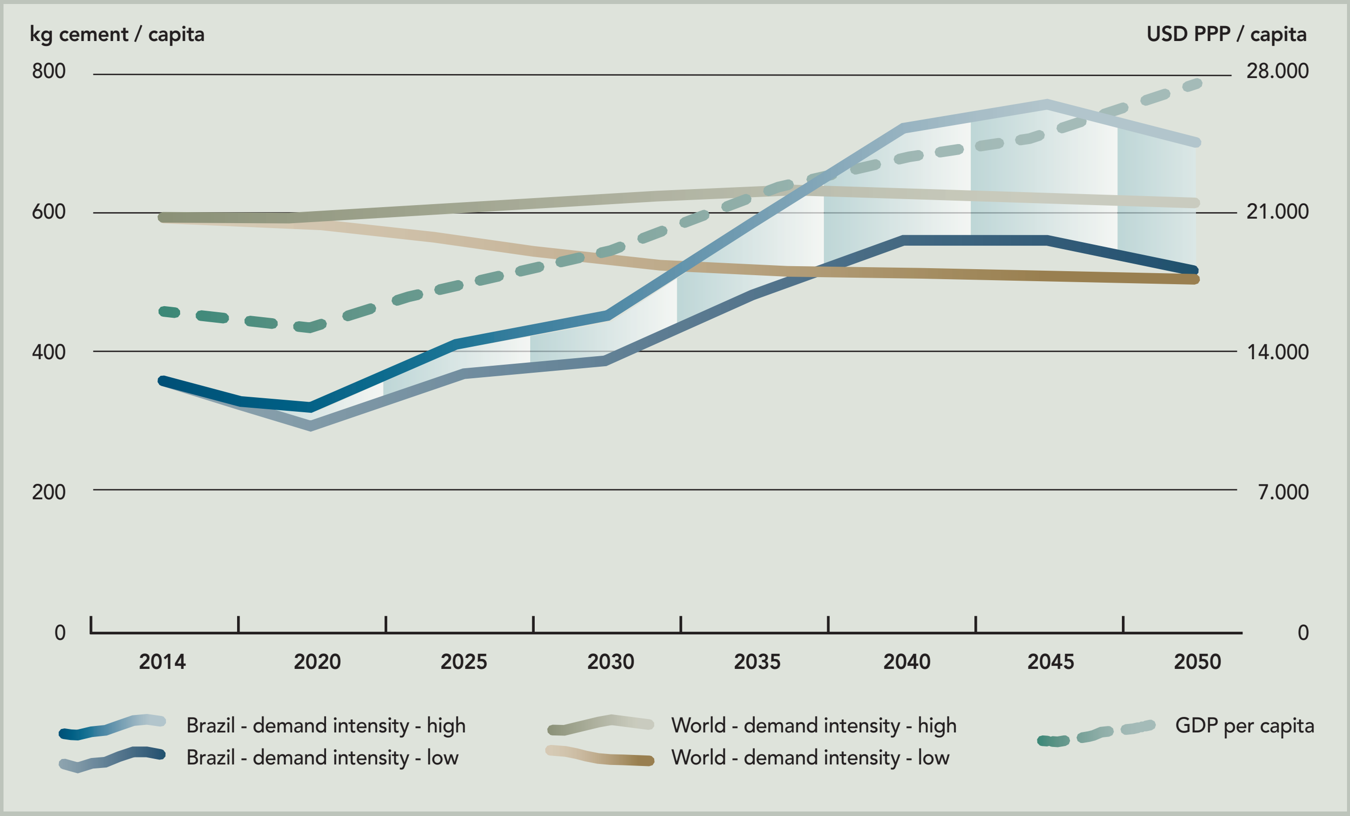
In the low-demand variant, cement production reaches its peak in 2045, at 127 Mt; while the high-demand variant peaks in the same year but a level that is about one third higher at 170Mt. In both cases, the long term growth in cement production poses a considerable challenge to the Brazilian cement sector in terms of energy demand and CO_2 emissions.

Figure 11: Projection of cement production in Brazil



Key message: The projection for emissions and potential reduction were evaluated with the low demand variant as a parameter, considered more realistic. The eventuality of more optimistic production variants can have a significant impact on the efforts of the sector to reduce CO_2.

Figure 12: Economic indicators and cement production



Key message: As incomes rise, increasing demand for cement drives up production levels, which then stabilize by 2050 as population growth levels off and high levels of demand intensity are reached.

Key indicators for reducing CO_2 emissions

Clinker substitutes

To achieve higher cement production with lower clinker content implies a reduction both in calcination emissions (decarbonation) and those resulting from burning fuels. Consequently the potential for mitigation of CO_2 from clinker substitutes is significantly greater than other measures, and is also the alternative with the best cost/benefit ratio, both in the short and long term. In 2050, in the "2°C Scenario", the relation clinker-cement should reach 52%,against the current 67%, nearing the best levels projected in the world. This would represent close to 69% of the cumulative emissions reductions in the "2°C Scenario" compared to the "6°C Scenario" over the period 2014-2050.

As the increasingly constrained supply of blast-furnace slag and fly ash (major clinker substitutes today) tends to be a limiting factor for the use of these alternatives, and considering the growth of demand for cement in the long term, the fall in proportion clinker/cement in the "2°C Scenario" should be based on the increase in use of limestone and calcined clays as clinker alternatives. The potential for reduction of clinker in the manufacture of cement, however, is also limited by the technical features demanded by the different applications of the final product, in regulations relative to cement standards and the local availability of raw materials.

Alternative fuels

While energy efficiency measures reduce the consumption of fuels in clinker production, the use of less carbon-intensive energy sources represent an additional option to reduce emissions from the burning of fuel.

In 2014, most of the sector's energy needs were met by petroleum coke (85%), though some biomass and waste was used in the remaining 15%. In the "6°C Scenario", this fuel mix remains constant, in that little or no effort to change is made, while in the "2°C Scenario", contributions from different fuels vary over time. By 2050, biomass will provide 11% and waste 44% of energy demand, together supplying 55% of the total thermal energy demand. Under these circumstances, there would be a reduction of the emission factor for fuels from 91 $kgCO_2/GJ$ in 2014 to 77 $kgCO_2/GJ$ in 2050.

The shift over time from use of petroleum coke in Brazil's cement kilns to alternative fuels represents a major contribution to the reduction of the sector's emissions, with potential mitigation of around 13% of cumulative emissions by 2050.

Energy efficiency

To produce clinker with less energy consumption, though having no effect on the emissions of the process – or calcination – has direct influence on the emissions from the fuels.

In 2014, thermal energy intensity per tonne of clinker stands at 3.5 GJ/t clinker, but decreases towards an improved level of 3.2 GJ/t clinker by 2050 in the "2°C Scenario". The reduction is based, in the short term and to a lesser degree, on the adoption of retrofit measures within the dry-process production (such as pre-calciners and additional pre-heating stages), since almost all Brazilian cement (99%) is produced by this process. As of 2030 a more significant reduction will be observed in thermal consumption, due to the substitution of more obsolete units by modern plants using the best available technology (BAT) at the time. Thermal consumption, however, will be impacted by the growing use of alternative fuels, with higher moisture content than fossil fuels.

At the same time, electricity intensity decreases by 0.4% per year on average in the "2°C Scenario" by 2050, from 113 kWh/t cement in 2014 to 91 kWh/t cement in 2050, mainly due to implementation of efficient technology in grinding and waste heat recovery – (WHR).

Vertical mills will be installed in the new clinker production lines in Brazilian plants, in place of ball mills, achieving around 40% of production in 2050. Roller press grinding, however, is not suitable for the majority of grinding operations in Brazil, due to the high moisture content in raw materials, representing challenges to this technology in comparison with other types of mills. Thus roller mills will be limited to a small part of raw meal, having a marginal market penetration of no more than 5% of the total future grinding capacity.

Waste heat recovery (WHR) will be increasingly diffused throughout the sector in the "2°C Scenario". On using the excess heat from the kiln combustion gases and the clinker cooler, the technology reduces the need for electricity. Today, this solution has been adopted by only one plant in Brazil, but has great potential for implementation in the "2°C Scenario", and can be used in a number of kilns, which together would represent around 35% of the total Brazilian production. This energy efficiency measure is becoming more widely used around the world; in some regions, for instance, it is now required in all new cement manufacturing facilities. The improvement in energy efficiency also includes the integration of processes, improved operations and maintenance practices.

Due to the current degree of modernization of the Brazilian industrial complex, and the minimal space for improvements, the impact of the measures for energy efficiency would be around 9% in reduction of cumulative emissions between 2014 and 2050.

Emerging and innovative technology (CCUS)

The advance of the three principal measures approached above would be almost sufficient to achieve a reduction of emissions compatible with the "2°C Scenario". This would exercise less pressure on the need for adoption of emerging and innovative solutions, such as CCUS (*Carbon Capture and Utilization or Storage*). Thus in 2040, around 1.7 Mt CO_2 would need to be captured using this technology, reaching 3.3 Mt CO_2 in 2050, and **the contribution of this alternative to the reduction of emissions accumulated over the period 2014-2050 would be around 9%.**

However, in a hypothetical high demand variant, with a significant increase in emissions compared to the low demand variant, CCUS should be implemented extensively to achieve the "2°C Scenario", insofar as the other options for carbon reduction, such as clinker substitutes, alternative fuels and energy efficiency approach their maximum potential. Thus, under these conditions, a volume around six times larger would need to be captured in 2050, contributing with around 37% of the reduction in cumulative emissions. The perspective for growth of consumption also indicates that CCUS would also have to be installed earlier in this variant, starting in 2035, while in the low demand variant only in 2040.

Table 3: Key indicators for the Brazilian cement industry by 2050

		2°C				6°C			
	2014	2020	2030	2040	2050	2020	2030	2040	2050
Cement production [Mt]	71	62	87	126	117	62	87	126	117
Clinker factor [clinker to cement ratio]	0.67	0.66	0.59	0.54	0.52	0.67	0.67	0.67	0.67
Thermal intensity [GJ/t clinker]	3.50	3.49	3.47	3.38	3.22	3.50	3.49	3.46	3.44
Electrical intensity [kWh/t cement]	113	110	106	95	91	111	108	101	99
Alternative fuel use [% of thermal substitution rate]	15%	22%	35%	45%	55%	15%	15%	15%	15%
CCUS [Mt CO_2/year]	-	-	-	1.7	3.3	-	-	-	-
Gross emission [Mt CO_2/year]	40	34	42	52	44	35	49	71	66
Emission intensity [t CO_2/t cement]	0.56	0.53	0.48	0.41	0.38	0.56	0.56	0.56	0.56

Note: Values shown are for low-demand variants of the scenarios. Alternative fuel use includes biomass as well as renewable and non-renewable waste. Electricity intensity of cement production does not include reduction in the demand for purchased electricity from waste heat recovery equipment or electricity used in carbon capture equipment. Direct CO_2 intensity refers to net CO_2 emissions, after carbon capture.

Source: IEA modelling developed for this project. © OECD/IEA, 2016.

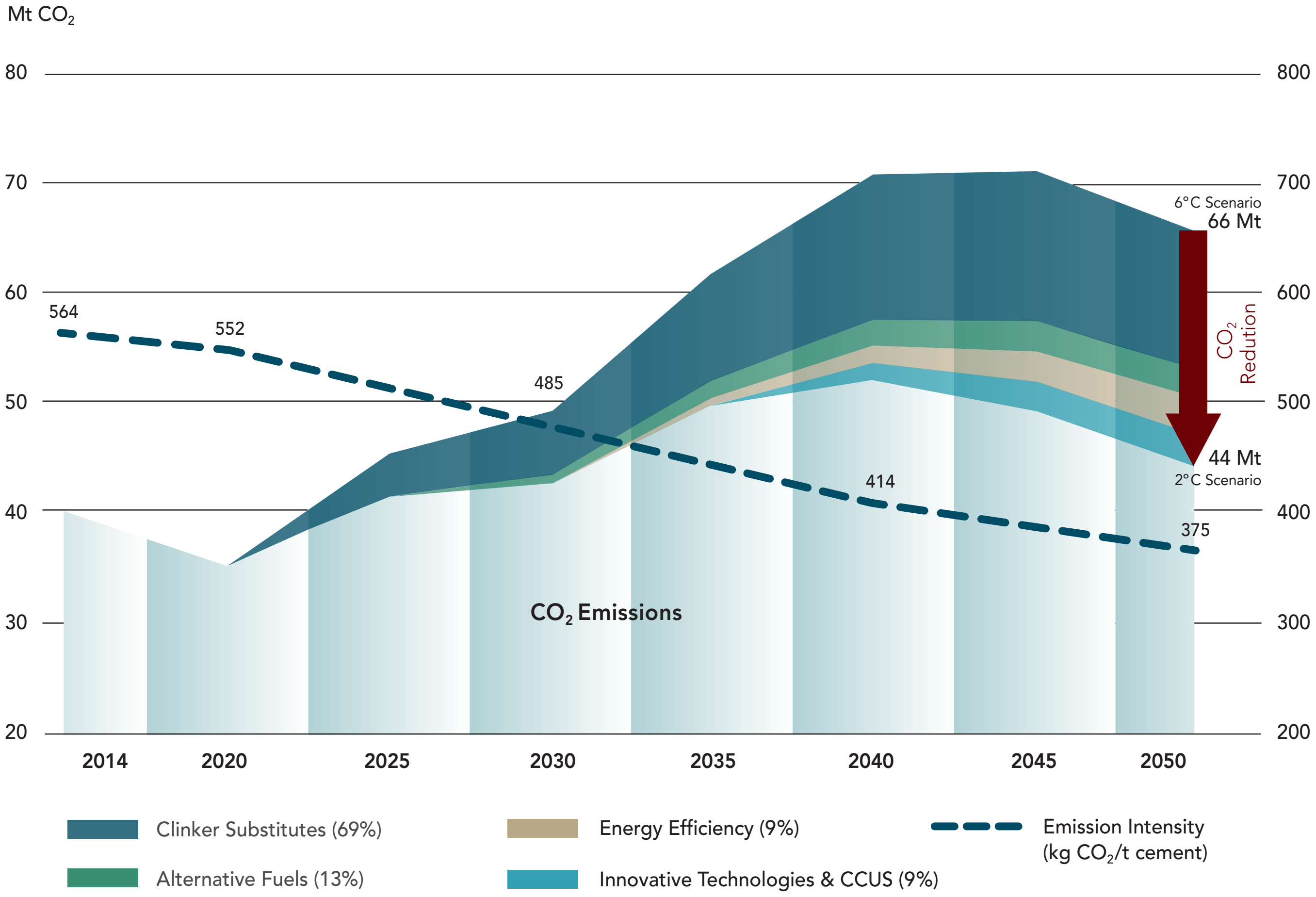
CO_2 emissions up to 2050

The potential for reduction of direct CO_2 emissions gives different results through time, reflecting both existing demand and the degree of maturity and penetration of solutions suggested for the sector. Using as a basis 40 Mt of CO_2 emitted by the Brazilian cement industry in 2014, emissions could reach around 66 Mt of CO_2 in 2050, if no mitigating action is adopted ("6°C scenario").

However, this value could fall to 44 Mt of CO_2 in the same year from a combination of measures suggested in this Roadmap ("2°C Scenario"). This represents a growth in emissions of only 10% on the current volume, against an increase in projected cement production of around 65% in the period. Under these conditions, the specific emissions would go from the current 564 kg CO_2/t cement to 375 kg CO_2/t cement in 2050, a reduction of 33%.

In terms of emissions accumulated throughout the whole period, comparing the two scenarios, it would be possible to avoid the emission of 421 Mt of CO_2. The chief factor contributing to this reduction is clinker substitution, with 290 Mt of CO_2 mitigated between 2014 and 2050 (or 69%). The use of less carbon intensive fuels, as the sector migrates from petroleum coke towards biomass and waste, contributes 55 Mt of CO_2 of this total (13%). Energy efficiency measures and innovative technology such as CCUS each account for 38 Mt of CO_2 (9%).

Figure 13: Reduction of direct CO_2 emissions per strategy, "2°C Scenario" compared with "6°C Scenario"



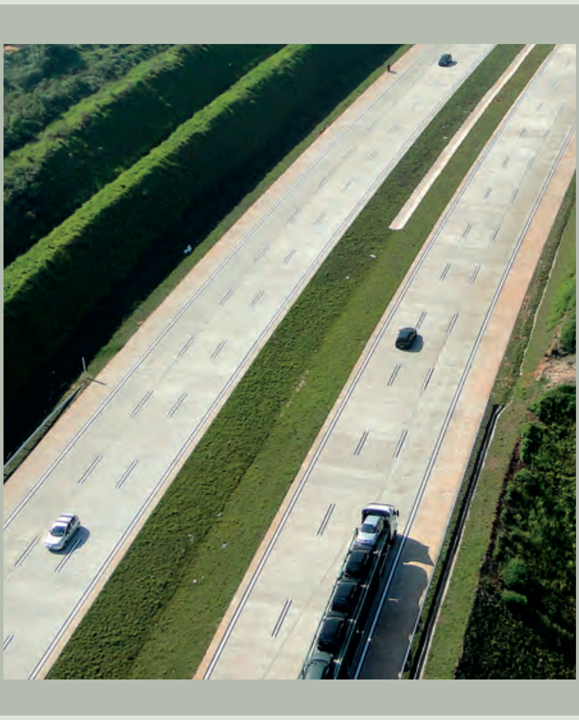
Key message: By impacting as much on emissions of calcination as on the burning of fuel, clinker substitutes will contribute a large part of the reduction in CO_2 emissions, compared to other options.

Source: IEA modelling developed for this project. © OECD/IEA, 2016

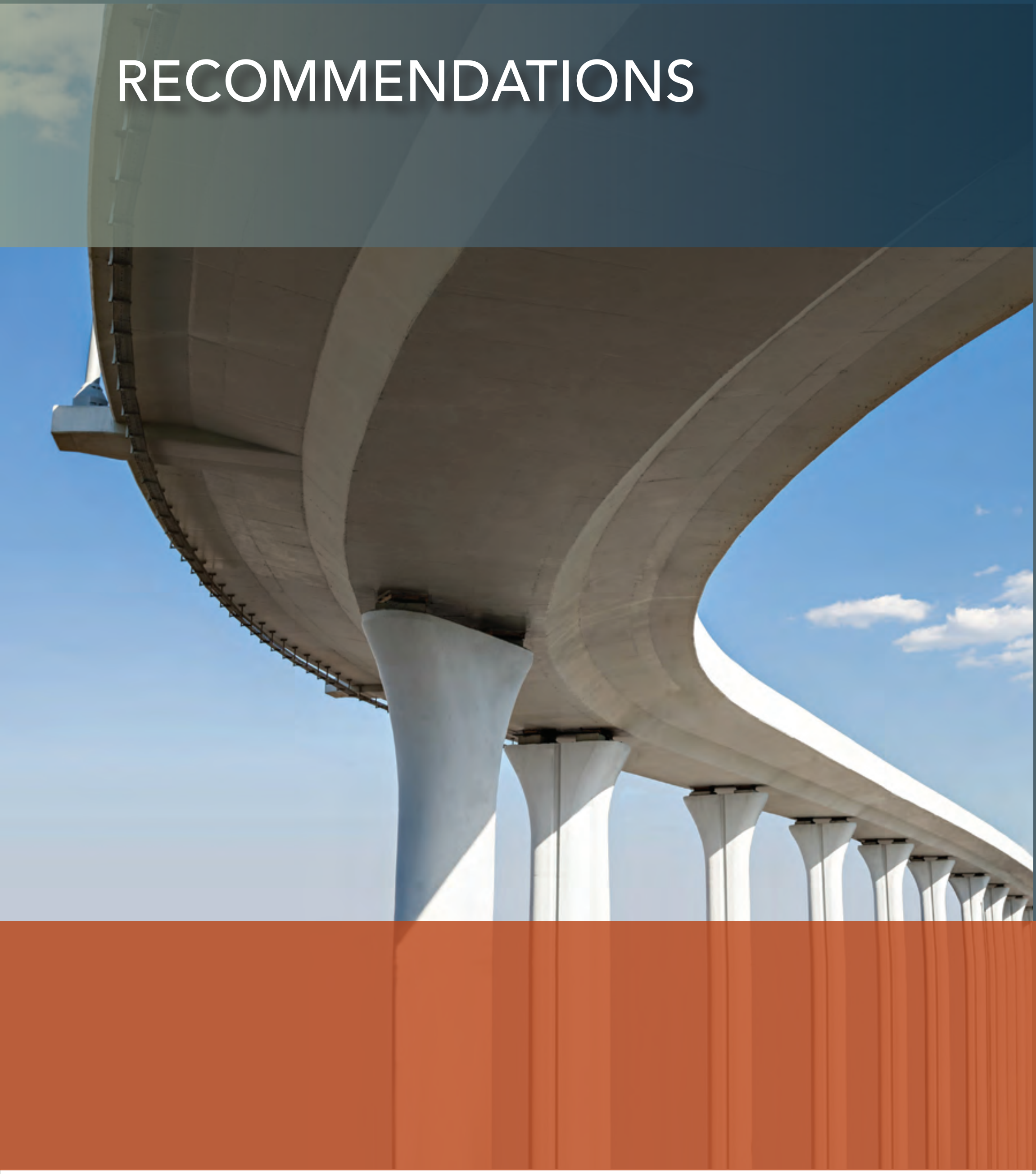
Box 3: Considerations on a high demand variant for cement

In an eventual high demand variant, the growth of cement production exerts greater pressure on the efforts to reduce carbon intensity, as the emission is also greater, reaching a total of around 88 Mt of CO_2 in 2050 or 807 Mt accumulated over the period. As maximum potential in terms of cost/benefit regarding clinker substitutes, fuel changes and improvements in energy efficiency will be reached in the low demand variant, high cost measures for emission reduction should be explored.

Therefore, to achieve reduction of CO_2 in the high demand variant by 2050, which represents an additional accumulation of 387 Mt of CO_2, innovative technologies will assume a predominant role. Although they contribute less than 10% for low demand reductions, representing the more onerous alternative, a greater production of cement will force this alternative to contribute around 37% of potential mitigation, the same as the clinker substitutes in this variant.



RECOMMENDATIONS



Overpass built in concrete

This *Roadmap* presents a series of measures and technical solutions capable of accelerating the transition of the Brazilian cement industry towards a low-carbon economy with less impact on climate change.

To achieve the levels of reduction of carbon dioxide emissions needed to meet the climate scenarios presented in this Roadmap, however, the removal of a series of obstacles and bottlenecks which today impede or hinder the advance of many of the technical alternatives is proposed. This requires, much more than the engagement of the industry itself, a joint effort at various levels of action, from municipal, state and federal government, legislative bodies, normative entities, development agencies, national and international research institutions, among many others.

The key recommendations for achieving these objectives are summarized as follows:

1. Increase the use of clinker substitutes

For the volume of clinker substitutes to grow, reducing the clinker factor from current levels (around 67%) to 59% in 2030 and to 52% in 2050, measures are needed that will be mostly implemented by industry, but for them to be implemented with success will need the support of the Brazilian government, research institutes and academia, as well as adequate understanding by consumers.

- **Promote the development and acceptance of new cement standards.** Action required here is to update Brazilian standards in order to permit the incorporation of greater content of clinker substitutes, following international standards already in use, mainly in relation to limestone filler, today limited to 10%.
- **Promote and encourage the propagation of good practices and R&D, in order to create better understanding of opportunities in clinker substitutes.** Currently there are technical or quality restrictions for the use of potential cementitious materials that could be resolved with research, for example. There is a pressing need for developing independent studies of environmental impact on the use of cementitious materials to illustrate the greater potential for reduction of carbon emissions, through Life Cycle Analysis.
- **Develop campaigns and training events and awareness for the actors in the entire length of the cement supply chain.** For example, to increase awareness and confidence of consumers in cement compounds and promote their acceptance in the Market, to educate standards organizations and accreditation institutes, to exchange experience on the reduction of the content of clinker in cement and the environmental and economic impacts.

2. Encourage and enable the use of alternative fuels

The use of alternative fuels by the cement industry has gained relevance in Brazil in recent years, representing today around 15% of its energy matrix. There exists, however, a large potential to be explored, especially when compared to developed countries, such as those of the European Union. There, the percentage of utilization of alternative fuels averages around 41%. In countries such as Holland and Austria, however, this index is already higher than 75%.

In Brazil, the National Policy for Solid Wastes (PNRS), instituted seven years ago by Law 12.305/10 and whose main objective was to completely eliminate the irregular landfills by 2014; only managed to eliminate them in 40% of Brazilian municipalities. There are still more than 2,000 irregular landfills spread around the country, receiving around 30 Mt of trash per year[24]. Some controlled sanitary landfills even became irregular landfills due to the lack of control and inspection, and the high cost of maintenance. Meanwhile, the volume of trash generated in Brazil tends to grow faster than the population[25].

Actions by the Brazilian government focused on the final disposal, or "ordered" disposal of waste in landfills. This is exactly the opposite of what most developed countries are doing, which is to prioritize the hierarchy of waste management practices[26]: no generation, reduction, re-use, recycling, treatment, and finally disposal.

Despite the existence of two specific CONAMA resolutions on co-processing (264/1999 and 316/2002) and some state laws (SP, MG, PR & RS) which exclude licensing of residue such as wood, agricultural matter, construction and demolition, there is still space to improve the legal framework that regulates or impacts this technology. The change in focus of co-processing as a potentially pollutant activity to a definitive solution to implementation

---

[24] ABRELPE. **Overview of Solid Waste in Brazil** 2016. São Paulo: [s.n.], 2017

[25] Consultation of publications 'Overview of Solid Waste in Brazil' from 2003 to 2015.

[26] Directive 31/1999 obliged European Union member countries to reduce the disposal of biodegradable Municipal Solid Waste in landfills to 35% by 2016.

of PNRS needs to be encouraged. For this to occur, a joint and institutional effort by the cement industry is needed to prepare a program of communication that engages all interested groups, from the generators, to the municipalities where the cement plants are installed, and to the appropriate ministries.

This *Roadmap* evaluates the technical potential of the Brazilian cement industry to substitute around 35% of its fossil fuels with alternative fuels in 2030 and 55% in 2050. To achieve these numbers, however, the following key recommendations must be implemented:

- **Modify existing legislation** in order to: i) dispense with or simplify the licensing of biomass derived from agricultural and industrial waste; ii) encourage (and not limit) energy recovery and the use of alternative fuels (not fossil); iii) establish standard procedures that must be followed by all stakeholders in the chain in order to guarantee adequate processes for documenting, monitoring and tracing waste in a reliable manner, including the emission of the Certificate of Thermal Destruction, which should only be accepted if conceded by the cement supplier, as established in Resolution CONAMA 316/2002, Art.28, IV; iv) de-bureaucratize and reduce costs associated with the licensing process.
- **Create specific legislation on co-processing of Solid Recovered Fuels (SRF) from Municipal Solid Waste (MSW)** in other Brazilian states, similar to Resolution SMA No 38, of 31/05/17, established in São Paulo. This becomes even more urgent in the face of the indebtedness to public garbage collection companies faced by the large majority of Brazilian capitals (23 plus the Federal District) and many of the Brazilian municipalities, that already totals more than US$ 3 billion, according to the Transparency Portal of the Federal Government.
- **Encourage other ways of disposing of waste, promoting isonomic conditions of competitiveness between disposal methods.** The focus of the National Policy for Solid Residue was the extinction of irregular landfills and the interpretation given was that this would mean building sanitary landfills. This has been the alternative most adopted by municipalities, instead of investing in earlier stages of the residue hierarchy. While countries like the United Kingdom implemented a surcharge of approximately £90/t for waste deposited in landfills[27], and cities such as São Francisco have a target of zero waste destined to landfills by 2020[28], in Brazil the tendency is to reduce the cost of wastage disposal in landfills.
- **Promote the creation of an energy policy that accelerates the transition from an economy based on fossil fuels to a low carbon economy.** Encourage the adoption of bio-fuels and less carbon intensive fuels through state programs and policies such as the National Biofuel Policy (RenovaBio) of the Ministry of Mines and Energy (MME).
- **Encourage the development and use of new alternative fuels, especially biomass.** This is possible in various ways, for example through cooperation with teaching and research institutions, and development of family agriculture for the production of biomass, with financial incentives for the use of biomass as fuel etc.

3. Promote the adoption of best available technologies in energy efficiency for new plants and retrofits

Since the energy used in the production of cement is mainly thermal and the Brazilian electric grid is for the most part hydroelectric, the most effective measures to be adopted by the industry for the future reduction of carbon intensity will be in thermal efficiency.

The fact that the Brazilian cement industry has made enormous investments in new plants and new production lines in recent years helped to reduce the industry's energy consumption, and it is currently very near the benchmark. A new technological leap and any significant energy reduction will therefore probably only happen as of 2030, with the renewal of units that will have then become obsolete. On the short term horizon, investment in retrofits and more specific actions will have a primary role in the reduction of energy consumption.

The actions this Roadmap is proposing for the industry to achieve values near to 3.22 GJ/t of clinker and 91 kWh/t of cement by 2050, are as follows:

- **Share the best practices on a national and international level for the promotion of energy efficiency and reduction of CO_2 emissions in the cement industry.** Best practices both in terms of productive processes and techniques and in Best Available Technology (BAT) applicable in Brazil for cement production.
- **Create or identify the available mechanisms for financing both on a public and private, national and international level.** This shows the importance

---

[27] HM Revenue & Customs. Available in https://www.gov.uk/government/publications/excise-notice-lft1-a-general-guide-to-landfill-tax/excise-notice-lft1-a-general-guide-to-landfill-tax. Accessed in: 19/12/2017.

[28] SF Environment. Available in: https://sfenvironment.org/zero-waste-by-2020. Accessed in: 19/12/2017.

of the restricted fiscal horizon that will figure in Brazil over the next 20 years, after the publication of Constitutional Amendment 95/2016, which impacted significantly one of the principal public funds currently available. For technology such as *Waste Heat Recovery (WHR)*, that demands heavy investment in importation of equipment and is subject to heavy fiscal effects of imports in this country, it is vital to procure financial mechanisms, products and services, as well as partnerships with development agencies and ministries that are adequate to the needs of the sector.

- **Encourage the adoption of public policies that result in lower consumption of energy and in less wastage.** Such as for example, government programs that remunerate the industrial consumer to offset the reduction of load in periods of high demand (as in the case of the pilot-project of the response to demand approved by ANEEL on November 28, 2017).
- **Promote tax exemption programs and reduction of import taxes for GHG reduction technologies that are not similar in the country.** The adoption of these programs would make the implementation of technologies such as *Waste Heat Recovery (WHR)* economically viable in a greater number of units, besides facilitating the adoption of BATs, making the cement industry even more energy efficient.
- **Reinforce national and international cooperation to collect reliable data on energy and emissions at industrial level,** for example from the database of the *Cement Sustainability Initiative (CSI)*[29] and partnership with the Brazilian government, via SIRENE[30] or BEN[31] .

4. Support the development and implementation of emerging and innovative low carbon technology, including capture, utilization and storage of carbon (CCUS).

Although this *Roadmap* suggests that innovative technologies will only become potentially viable for the Brazilian cement industry as of 2040, studies needed for their implementation need to start to be developed in the short and medium terms. In order to make these studies viable, as well as the later phases needed for projects with the use of innovative technology, recommendations aim to:

- **Promote R&D in emergent and innovative technology** – by means, for example, of resources existing in the country, such as the BNDES' FUNTEC, FINEP's National Fund for Scientific and Technological Development (FNDCT) and others, and also cooperation and partnerships with research institutes and management of research projects. Risk can be reduced, through government and development agencies, through investment mechanisms that leverage private financing for pilot projects developing capture technologies in the cement sector.
- **Develop public policies for establishing governance of application of low carbon disruptive technology.** Especially with regard to rules for conducting collaborative and pre-competitive research for emerging technology, including CCS/U, on a national level.
- **Explore and develop technology complementary to CCS, necessary for the conversion of CO_2 in products of added value (CCU).** The high costs of exploring CCS technology, together with the low added value of cement and the elevated carbon intensity of the sector, indicate that CCU alternatives will become more attractive and viable than those of CCS for the cement industry on the medium to long term horizon.
- **Improve methodology for measuring the volume of carbon captured by the carbonation effect.** Part of the carbon emitted in the cement production process is re-absorbed when the mortar or concrete enters in contact with atmospheric CO_2. Considering its relevance in the compensation of the sector's emissions, it becomes important to measure this effect, as well as its potential maximization by the recycling of concrete.

---

[29] Data base Getting the Numbers Right (GNR).

[30] SIRENE – National System for Recording Emissions, of the Ministry of Science, Technology, Innovations and Communications (MCTIC).

[31] BEN – Brazilian Energy Balance, Ministry of Mines and Energy (MME).

ROADMAP ACTION PLAN FOR STAKEHOLDERS

Concrete towers at the Osório Wind Farm

This chapter defines the action plan with ministries, state and municipal governments, development and promotion agencies, industry associations, universities and research institutions, ABNT, and the cement industry itself.

ROADMAP ACTION PLAN

Stakeholders	Action
Ministry of Environment	Reduce cost and streamline procedures associated with the process of licensing for co-processing.
	Streamline licensing of biomass originating from agricultural and industrial waste.
	Establish standardized procedures to be followed by all stakeholders in the chain to document, monitor and guarantee, in a reliable manner, the traceability of waste.
	Legislatively encourage (and not limit), via legislation, energy recovery and the use of alternative fuels (not fossil) to substitute fossil fuels.
	Encourage other ways of disposing of waste, apart from landfills, promoting isonomic conditions of competitiveness between them.
	Develop and apply a surcharge to municipal solid waste dumped in landfills.
Ministry of Mines and Energy	Offer fiscal and financial incentives for the use of biomass and low-carbon wastes for the production of cement, generation of electricity and other valuation techniques.
	Encourage the adoption of public policies that result in lower consumption of energy, as for example, the possibility of commercializing the cement industry's own generation with the power grid or other consumers.
Ministry of Science, Technology, Innovation and Communications	Support R&D in the use of different types of alternative fuels and their impacts on the reduction of emissions, and fully share the expertise.
	Promote R&D for emerging and innovative technology, like CCUS, by means of pre-existing resources and by cooperation and partnerships with research institutes and management entities for research projects.
Ministry of Agriculture, Livestock and Supply	Integrate the cement industry in the Agroindustry Residue Plan.
	Incentivize family-owned agriculture business to produce energy-biomass.
Ministry of Regional Development	Encourage the development of modern waste management practices in Brazilian cities, creating potential for recycling and re-use of waste and sludge from sewage treatment stations for generating energy.
Ministry of Economy	Promote, through the Technical Committee of the Low Carbon Industry (CTIBC), links between the industrial sector and the different ministries and government agencies, to promote and accelerate the adoption of the measures proposed in this roadmap.
State and Municipal Governments	Develop co-processing in the regions of the country where the technology is not yet a standard of operation.
	Provide training and qualification of authorities and technical training of public servants responsible for licenses, control and supervision.
	Create specific legislation on co-processing of Fuel Derived from Solid Urban Residue in other Brazilian states, São Paulo being an example.

ROADMAP ACTION PLAN

Stakeholders	Action
Brazilian Technical Standards Association	Promote the development of new cement standards and revision of existing standards, in order to increase use of clinker substitutes in cements.
Development Agencies	Develop or identify mechanisms available for financing of low carbon technology applicable to the cement industry (energy efficiency, alternative fuels, clinker substitutes etc.), both on public and private, national and international levels (ex: Green Climate Fund, Green Bonds, specific BNDES lines of credit).
	Support and fund programs of research, development, demonstration and scaling up to drive knowledge and application in different aspects of development of innovative technologies to mitigate emissions, as CCU.
Cement Producers	Develop agreements and/or partnerships with academic, research and development institutions, with a view to consolidating the technology of co-processing.
	Disseminate good practices of safety and occupational health in the co-processing activity.
	Develop training and qualification for stakeholders in the cement chain, enabling the exchange of experience and best practices in the reduction of clinker content in cement and the resultant environmental and economic impacts.
	Share best practices at a national and international level applicable to the industry for promoting energy efficiency and reduction of CO2 emissions in the cement industry.
	Partner with research institutes to develop and publish a Reference Guide on the Best Available Technology (BAT) for cement production applicable to Brazil..
	Establish agreements with research institutes to leverage energy efficiency in the industry, as well as training human resources.
Industry Associations	Partner with the Brazilian government to reinforce national and international cooperation for the collection of data on energy and emissions at an industrial level.
	Develop and deploy a communication program on co-processing that engages all interested groups (wastage generators, municipalities, NGOs, related ministries etc.).
Universities and Research Institutes	Carry out life cycle assessment of alternative fuels to determine their carbon intensity.
	Promote and encourage R&D of potential clinker substitutes and new cements..

Abbreviations and units of measure

Abbreviations and acronyms

ABCP	Brazilian Portland Cement Association
ABRELPE	Brazilian Association of Public Cleaning and Special Wastes Companies
ANEEL	Brazilian Electricity Regulatory Agency
BAT	Best Available Technologies
BEN	Brazilian Energy Balance - Ministry of Mines and Energy (MME)
BNDES	Brazilian Development Bank
CAGR	Compound Annual Growth Rate
CAPEX	Capital Expenditure
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CCUS	Carbon Capture and Utilization or Storage
CO_2	Carbon dioxide
CONAMA	National Environment Council – Ministry of the Environment (MMA)
CSI	Cement Sustainability Initiative
EOR	Enhanced Oil Recovery
ETE	Sewage Treatment Station
FINEP	Brazilian Innovation and Research Agency
FNDCT	National Fund for Scientific and Technological Development
FUNTEC	Technological Fund National Bank for Economic and Social Development
GCCA	Global Cement and Concrete Association
GEE	Green House Gases
GNR	Getting the Numbers Right (database)
IEA	International Energy Agency
IFC	International Finance Corporation
KPI	Key Performance Indicator
LCA	Life Cycle Analysis
MSW	Municipal Solid Waste
OPEX	Operational Expenditure
PNRS	National Policy for Solid Waste
R&D	Research and Development
RenovaBio	Brazilian Policy for Biofuels
SIRENE	National System for Recording Emissions
SRF	Solid recovered Fuel
SNIC	National Cement Industry Association
WBCSD	World Business Council for Sustainable Development
WHR	Waste Heat Recovery

Units of measure

°C	Celsius Degrees
EJ	Exajoules (10^{18} joules)
GJ	Gigajoules (10^9 joules)
Gt	Gigatonnes (10^9 tonnes)
GWh	Gigawatt hour (10^3 watt hour)
kcal	Kilocalories (10^3 calories)
kg	Kilogramme (10^3 grammes)
kWh	Kilowatt hour (10^3 watt hour)
MJ	Megajoules (10^6 joules)
Mt	Million tonne (10^6 tonnes)
Mt/year	Million tonne (10^6 tonnes) per year
MW	Megawatt (10^6 watt)
PJ	Petajoules (10^{15} joules)
t	Tonne
tpd	Tonne per day

References

BJERGE, L-M.; BREVIK, P. CO_2 capture in the cement industry, Norcem CO_2 capture Project (Norway). **Energy Procedia**, v. 63, p. 6455-6463, 2014.

BOUMA, R. et al. Membrane-assisted CO_2 liquefaction: performance modeling of CO_2 capture from flue gas in cement production. **Energy Procedia**, v.114, p. 72-80, 2017.

CHINA CEMENT ASSOCIATION. **Cement performance data submission through personal communication.** China, 2017.

CHANG, M.-H., et al. Design and experimental testing of a 1.9 MWth calcium looping pilot plant. **Energy Procedia**, v. 63, p. 2100-2108, 2014.

CLIMATE & STRATEGY PARTNERS. **Finance for innovation: towards the ETS Innovation Fund.** Madrid, 12 june 2017. Summary Report. 24p.

EUROPEAN COMMITTEE FOR STANDARDIZATION. **EN 197-1 Cement – Part 1: Composition, specifications and conformity criteria for common cements.** Brussels, 2000. (English version)

Forth coming Confederation of Indian Industries (CII), World Business Council for Sustainable Development (WBCSD) and International Energy Agency (IEA) (2018), **Status up date project from 2013 Low-Carbon Technology for the Indian Cement Industry,** CII, WBCSD and IEA, Nova Delhi, Genebra and Paris.

CEMENT SUSTAINABILITY INITIATIVE. **CO_2 and energy accounting and reporting standard for the cement Industry.** Genebra: CSI/WBCSD, 2011.

CSI. **Global Cement Database on CO_2 and Energy Information, WBCSD, Genebra.** Available in: www.wbcsdcement.org/index.php/key-issues/climateprotection/gnr-database. Accessed in January 2017.

Ecofys. **Status and prospects of co-processing of waste in EU cement plants.** Ecofys, Utrecht, 2017.

EUROPEAN CEMENT RESEARCH ACADEMY. **Development of state of the art-techniques in cement manufacturing: trying to look Ahead, revision 2017.** Düsseldorf, 2017.

Global CCS Institute. **Projects database.** Disponível em: https://www.globalccsinstitute.com/projects Accessed in August 2017.

Green Climate Fund. **About the Fund.** Disponível em: https://www.greenclimate.fund/who-we-are/about-the-fund. Accessed in November 2017.

HONGYOU LU. **Capturing the invisible resource: analysis of waste heat potential in chinese industry and policy options for waste heat to power generation** Berkeley, CA : Ernest Orlando Lawrence Berkeley National Laboratory, 2015. Available in: https://eta.lbl.gov/sites/all/files/publications/lbnl-179618.pdf

IEA and WBCSD (2009), **Cement Technology Roadmap 2009: Carbon Emissions Reductions up to 2050**, OECD/IEA and WBCSD, Paris and Geneva. Disponível em: www.iea.org/publications/freepublications/publication/Cement.pdf.

IEA and WBCSD (2018), **Technology Roadmap - Low-Carbon Transition in the Cement Industry.** IEA and WBCSD, Paris and Geneva. Available in: https://webstore.iea.org/technology-roadmap-low-carbon-transition-in-the-cement-industry.

INTERNATIONAL ENERGY AGENCY. **Tracking industrial energy efficiency and CO_2 emissions.** Paris: OECD/IEA, 2007. 321p.

MCTI. **Third National Communication of Brazil to the United Nations Framework Convention on Climate Change**, Brazil, 2016.

XI, F. et al. **Substantial global carbon uptake by cement carbonation.** Nat. Geosci. advance online publication, 2016.

Abrelpe. **Overview of Solid Waste in Brazil 2016.** São Paulo: [s.n.], 2017

HM Revenue & Customs. Available in: https://www.gov.uk/government/publications/excise-notice-lft1-a-general-guide-to-landfill-tax/excise-notice-lft1-a-general-guide-to-landfill-tax. Accessed in 19 December 2017.

SF Environment. Available in: https://sfenvironment.org/striving-for-zero-waste. Accessed in 19 December 2017.

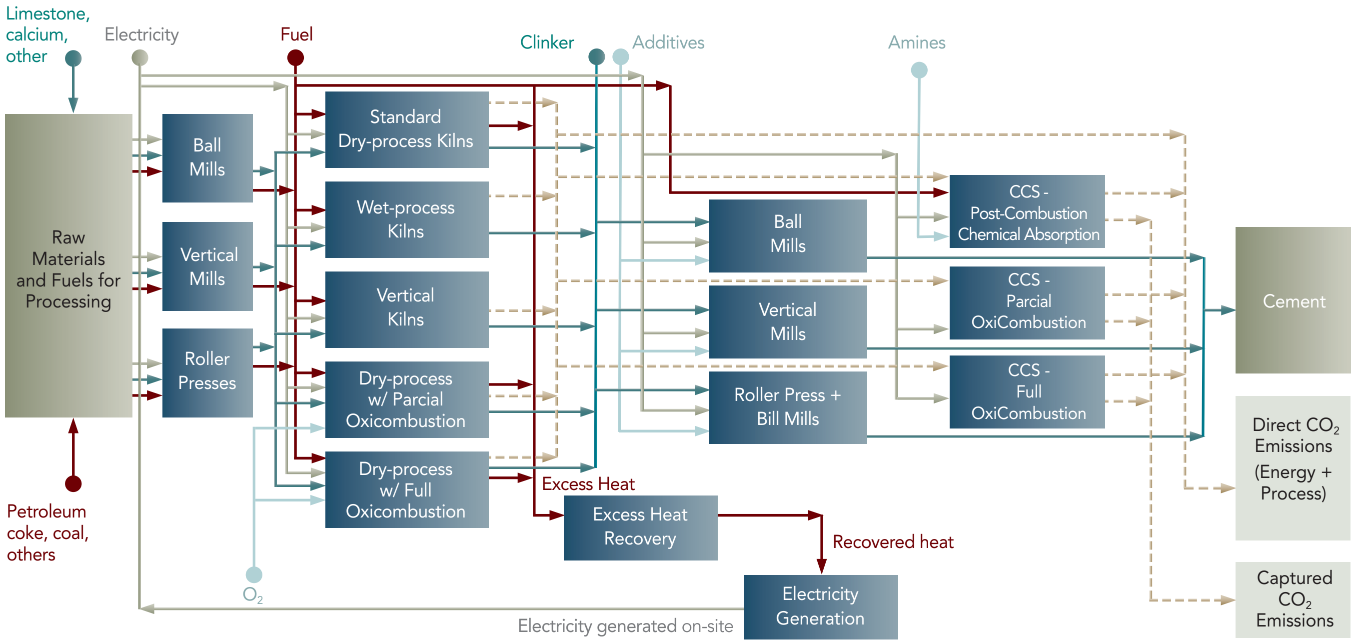
ANNEXES

Annex 1: Modelling framework and methodology

The energy and direct CO_2 results of this roadmap are derived from the IEA's Energy Technology and Policy model, which covers the global energy system; the results discussed here come from the cement sector module of the ETP-Industry model. The ETP cement model follows a bottom-up approach to account for the cement manufacturing process from raw materials and fuel preparation through cement grinding and milling. Each relevant process or technology is characterised by energy performance, material yield and cost, and within a set of realistic constraints. The model is based on TIMES[32] and generates a cost-optimal technology portfolio to meet an exogenously set cement production level within defined constraints. Final energy demand by energy carrier, material and direct CO_2 flows, as well as related technology investments are generated as results from the ETP cement model.

The cement sector energy use and technology portfolio for Brazil is characterised in the base year (2014) using relevant energy use and material production statistics and estimates, including data from the National Cement Industry Association (SNIC), the World Business Council for Sustainable Development - Cement Sustainability Initiative (WBCSD-CSI), the International Energy Agency (IEA), and the Brazilian Institute of Geography and Statistics (IBGE). Shifts in technologies' deployment and fuel mix over time in each scenario are influenced by exogenous assumptions on the potential for market penetration and energy performance of best available technologies (BAT), constraints on the availability of raw materials, techno-economic characteristics of the available technologies and process routes, assumed progress on demonstrating innovative technologies at commercial scale, and direct CO_2 emissions budget defined in the scenario. The results are therefore sensitive to assumptions on the pace of physical capital turnover, relative costs of various technology options and fuels, and incentives for the use of BAT for new capacity. Fuel costs are based on outputs from the ETP Supply sector model, and are specific for each scenario analysed.

High-level structure of the IEA ETP cement sector model



---

[32] TIMES (The Integrated MARKAL-EFOM System) is a model generator developed by the Energy Technology Systems Analysis Programme (ETSAP) Technology Collaboration Programme (TCP) of the IEA, which allows an economic representation of local, national, and multiregional energy systems on a technologically detailed basis.

Annex 2: Cement demand projection

Several variables are related to cement consumption and therefore have the potential to explain and design it. The national income is an obvious candidate, since it is a satisfactory measure of the dynamism of the economy and its growth. The observation of the long-term relationship between income, as measured by GDP, and cement consumption for a significant and varied set of countries, including Brazil, shows that in fact this variable is strictly correlated with cement consumption, being strongly influenced by economic cycles. This integration between the two series led to the successful estimation of a projection model based on an error correction mechanism (ECM).

Three scenarios for GDP growth were considered until 2050: reference, optimistic and pessimistic. With this, the per capita and total cement consumption projection was made, taking into account the estimated long-run elasticities. The scenarios for GDP growth were built from a set of projections of financial institutions and international organizations.

Some factors were taken into account for the projection of cement: population growth, major infrastructure deficiencies, high housing deficit and technological advances.

Regarding the demographic projection, estimates by the Brazilian Institute of Geography and Statistics (IBGE)[33] point to a population growth up to 2040, followed by stabilization and a predicted fall from 2050 onwards.

Roads, bridges, ports, airports, generation and distribution of electricity and sanitation and water supply networks, among many other types of work, will require cement in its construction. Once this infrastructure is built, growth in the demand for the material will slow down, although its maintenance will tend to keep consumption at high levels.

With regards to housing, the expectation is that with the growth of income and assuming the persistence of active housing policies, the elimination or at least a significant reduction of this deficit will occur, which would also boost cement consumption for some years , followed by a period of stabilization in consumption for use in residential construction.

Finally, in the long term, technological advances and more modern techniques of construction tend to increase the efficiency in the use of the material, resulting in a lower demand of cement for a same number of buildings.

All these factors point in the direction of a reduction, from some moment in the horizon of projection, in the intensity of the long-term relation between the income of the country, measured by the GDP, and the consumption of cement. This effect was included in the estimated model.

The analysis of the results indicates a significant increase in demand for cement in Brazil between 2016 and 2050 in both the high and low demand scenarios. It is projected that consumption should grow strongly until the beginning of the 2040s and then decline until there is a reduction in demand after 2045.

Key parameters of the basic assumptions and input module for Brazil

	2014	2020	2025	2030	2035	2040	2045	2050
GDP (billion 2015 USD at ppp[34])	3.234	3.196	3.796	4.232	4.928	5.413	5.660	6.218
Population (million)	203	212	218	223	226	228	228	226
Per-capita income(2015 USD at ppp/capita)	15.951	15.072	17.386	18.966	21.765	23.724	24.810	27.470
Cement demand intensity (kg/capita)								
Low-Demand Case	352	290	365	388	478	554	557	515
High-Demand Case	352	305	402	441	579	714	744	691
Cement production (Mt)								
Low-Demand Case	71	62	80	87	108	126	127	117
High-Demand Case	71	65	88	98	131	163	170	156

---

[33] "Brazil's Population Projection by Sex and Age for the Period 2000-2060". IBGE, 2013.

[34] Purchasing Power Parity..

Annex 3: Technological profile of the cement industry in Brazil

2014		
Indicator	Unit	Value
Cement Plants	/	100
Integrated	/	64
Grinding Mills	/	36
Clinker Capacity	Mt/year	57
Cement Capacity	Mt/year	95
Cement Production per Type	% of production	
CPI (ordinary portland cement)	%	1%
CPII (composite portland cement)	%	63%
CPIII (blast furnace cement)	%	9%
CP IV (pozzolanic cement)	%	15%
CP V (high early strength cement)	%	11%
Others	%	1%
Process Type	% of capacity	
Wet	%	0,6%
Vertical	%	0,4%
Dry	%	99%
Dry with Preheater 4 stage	%	30%
Dry with Preheater 4 stage + Precalciner	%	20%
Dry with Preheater 5 stage + Precalciner	%	37%
Dry with Preheater 6 stage + Precalciner	%	12%
Cooler Type	% of capacity	
Planetary (or Satellite) Cooler	%	20%
Grate Cooler	%	80%
Raw Meal Mill Type	% of capacity	
Ball Mill	%	54%
Vertical Mill	%	46%
Moinho de Cimento	% of capacity	
Ball Mill	%	84%
Vertical Mill	%	16%
Moinho de Combustíveis	% of capacity	
Ball Mill	%	65%
Vertical Mill	%	35%
Specífic Electric Consumption	kWh/t cement	
Up to Raw Meal Grinding	%	3%
Raw Meal Grinding	%	21%
Fuel Grinding (coal; petcoke; others)	%	4%
Kiln	%	26%
Cement Grinding	%	44%
Others (loading, bagging, ...)	%	3%
Average Age of Kilns	% of capacity	
≤ 15 years	%	32%
16-30 years	%	25%
31-50 years	%	30%
≥ 51 years	%	13%

Annex 4: Main results of this Roadmap

Production	2014	2020	2030	2040	2050
Cement (Mt)	71	62	87	126	117
Clinker (Mt)	48	41	51	67	61

Clinker substitutes	2014	2020	2030	2040	2050
Clinker Factor (%)	68%	65%	59%	54%	52%
Blast Furnace Slag	14%	11%	11%	11%	11%
Fly Ash	3%	3%	3%	3%	2%
Calcined Clays	3%	3%	4%	4%	4%
Limestone Filler	8%	13%	18%	23%	25%
Others	1%	1%	2%	2%	2%
Gypsum	4%	4%	4%	4%	4%

Alternative Fuels	2014	2020	2030	2040	2050
Substitution Rate (%)	15%	22%	35%	45%	55%
Waste	8%	15%	29%	36%	44%
Non Hazardous Waste	0%	5%	11%	14%	17%
Hazardous Industrial Waste (Blend)	4%	3%	3%	4%	4%
Tires	5%	5%	5%	5%	5%
Municipal Solid Waste	0%	2%	10%	13%	17%
Biomass	7%	7%	6%	9%	11%
Charcoal	6%	4%	0%	0%	0%
Sewage Sludge	0%	1%	2%	6%	7%
Agricultural Waste	1%	2%	3%	3%	4%

Energy Efficiency	2014	2020	2030	2040	2050
Thermal (GJ/t clinker)	3,50	3,49	3,47	3,38	3,22
Electric (kWh/t cement)	113	111	106	95	91

Carbon Capture and Use or Storage (CCUS)	2014	2020	2030	2040	2050
Mt CO_2	0,0	0,0	0,0	1,7	3,3

Total Emissions	2014	2020	2030	2040	2050
Mt CO_2	40	34	42	52	44

Emissions Intensity	2014	2020	2030	2040	2050
(kg CO_2/t cement)	564	552	485	414	375

ROADMAP PARTNERS AND COLLABORATORS

General Coordination

National Cement Industry Association (SNIC)

Founded in 1953 as the legal representative of the sector, the SNIC stands out in the political-institutional representation of the category. Interacting in the scope of industry, commerce and services - through public and private, national and foreigners - collaborates with the State, as a technical and consultative entity, in the economic, tax, environmental, mining, and health and safety issues. It develops studies and formulates sector indicators that contribute to the values generated by the cement activity being shared with millions of people and favoring the economic and social growth of the country.

Brazilian Portland Cement Association (ABCP)

Founded in 1936 to promote studies and research on cement and its applications, ABCP - Headquartered in São Paulo and Regionals Offices in 9 Brazilian capitals - has become a technological center for the improvement of cement manufacturing and for the development of construction market. Through laboratory tests, training courses, technical publications, quality programs, innovative solutions among other products, services and research, it contributes to the industry offering a high quality product and produced within the most rigorous environmental standards, at the same time in which it promotes and increases the use of construction systems based on cement of great durability.

Participating companies

CIPLAN - CIMENTO PLANALTO S.A.

INTERCEMENT DO BRASIL S.A.

CIA. DE CIMENTO ITAMBÉ

LAFARGE HOLCIM

EMPRESA DE CIMENTOS LIZ S.A.

VOTORANTIM CIMENTOS S.A.

Collaborators

International Energy Agency (IEA)

The International Energy Agency (IEA) examines the full spectrum of energy issues including oil, gas and coal supply and demand, renewable energy technologies, electricity markets, energy efficiency, access to energy, demand side management and much more. Through its work, the IEA advocates policies that will enhance the reliability, affordability and sustainability of energy in its 30 member countries, 7 association countries and beyond.

The four main areas of IEA focus are:

- Energy Security: Promoting diversity, efficiency, flexibility and reliability for all fuels and energy sources;
- Economic Development: Supporting free markets to foster economic growth and eliminate energy poverty;
- Environmental Awareness: Analysing policy options to offset the impact of energy production and use on the environment, especially for tackling climate change and air pollution; and
- Engagement Worldwide: Working closely with association and partner countries, especially major emerging economies, to find solutions to shared energy and environmental concerns.

World Business Council for Sustainable Development (WBCSD)

Cement Sustainability Initiative (CSI)

The CSI was a global effort by 25 major cement producers with operations in more than 100 countries who believed there is a strong business case for the pursuit of sustainable development. Collectively these companies accounted for about one-third of the world's cement production and ranged in size from large multinationals companies to small local producers.

All CSI members integrated sustainable development into their business strategies and operations as they sought strong financial performance with an equally strong commitment to social and environmental responsibility. The CSI, an initiative of the World Business Council for Sustainable Development (WBCSD), remains one of the largest global sustainability projects ever undertaken by a single industrial sector.

Its activities were ended at the end of 2018 and officially transferred to the newly created Global Cement and Concrete Association (GCCA) as of January 2019.
For more information, visit www.wbcsdcement.org

International Finance Corporation (IFC)

IFC—a sister organization of the World Bank and member of the World Bank Group—is the largest global development institution focused exclusively on the private sector in developing countries.

IFC leverages its products and services—as well as products and services of other institutions across the World Bank Group—to create markets that address the biggest development challenges of our time. IFC applies its financial resources, technical expertise, global experience, and innovative thinking to help its clients and partners overcome financial, operational, and other challenges.

In Fiscal Year 2017, IFC invested $19.3 billion, including nearly $7.5 billion mobilized from other investors.
For more information, visit www.ifc.org

Acknowledgements

This publication is the result of a joint effort by the National Cement Industry Association (SNIC) and the Brazilian Portland Cement Association (ABCP) – representing the manufacturing groups Cimentos Liz, Ciplan, InterCement, Itambé, LafargeHolcim and Votorantim Cimentos -, in collaboration with the International Energy Agency (IEA), the Cement Sustainability Initiative (CSI) of the World Business Council for Sustainable Development (WBCSD) and the International Finance Corporation (IFC) of the World Bank Group. This Roadmap also contains valuable contributions from academics from renowned universities and Brazilian technology centers in the elaboration of the Technical Papers, under the technical coordination of José Goldemberg. Our thanks also to the more than 200 professionals from industry, government, academia, development agencies and other stakeholders who took part in meetings and workshops held during the project, providing rich contributions that helped to compose this report.

Elaboration

General Coordination

Gonzalo Visedo (SNIC) e Marcelo Pecchio (ABCP).

The Industry's technical committee

Ana Rita Pinton (Liz), Luiz Germano Bernartt (Votorantim), Norberto Schutz Cruzeiro (Itambé), Patricia Montenegro (Votorantim), Seiiti Suzuki (InterCement), Silvana Ottoboni (Ciplan).

National Cement Industry Association (SNIC)

José Otavio Carvalho, Bernardo Jannuzzi, Brenda Ruhle, Camila Jordan, Carlos Maia e Flavio Guimarães.

Brazilian Portland Cement Association (ABCP)

Renato José Giusti, Ana Starka, Antonia Jadranka Suto, Arnaldo Battagin, Hugo Rodrigues, Mario William Esper e Yushiro Kihara.

Collaboration

International Energy Agency (IEA)

Araceli Fernandez, Cecilia Tam e Kira West.

Cement Sustainability Initiative (CSI/WBCSD)

Cristiana Ciaraldi, Philippe Fonta, Yvonne Leung (extensive to the entire CSI Climate Change Task Force)

International Finance Corporation (IFC/World Bank)

Alexander Sharabaroff, Luis Salomon e Michel Folliet.

Technical Papers (Coordination: José Goldemberg)

Maria Alba Cincotto and Maristela Gomes (Clinker substitutes); Mauricio Henriques Junior (Energy efficiency); José Goldemberg (Alternative fuels); Marcelo Ketzer and Sergio Pacca (CCUS); Patricia Montenegro (Regional differences); Vanderley John (Mitigation potential in the construction chain).

Graphic Design: Gisela Fiuza / GF Design

English version: Chris Hieatt e Bern Hoffmann

Photos: Image banks from SNIC, ABCP, Votorantim, Deposit Photos
Photo page 51: Amanda Menger

Printed in Rio de Janeiro, Brazil, March 2019

Roadmap objectives, partners and collaborators

This study aims to map the current situation and future trends of the Brazilian cement industry, proposing ways to further reduce its already low CO_2 emissions. It's also points out barriers and constraints that limit the deployment of identified measures, and suggests a series of recommendations for public policies, support mechanisms, regulatory and legal issues, among others, that are emissions reduction enablers in the short, medium and long term.

This Roadmap represents the joint effort of a number of national and international partners plus the views and contributions of numerous local experts. The Brazilian cement sector was represented by the manufacturing groups Cimentos Liz, Ciplan, InterCement, Itambé, LafargeHolcim and Votorantim Cimentos, as well as through the industry associations SNIC and ABCP. The project also had the collaboration of IEA, CSI and IFC and a number of renowned specialists from Brazilian universities and technological centers.

General Coordination

SNIC
SINDICATO NACIONAL DA INDÚSTRIA DO CIMENTO

Associação Brasileira de Cimento Portland

Collaborators

IFC International Finance Corporation WORLD BANK GROUP

iea International Energy Agency

wbcsd

Participating Companies

InterCement

LIZ CIMENTOS

CIPLAN CIMENTO

ITAMBÉ

LafargeHolcim

Votorantim Cimentos