WE MEAN BUSINESS COALITION

CORPORATE CLIMATE STOCKTAKE: CONCRETE AND CEMENT SECTOR

October 2023

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Global cement production reached ~4.4B metric tons in 2021, driven in large part by China

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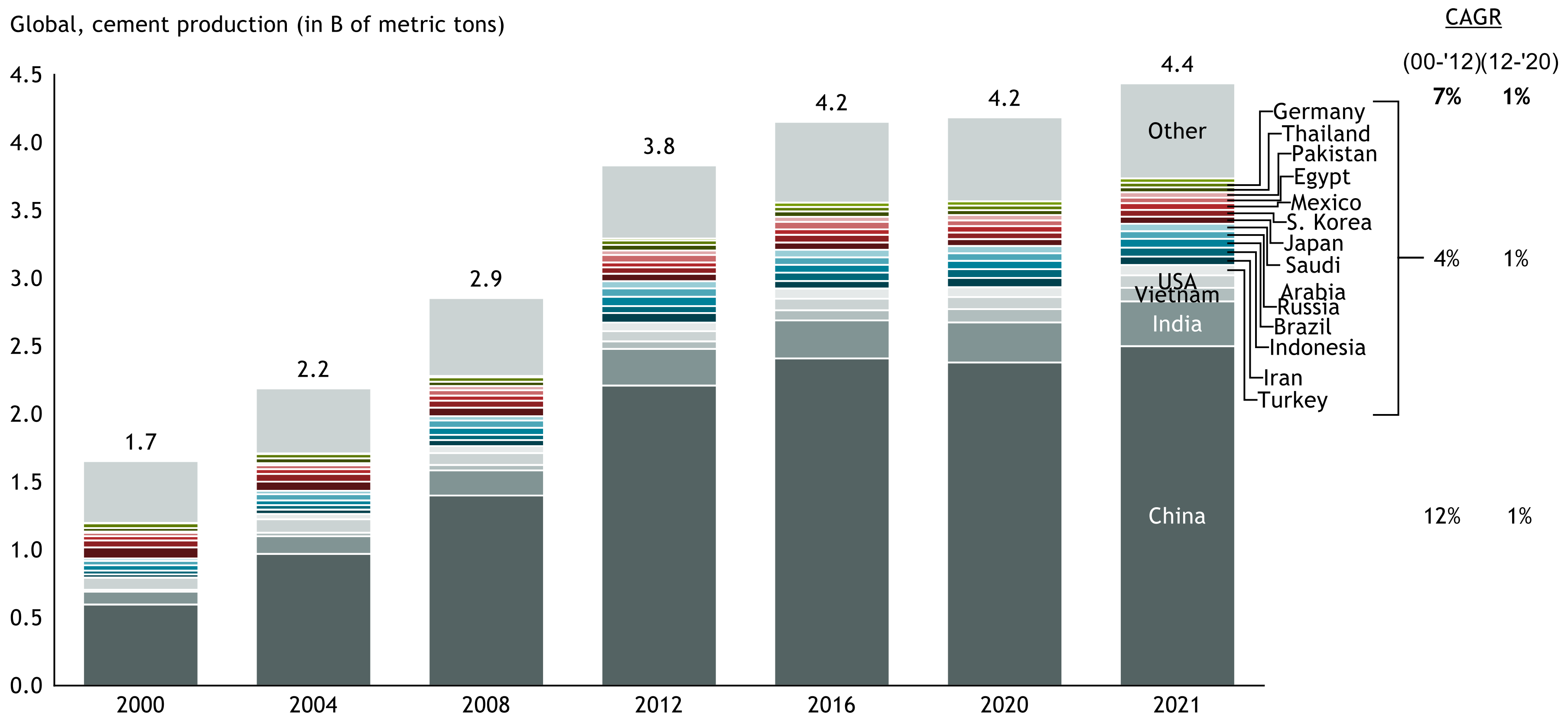
China cement production has ~4x in less than 20 years; ex-China growing much slower

Global, cement production (in B of metric tons)



Source: US Geological Survey

There are two drivers of production

1. **The number of construction projects** is driven by:
   - Economic activity
   - Economic forecast and certainty
   - Government stimulus / intervention
   - Housing requirements
2. **Share of cement in concrete** is driven by:
   - Share of construction materials that are concrete and cement
   - Construction type
   - Durability regulations
   - Environmental impact regulations

Players across the cement sector value chain have portfolios that include a combination of cement, concrete, and supplementary materials

/ NON-EXHAUSTIVE

Part of value chain in which player participates

- Raw materials (incl. limestone, gypsum, etc.)
- Clinker production
- Supplementary cementitious materials (SCMs)
- Cement production
- Aggregates
- Concrete

Vertically integrated players

CRH, HOLCIM, Buzzi Unicem, Heidelberg Materials, CEMEX, Vulcan Materials Company

- Own and operate facilities for extraction of raw materials
- Clinker production is typically co-located with limestone excavation (being the most significant input, ~1.6T limestone required for ~1.0T clinker)
- Cement production can be co-located with clinker production ("integrated plant") or separate ("grinding plant")
- Cement players forward integrate into concrete, which although lower margin (single digit % EBITDA margin), provides reliable volume pull-through for the more profitable cement business (20-30% margin)

There are a select number of cement-only players who complete all but the forward-integrated concrete production that vertically-integrated players do

Materials players

CARMEUSE, Minerals Technologies, United States Lime & Minerals

- Own and operate facilities for extraction of raw materials

- In the US, Supplementary Cementitious Materials (SCMs) are often sold to concrete makers by standalone players who control supply of fly ash, slag, etc.
- In EU, SCMs are usually not sold separately

- Own and operate facilities for extraction of aggregates (sold direct to Concrete and Integrated players)

Concrete only players

FORTERRA, ELO BETON, SPANCRETE

Arrows represent direction products are sold in (e.g., materials players sell SCMs to both vertically integrated and concrete only players)

- Produce concrete (liquid and pre-cast structures) from cement and aggregates for use in construction industry (infrastructure, residential, non-residential)

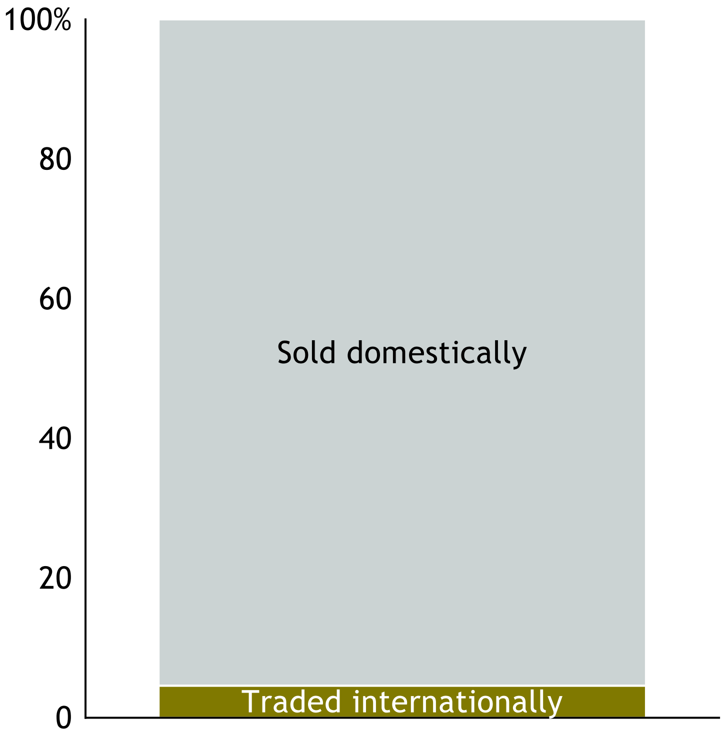
Source: Lit. search

Production and sale of cement is almost completely localized

01 SECTOR OVERVIEW 02 03 04

Only 5% of global cement production is traded internationally

% of global cement production that is traded (in 2021)



Source: JP Morgan Cement Market Overview

Cement markets are largely localized to where construction needs are, meaning cement pricing is localized too

Why cement markets are localized

Transportation costs

Cement's bulky nature makes local production more economical

Local regulations

Some countries restrict trade of cementitious materials

Excess capacity

Some countries with excess capacity can meet demand spikes, limiting trade needs

Drivers of cement pricing

Local cost base

Local costs determine the minimum price, driven mostly by fuels

Market concentration

Markets with fewer producers typically have higher prices

Capacity utilization

The more production capacity is utilized, the higher prices will be

Carbon is emitted throughout the cement and concrete lifecycle, with 88% of emissions coming during clinker production

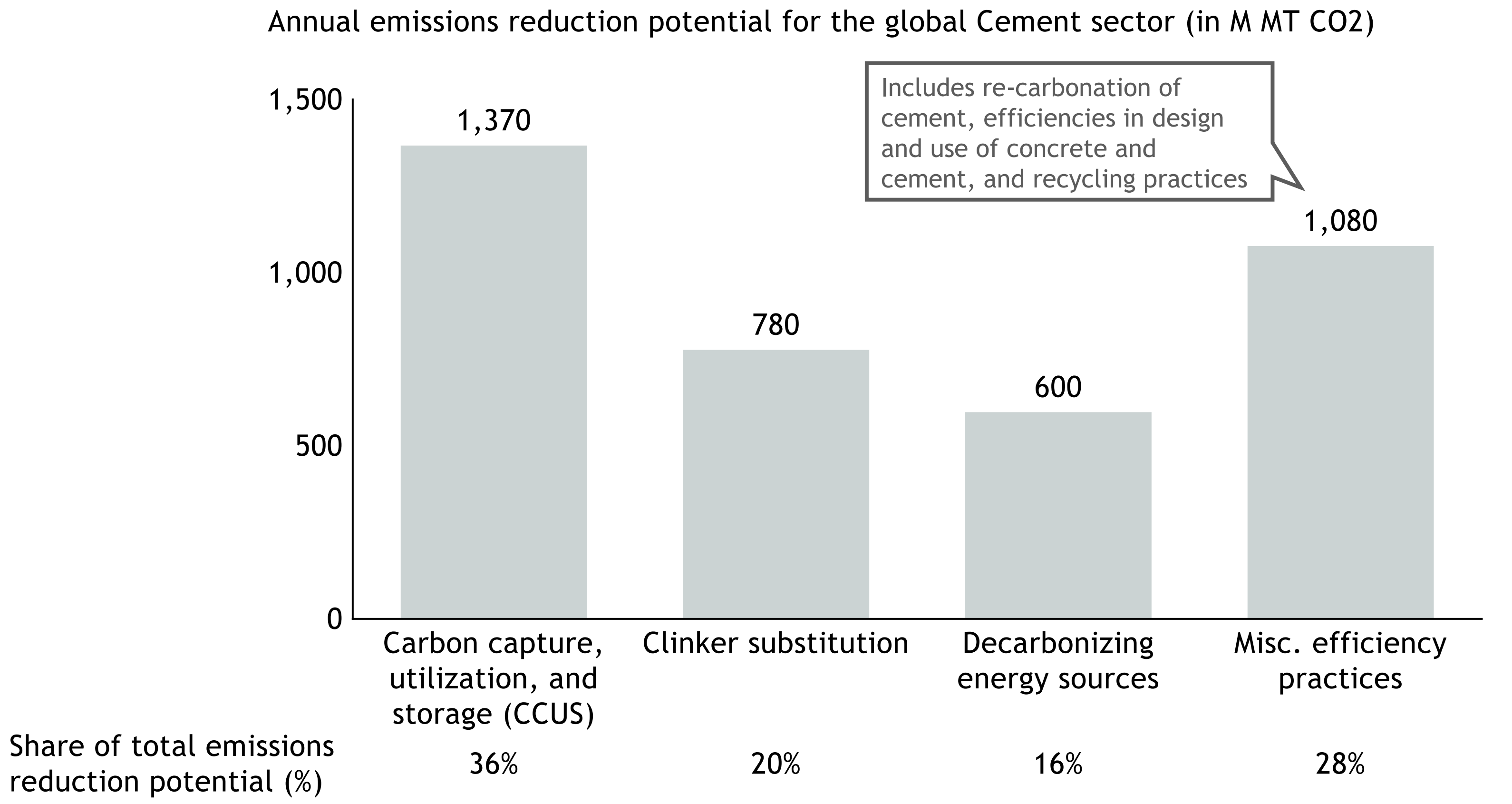
Focus of these materials

Stage	Description	Share of emissions	
Extraction and preparation of raw materials	• "Raw meal" – the raw material of clinker – is primarily a mixture of limestone and clay • ~1.6 metric tons of limestone – excavated from quarries located near cement facilities – are required per metric ton of clinker, with calcium oxide as the key ingredient in limestone used as a binding agent for the mix • The materials are crushed, blended and homogenized to ensure consistent, high quality	1%	 Limestone
Clinker production	• Raw meal is milled and heated to 1450^{0} C in a kiln to ensure the mix will harden with the addition of water, releasing the carbon contents of the limestone in the raw meal (53% of sector emissions) • Heat is generated via fuel combustion – most commonly coal or natural gas (35% of sector emissions) • The result of the heated raw meal is clinker, an intermediate, rock-like material which is the foundation for cement	88%	 Clinker
Cement production	• Once cooled, clinker is ground and mixed with gypsum to produce Portland cement, a finely ground powdery mix • To produce composite cement, Portland cement is mixed with Supplementary Cementitious Materials (SCMs) such as: fly ash (residue from coal production), ground granulated blast-furnace slag (residue from steel production), or alternative pozzolans (rock-like materials like calcined clays, pumice stones, etc.)	5%	 Cement
Concrete production	• Concrete is created by mixing cement, water, and an admixture composed of sand, gravel, and crushed stone • This process can occur on-site (using bagged cement) or in bulk at a plant that produces ready-mix concrete or a factory making pre-cast products	5%	 Concrete
Concrete application	• Concrete is then used in the construction of buildings and infrastructure	1%	

Source: Mission Possible Partnership

“We aim to decarbonize at scale, which requires all levers available, from clinker substitution to non-fossil energy to carbon capture”

CCUS and clinker substitution are the largest opportunities for cement decarbonization



Commentary

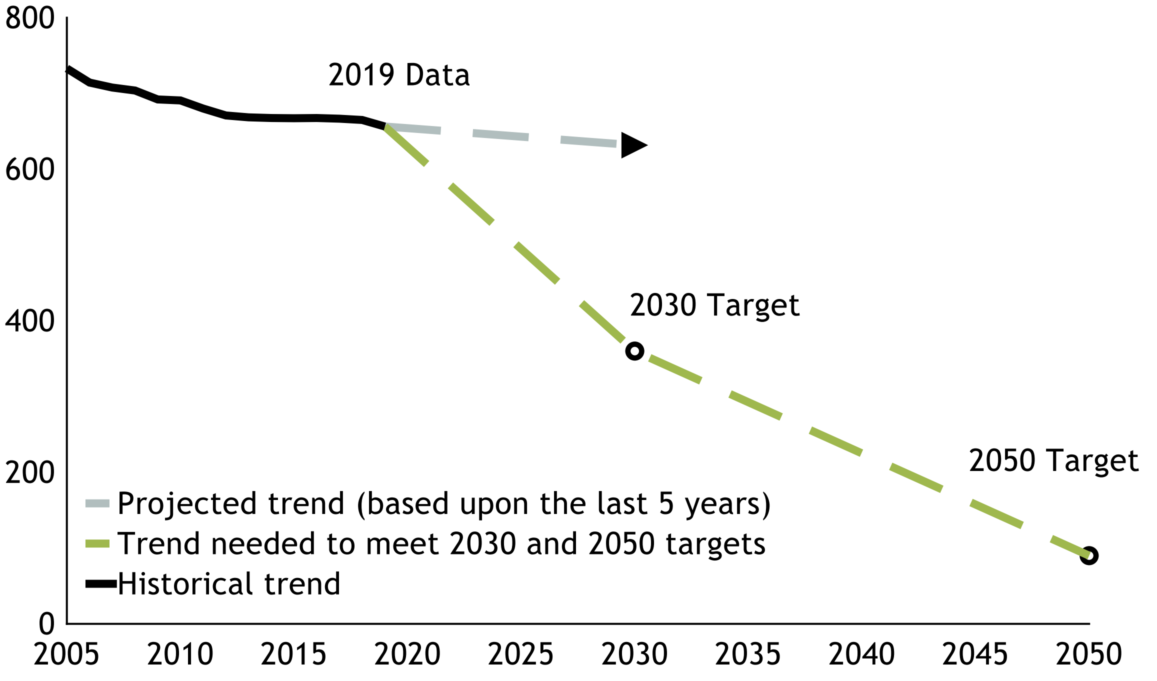
- Process emissions are inherent to the production of cement, making **CCUS critical for emissions reduction from limestone use**
- While clinker production generates 88% of the sector’s emissions, **clinker’s unique characteristics make it challenging to fully replace** in concrete and cement mixes
- Clinker needs to be heated to 1450 ^{0}C, requiring significant thermal energy from coal and natural gas. The transition to **renewable electricity and green hydrogen is also an important decarbonization lever.**

Note: Title quote is from VP Group Affairs and Government Relations, Cement producer #4
Source: The GCCA 2050 Cement and Concrete Industry Roadmap for Net Zero Concrete; Corporate interviews

"We're looking at how we can decrease the embodied carbon of our buildings, and that will require many innovations including low-carbon concrete"

Emissions intensity has decreased over time, but significant acceleration in emissions reduction is needed to reach targets

Emissions intensity of cement (kg CO2/t cement)



As cement production has increased, carbon intensity of cement has decreased

- **Cement production has increased over time** in order to meet demand, rising to 4.4B metric tons of cement in 2021
- **Carbon intensity of production has decreased continuously over the past two decades**; however, the rate of change has **leveled off in recent years**
- **Carbon-reducing strategies and technologies, such as clinker ratio reduction, alternative fuel use, and CCUS installations will be needed to** continue reducing emissions intensity of cement production

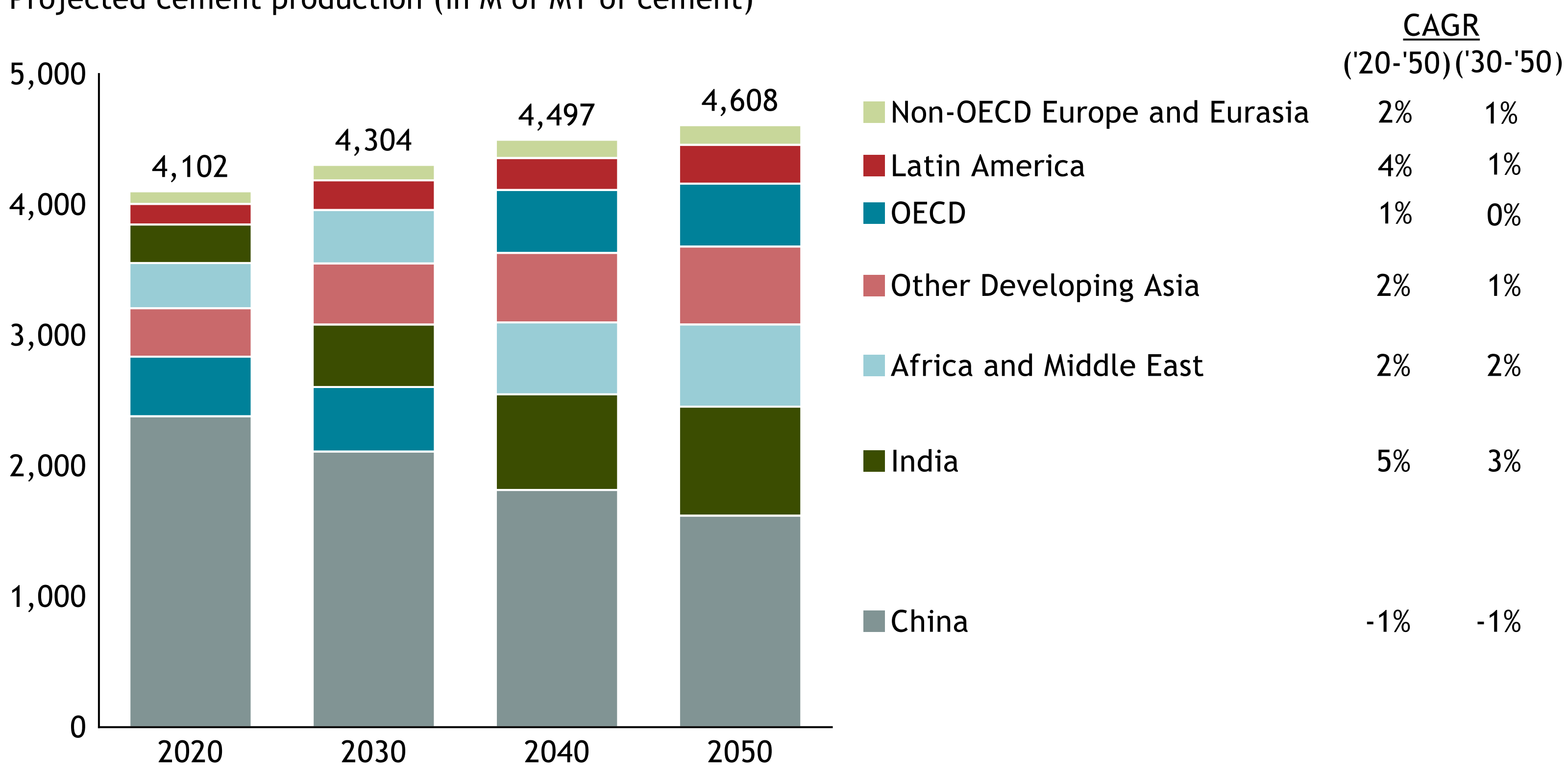
Installing technologies which reduce cement's carbon intensity is easiest when new plants are built

Note: Title quote is from Head of ESG and Sustainability, Building owner #1
Source: Systems Change Lab, Corporate interviews

Absent intervention to promote carbon-friendly cement processes, absolute emissions will rise as production grows in emerging cement markets

India, Africa, and the Middle East are expected to see the largest increase in cement production through 2050

Projected cement production (in M of MT of cement)



Source: IEA, WBCSD, US Geological Survey (USGS)

Green processes in emerging cement markets will be crucial for decarb.

- Shifts in cement production driven by changes in the demand for buildings, which occur when countries undergo **infrastructure revolutions**
  - Over the next 30 years, emerging cement markets will include regions hitting infrastructure revolutions like India, African nations, and developing Asian countries
  - More developed countries like OECD nations and China expect stagnant or declining cement production
- Emerging cement markets will **install new cement plants and increase capacity in existing ones** to meet demand

"Growing concrete markets need to optimize policy for the feedstocks accessible in each of their regions"

Lack of policy inhibits lower carbon production

- Near-term development needs tends to drive the rapid scale up of **low-cost cement production**
- **Developed markets in Europe are incentivizing the adoption of lower carbon processes, but this isolated regulatory shift creates opportunities to expand to less regulated regions** like North Africa and then shipping clinker to where it is needed
- Some countries at the forefront of the next wave of cement production growth have **adopted a mix of policies to ensure that new production is "green"**

	Vietnam	Turkey	Indonesia	Nigeria
2022 production capacity	116M MT (3rd largest in the world)	85M MT (largest in Europe)	64M MT (6th largest in the world)	60M MT
Historical CAGR	↗ ~7% (2018-22)	↗ ~4% (2018-22)	↗ ~7% (2012-22)	Unknown
Projected CAGR	↗ ~8% (2022-27)	↗ >8% (2023-25)	↗ ~8% (2023-28)	↗ 6% (2021-26)
Growth drivers	• Decline in Chinese production • Low labor costs • Rich limestone supply • Large infrastructure projects (gov't to spend ~$65B through 2030) • Expected increase in urbanization	• Swell in reconstruction projects in the aftermath of the earthquake • Myriad gov't projects incl. airports, railways, bridges, housing schemes, etc. • Rich limestone supply • Ample export partners in EU, US, Saudi Arabia, and Canada	• Push for construction in Nusantara expected to demand ~20M MT over next 20 years • Gov't infra. agenda includes 2,650 km of roads, 15 airports, 24 port refurbishments, urban and national railroads, 49 dams, 2 oil refineries, and >500K housing units	• Removed import duty on cement and concrete production equipment and lifted restrictions on import of gypsum • Increase in demand fueled by: - Infrastructure growth (8.9% of government budget in '22) - Real estate demand (30M unit housing deficit)
Green cement and concrete policies	• **Subsidies:** Low-clinker cement exports are exempted from VAT and 5% export tax • **Standard setting:** Gov't requiring ~15% of cement production must utilize waste substitutes by 2030 and plants with <2.5K MT capacity per day are expected to submit plans to invest in improved efficiency	• **Pricing:** Gov't has included cement on its list of products that require export permissions and domestic pricing regulation to optimize pricing for lower clinker mixes • **Standard setting:** Has mandated 41% reduction in cement and concrete producers' emissions by 2030 and 0% by 2050	• **Standard setting:** Gov't has begun to slow down and regulate the speed at which new production capacity is approved and has set a goal for cement and concrete production to be net zero by 2060	• **Subsidies:** Tax incentives introduced to shift away from coal-fired kilns • **Standard setting:** Has mandated 20% reduction in cement and concrete producers' emissions by 2030

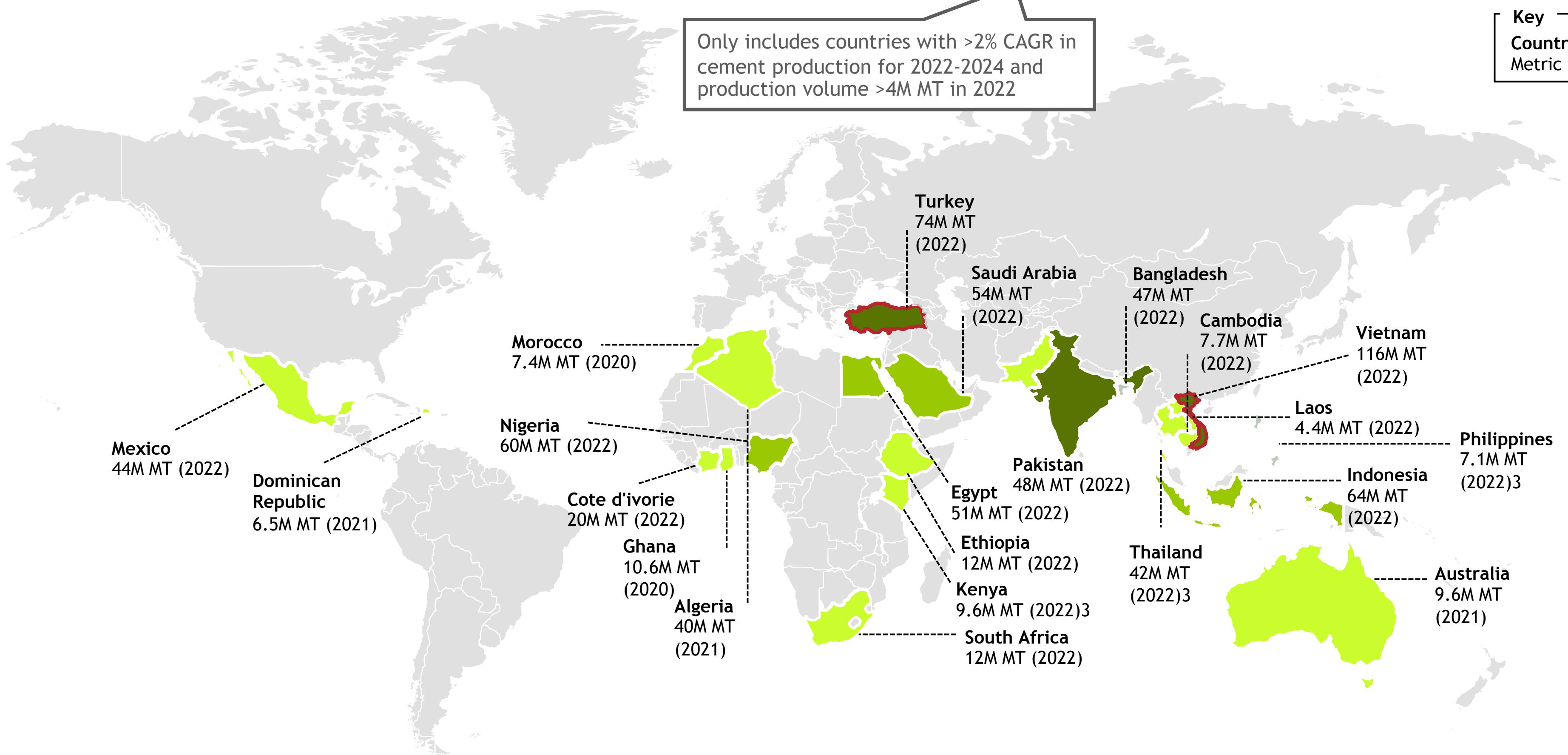
Note: Title quote is from Global Sustainability Lead, Utility company #5
Source: Lit. search, Corporate interviews

A significant driver of market demand is public procurement, and governments are huge infrastructure developers, especially in growing cement markets

Legend: Production volume (2022)[4] — >100M MT; 50-100M MT; <50M MT; >8% CAGR ('23-'25)

Key
Country
Metric tons of cement production (Year)

Only includes countries with >2% CAGR in cement production for 2022-2024 and production volume >4M MT in 2022

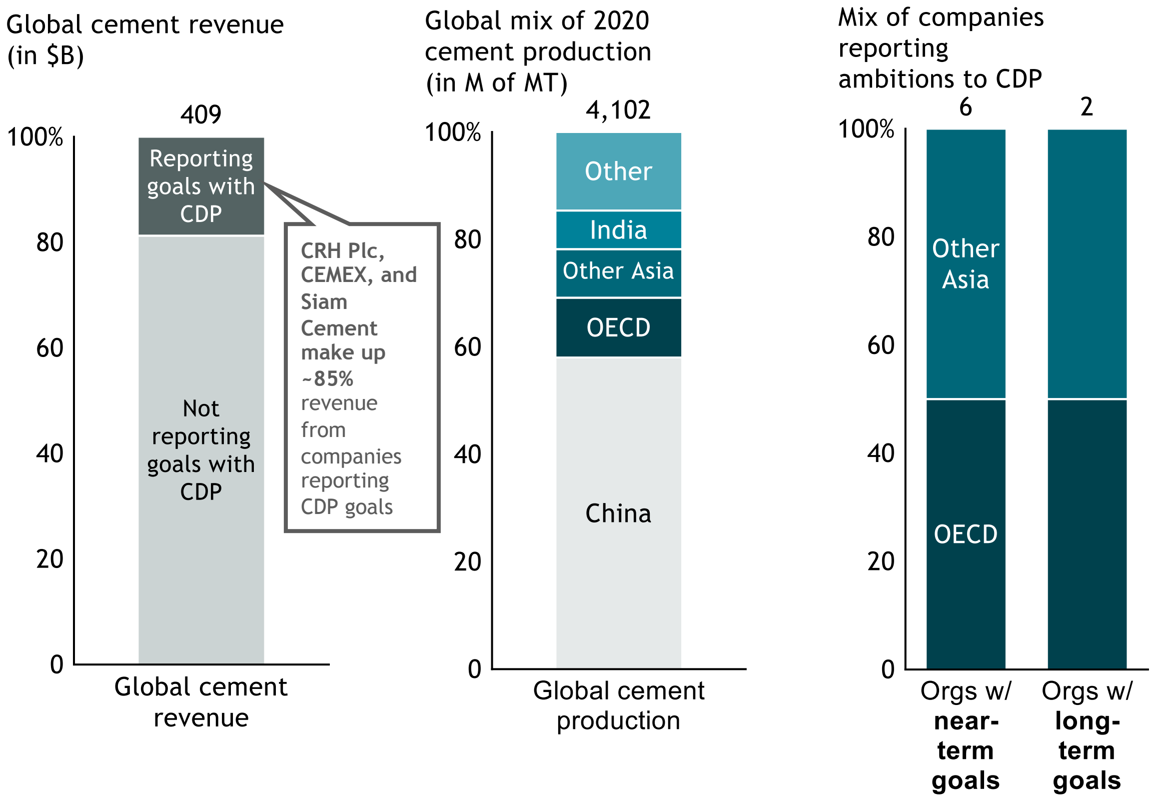


Notes: 1) Countries with >2% CAGR for cement demand for the next 2 years have been selected and a production volume >4M MT in 2022 have been selected (~0.1% of global cement production of 4,300M MT); 2) Eliminated countries which are historically relying on imports to meet cement demand (NA) and included countries which do not have a high domestic demand growth but are expected to expand exports (Thailand, Kenya, Mexico); 3) Production in Philippines for H1 FY 22 was 3.51M MT, Production in Thailand up to Q3 was 32M MT, Production in Kenya for 10 months was 80.2M MT (which has been extrapolated to arrive at annual production); 4) For some countries data for 2020 and 2021 has been used
Sources: Global Cement Industry - Trends, forecasts and the decarbonization challenge, June 2023, Lit. search

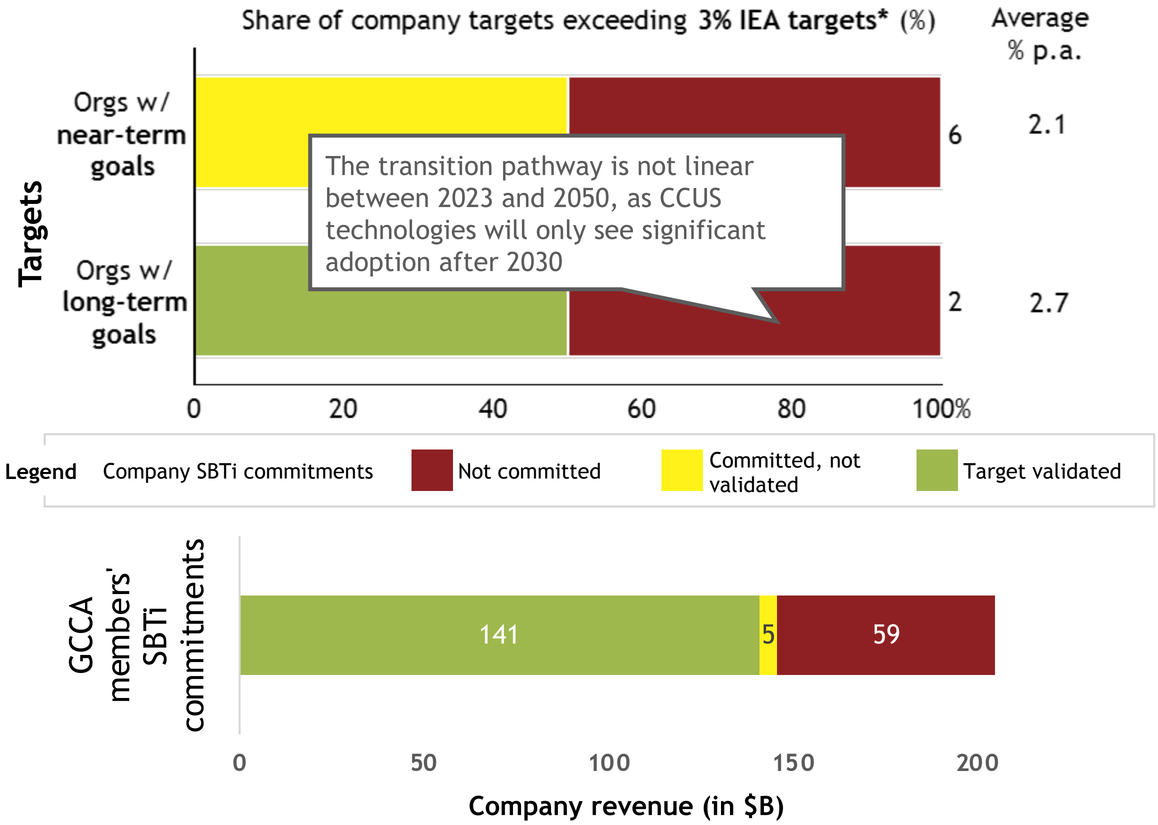
<20% of the Cement market is reporting to the CDP, however majority of GCCA members have set SBTs aligned with cement sector guidance

Legend Company performance vs. IEA: Missed target (<80%) | Near miss (80-100%) | Hit target (+100%)

CDP data leans toward OECD and Asia (excl. China)



CDP/IEA target-setting not as common as SBTi-aligned targets



Note: (*) 3% IEA target is aligned with IEA's net-zero scenario; Annual reduction ambition shows the % reduction a company will need per year in order to reach their target from the base year (includes underway, new, or revised targets); near-term defined as target year before 2030; Priority countries selected based upon highest emission countries from 2022 Global Carbon Project Data; % reduction refers to an annual percentage and does not take into account compounding; IEA Agenda goals account for Scopes 1+2 only

Source: 2022 CDP Climate Questionnaire Data; 2022 Global Carbon Project; USGS; IEA; GCCA; Company websites

Executive Summary: The State of the Transition in Concrete & Cement

Dimension of sector	Clinker substitution	Fossil fuel alternatives	CCUS installations
Future decarbonization scenario	Concrete and cement recipes accommodate ingredients with lower emissions intensity	Cement producers decarbonize kiln heating processes	Existing production facilities are retrofitted with CCUS technologies
Indicators of progress towards accelerating decarbonization	Despite availability of some clinker alternatives like fly ash and blast furnace slag, supply is **regionally varied and will decrease in countries where industries decarbonize** There are few **financial incentives driving the adoption of** lower emissions mixes While some producers are investing in **clinker-free cement, its long-term decarbonization potential is limited** by supply constraints, lack of market acceptance, and remaining emissions footprint from activators used in production	**In the short-term, biomass and waste substitutes could replace some coal in many geographies** but are in limited supply, not universally available, and not carbon-zero **In the long-term, green hydrogen and kiln electrification are likely more viable alternatives** to coal but today still face barriers to adoption	There are **upfront investment costs and ongoing operational costs** associated with CCUS technologies and therefore measures such as low carbon procurement will need to be established to drive green premiums In addition, **access to infrastructure to support carbon transport and storage is insufficient** and should be addressed through permitting frameworks and public sector investment plans

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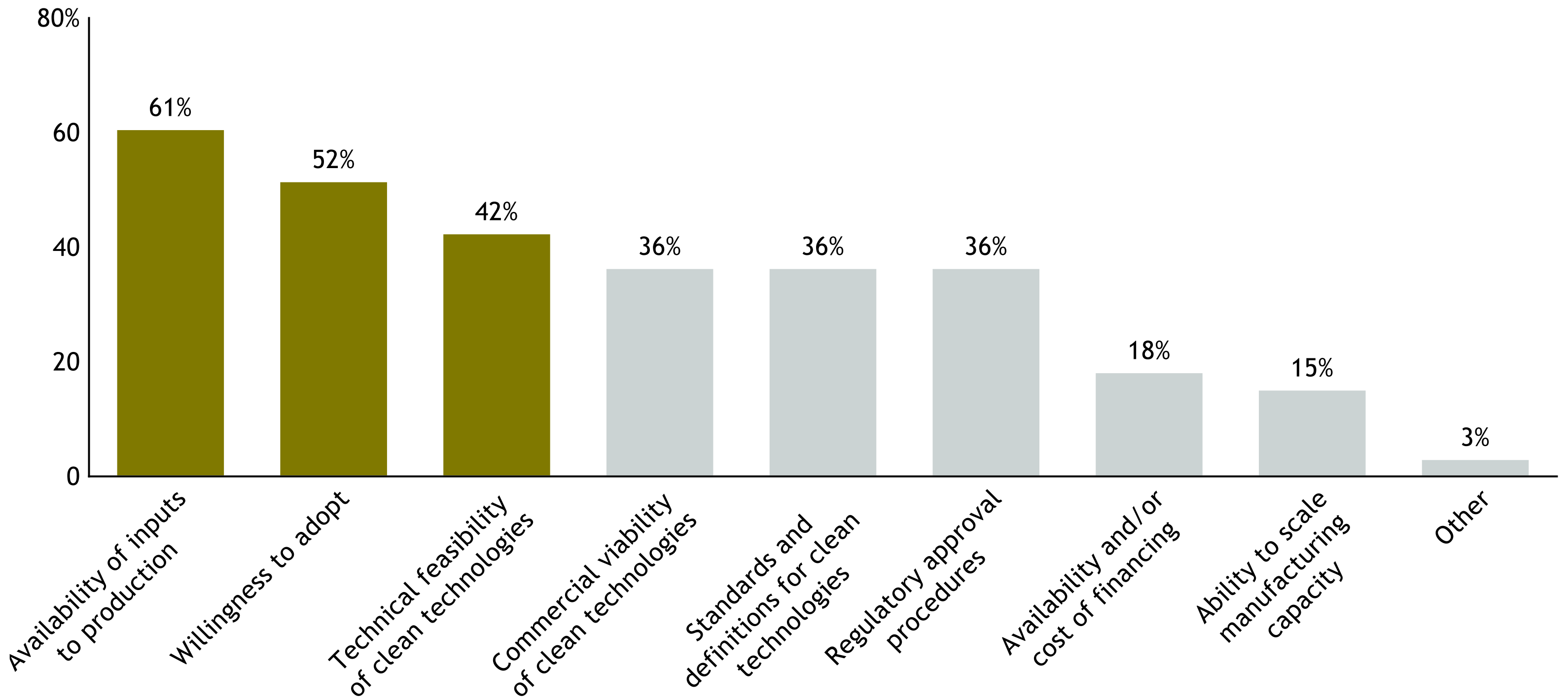
Business leaders are most concerned with access to the supply of clinker alternatives but also cite concerns with feasibility and willingness to adopt

Which of the following do you view as the greatest barriers toward increasing the use of clinker alternatives? Please select the top 3 most impactful barriers.

Share of survey respondents selecting barrier in the top 3 (%)



Note: Chart includes data from energy consumers with expertise in the cement sector (N = 33)
Source: Bain / WMBC Global Stocktake Survey (N = 215); Corporate interviews

Commentary

- For the most cost effective clinker substitutes, namely **BF slag and fly ash, supply is likely to diminish in Europe and North America**
  - However, in India and China BF slag and fly ash remain widely available for coming decades
- **There are technically viable and scalable alternatives that can fill shortfalls in BF slag and fly ash supply,** and in many cases these alternatives are already being adopted
  - E.g., Alternative pozzolan adoption in New Zealand, ground limestone adoption in France
- **Project developers (including some governments and municipalities) prefer to use trusted cement mixes** that are established in the market, limiting the adoption of lower clinker mixes

*"**A critical element is the availability of raw and alternative materials.** There is no universal answer, as it largely depends on one's geographical location."*
VP Group Public Affairs and Government Relations, Cement producer #4

“There are several alternate materials and technologies to decrease the clinker content of cement - we are looking at all of them - the question is scalability”

Legend Company performance vs. IEA: Most favorable; Mixed favorability; Least favorable

	Clinker	Fly Ash	Blast furnace slag	Calcined clay	Limestone
Description	• Clinker is a byproduct of heating calcium carbonate-based rocks to high temperatures and is the main cement ingredient	• Fly ash is a byproduct of coal combustion, serving as an effective SCM	• Blast furnace slag is a byproduct of the iron-making process	• Metakaolin, also known as calcined clay, is a pozzolanic material produced from heating kaolin clay to high temperatures	• Limestone can serve as a filler material in lieu of some (5-15% in NA, 20-30%+ in EU) of clinker in a given cement or concrete mix
Emissions	• When made with limestone: ~800-900 kg/t of clinker • When made with calcium silicate: carbon-zero Most producers use limestone, but some startups like Brimstone use calcium silicate*	• Fly ash itself does not emit carbon when used in cement, but carbon is produced during coal production	• BF slag itself does not emit carbon when used in cement, but the smelting process does	• Kaolin clay, the base material used to make metakaolin, must be heated in kilns, requiring high amounts of energy	• Using limestone in cement does not emit carbon - Note: Limestone that is heated and turned to clinker does emit carbon, but ground limestone that is not converted to clinker does not emit carbon in its production and use
% of global cement mix (’14)	65%	6%	13%	0%	8%
Supply constraints	• The calcium carbonate-based rocks that serve as the primary ingredient for clinker is widely available (e.g., limestone, calcium silicate)	• Fly ash quality varies regionally, and supply is insufficient to meet demand in certain areas • As power plants shift to greener practices, fly ash supply is expected to decrease	• Supply is highly constrained, and as steel and iron plants shift to greener practices, BF slag supply is expected to decrease	• Kaolin clay, the base material used to make metakaolin, is a generally abundant resource for most regions	• Widely available
Technical constraints	• Clinker makes up most of the cement mix and requires high temperatures to produce	• Fly ash **can substitute up to 35% of clinker** in cement and has some potential benefits such as improved workability and reduced permeability	• BF slag **can substitute up to 65% of clinker** in cement and has other potential benefits such as reduced permeability • BF slag-based cement has some application limitations due to longer setting times, limiting durability and strength	• Calcined clay **can substitute about 10-30% of clinker** in cement and has significant strength and permeability benefits • The composition of a calcined clay-based mix can limit how quickly a mix will set and mold to its frame	• Limestone **can substitute about 5-30% of clinker** in cement, depending on region • Limestone’s composition limits its ability to contribute to the strength, permeability, and durability of a mix, so it can only substitute so much clinker on its own
Cost	• Cost of limestone varies from $10 to $25 per metric ton • Cost of calcium silicate varies $40 to >$1,000 per metric ton	• Cost is similar to OPC where supply exists	• Cost is similar to OPC where supply is sufficient	• Higher raw material, processing, and production costs	• Cost of limestone varies between $10 to $25 per metric ton

Note: Title quote is from VP Group Public Affairs and Government Relations, Cement producer #4; (*) Calcium silicate, while widely available, is not yet cost effective nor technically and commercially proven as a complete substitute for limestone at-scale | Source: IEA Roadmap; “Calcined Clay as Supplementary Cementitious Material”; Global Cement; Climate Action Reserve; ECRA; Corporate interviews

"There's not one answer to substituting clinker; there's any number of materials that we are trying to optimize, and progress is incremental but slow"

Clinker ratios can be reduced through several methods

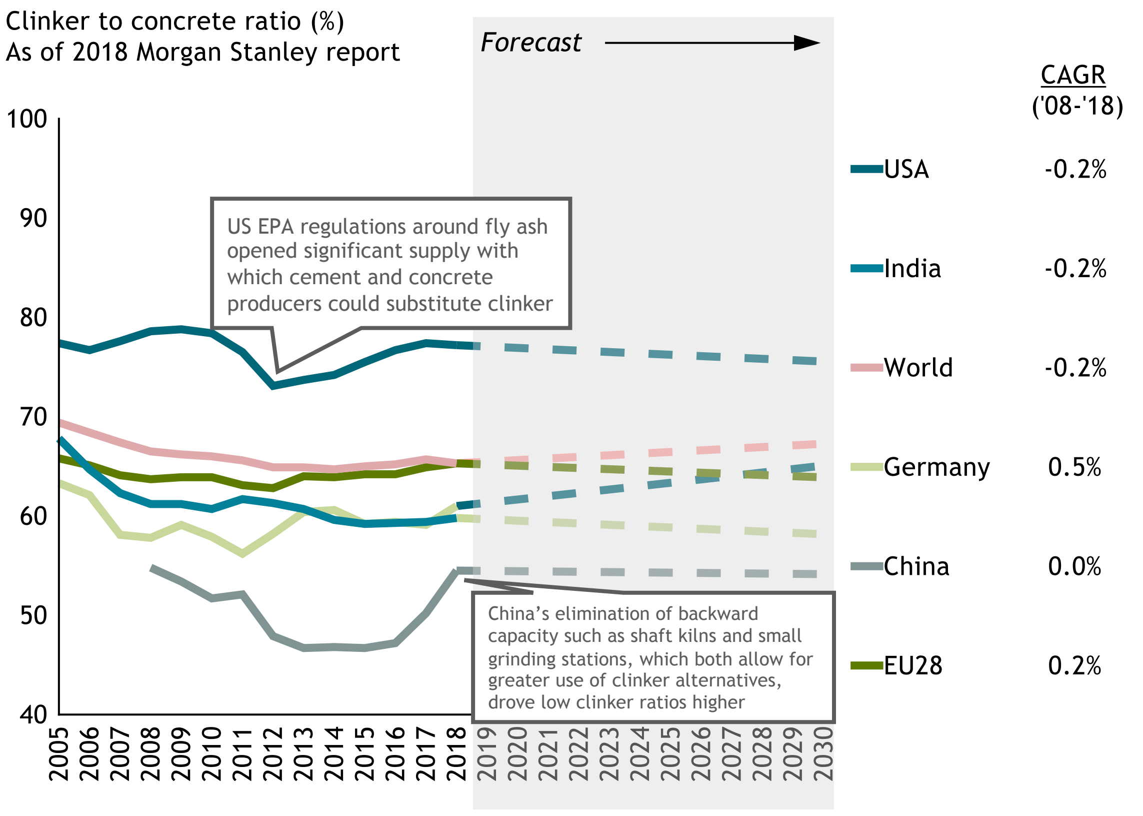
1. **BF slag and fly ash** reduce cost and carbon, so their **use has been optimized by producers** and supply is now constrained

2. As supplies for BF slag and fly ash dwindle in certain countries, **alternative pozzolans*, like calcined clay and ground limestone mixes, can be used** to substitute clinker, but these typically cost more

3. To complement clinker substitutes, **improved chemical admixtures can be developed to enhance the strength, durability and plastic properties** of highly substituted concretes

> ***"We are developing new cement types containing limestone, calcined clay and other secondary cementitious materials to avoid potentially increasing challenges with the supply of BF slag and fly ash.*** *Limestone is always available near our plants because we need that for clinker too, while calcined clays have varied availability."*
>
> Senior Manager Sustainable Construction & Public Affairs, Cement producer #2

Clinker ratios have slowly decreased over time across regions, with big differences across geographies



Forecast

Note: Title quote is from Head of Design Innovation and Property Solutions, Building owner #1; (*) Pozzolans are a broad class of siliceous and aluminous materials which, in themselves, possess little or no cementitious value but which will, in finely divided form and in the presence of water, react chemically with calcium hydroxide at ordinary temperature to form compounds possessing cementitious properties
Source: Morgan Stanley; World Cement; Ecostandard; Corporate interviews

Producers have optimized substitution rates given cost incentives to employ SCM - additional substitution calls for buyers' willingness to employ new mixes

"We've been relying on materials where there is experience and knowledge. BF slag and fly ash are known. Producers know how to incorporate them without adding cost. Now, we must look at the next frontier of available substitutes *by geography, understand how they work, and figure out how to feed them into design and construction in a way that is commercially viable."*

Head of Design Innovation and Property Solutions, Building owner #1

Source: Corporate interviews

From building owners, to engineers, to financing bodies, incentives are not yet aligned to drive market-wide adoption of low-carbon mixes

*"The challenge is going to be aligning everyone on these new building products. We need the producers to manufacture lower carbon mixes, sure, but **building owners need to drive purchasing of lower embodied carbon mixes, engineers need to be comfortable with the testing being done on them, and financing bodies are going to need to get comfortable with a pricing premium** too. Right now, the incentives are not there for everyone to get in line for additional clinker substitutes."*

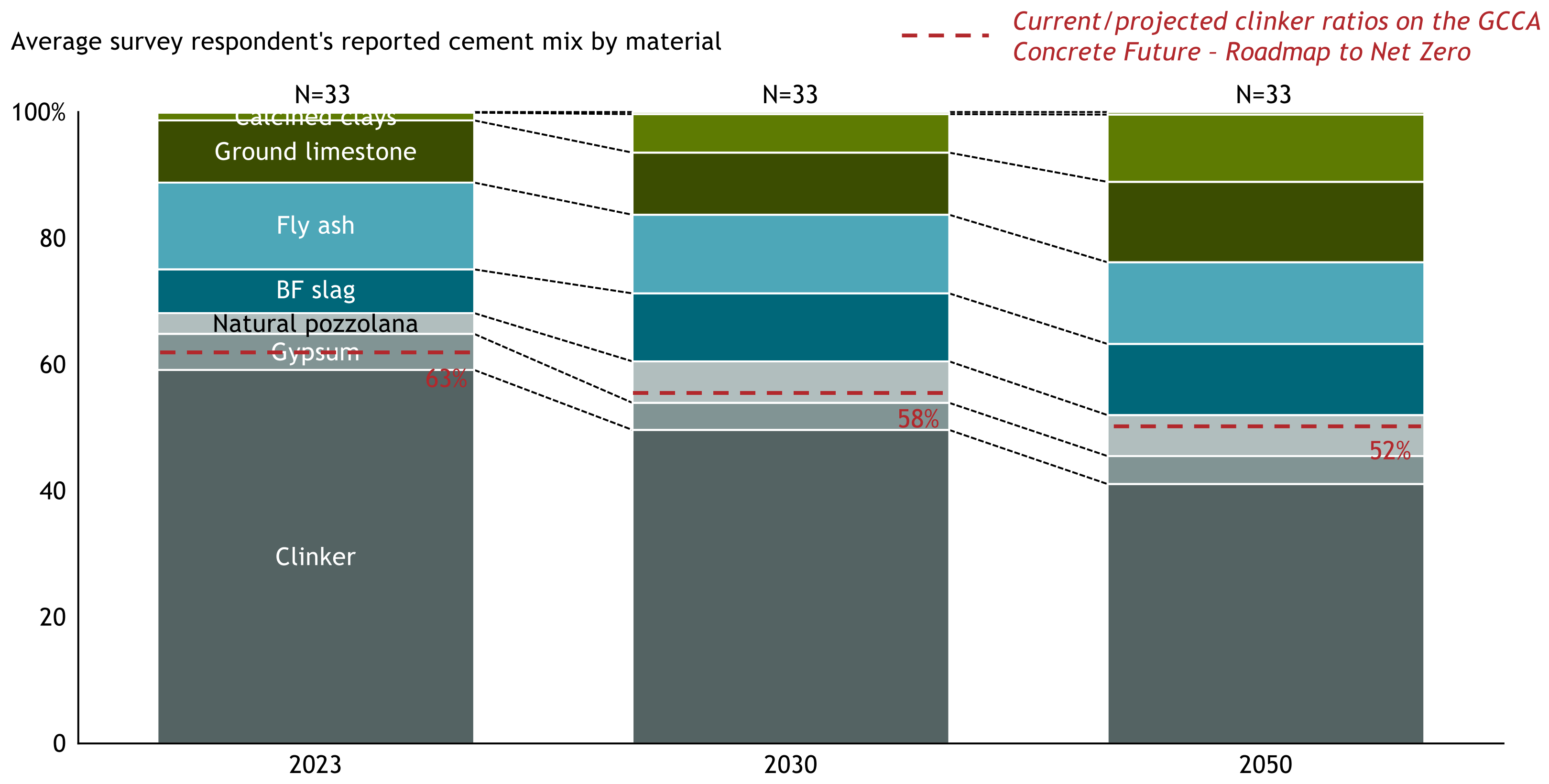
Head of Design Innovation and Property Solutions, Building owner #1

Source: Corporate interviews

Industry experts expect the average clinker ratio to drop from ~60% to ~50%, with some industry leaders suggesting ratios even closer to ~40%

*We would like to understand how cement producers are thinking about potential clinker substitutes. What is the **average mix of your cement** today? In 2030? In 2050?*

Average survey respondent's reported cement mix by material



Note: Chart includes data from energy consumers with expertise in the cement sector (N = 33)
Source: Bain / WMBC Global Stocktake Survey (N = 215); Corporate interviews

Commentary

- Today, the **most significant clinker alternatives are fly ash and BF slag** due to their prevalence and cost effectiveness
  - However, supply of each will become constrained as coal and steel production practices decarbonize
  - As a result, business leaders expect their share of the average cement mix to be limited compared to other substitutes through 2050
- In the long-term, **ground limestone and calcined clays are expected to take a larger share of cement mixes**

*"It's important to use local materials, but those materials don't have a track record. They need to be experimented upon. **We have access to many clays, but only certain types have been tested so far.**"*

Head of Design Innovation and Property Solutions, Building owner #1

"Our innovations are linked not just to the low-carbon materials we use but also where and how much we use them"

HOLCIM **Case Study: Holcim**

Overview

- **Description:** The Holcim Group, is a Swiss multinational company that manufactures building materials including cement, aggregates, concrete, and other building materials
- **Founded:** 1912
- **Headquarters:** Zug, Switzerland
- **Ownership:** Public (PSE: HLCM)
- **Revenue (2022):** ₣26.8B

Targets

2023
- Reduce CO_2 per net sales >31% vs. 2021

2025
- Recycle 10M metric tons of construction waste for reuse in new buildings
- Scale up production of calcined clay cements across all regions to expand the geographies to which it can sell

2030
- Invest ₣2B in mature CCUS technology to capture 5M+ metric tons of CO2 per year

2050
- Net-zero GHG emissions across the value chain

Activities

Securing financing to bolster supply of low-carbon mixes

- Holcim **secured €6M from the French government in March 2022 to invest in production of its calcined clay cements** in its La Malle and Saint Pierre la Cour facilities
- **In 2023, Holcim invested €40M and launched Europe's first calcined clay cement operation** in its Saint-Pierre-la-Cour plant in France to deliver its ECOPlanet green cement product, which incurs **50% less carbon emissions than conventional CEM I cement mixes**

Pushing the boundary of cement and concrete sector to tackle hard-to-abate process

- The European production facility runs on Holcim's proprietary proximA technology and will **produce up to 500K metric tons of low-carbon cement per year**
- The facility is also **powered with 100% biomass-based alternative fuels and waste heat recovery systems,** making the manufacturing of calcined clay nearly carbon free
- Holcim **continues to invest in its limestone calcined clay cement (LC3) initiative** to advance its ECOPlanet products and improve its production through its technical center operations in Lyon, France

Note: Title quote is from VP Group Affairs and Government Relations, Cement producer #4
Source: Holcim company website, Lit. search; Corporate interviews

Many cement businesses are figuring out how they can best optimize cement and concrete mixes to balance cost, performance, and emissions footprint

CHRYSO **Case Study: CHRYSO**

Overview

- **Description:** CHRYSO is a cement technology division of the broader industrial conglomerate Saint-Gobain
- **Founded (Saint-Gobain):** 1665
- **Headquarters (Saint-Gobain):** Courbevoie, France
- **Ownership (Saint-Gobain):** Public (OTCMKTS: CODYY)
- **Revenue (Saint-Gobain, 2022):** €51.2B

Technology overview

Enviromix
- Recently released first line of admixture solutions and services for low-carbon concrete without compromising on performance

Maturix
- Real-time and remote concrete maturity monitoring, reducing energy consumption

Quad Tech
- Facilitates local aggregate sourcing to reduce emissions from transportation

Activities

Enabling further emissions reduction by improving admixture offering

- CHRYSO's recent EnviroMix product line enables greater volumes of cement to be replaced with admixture, thus **limiting the share of clinker in the final mix**
- CHRYSO is working on augmenting the technical and commercial viability of its EnviroMix product line, including:
  - **Improving cost profile** of product line to improve price point relative to conventional admixtures
  - **Conducting research to prove long-term viability** of product
  - **Driving awareness in construction community** to augment demand
  - **Lobbying for building regulations** that accommodate EnviroMix
  - **Increasing production** to meet expected demand

Leading the industry on emissions reducing operating efficiency

- CHRYSO has implemented operational efficiencies in its own production processes to further reduce emissions:
  - **Alternative activation methods to reduce energy needs** during admixture production process
  - **Optimizing heating time during curing process** to further reduce energy needs
  - **Leveraging local procurement where possible to reduce transport emissions** for energy sources

Source: CHRYSO company website; Lit. search

Clinker-free cement is still some way down the track

"The concrete mixes that use no clinker at all have not proven to have great longevity and will cause massive supply problems later *when producers just trying to create lower clinker mixes do not have access to the substitutes they need."*

Head of Design Innovation and Property Solutions, Building owner #1

Source: Corporate interviews

“Most countries have 40%+ GDP managed by public actors; countries should introduce public procurement requirements - the shift would be immediate”

/ NON-EXHAUSTIVE

Leading governments have been leveraging their market power to generate significant demand for low-carbon mixes

United States

- **San Francisco-Oakland Bay Bridge (CA):** bridge using a concrete mix with fly ash and BF slag that reduced clinker ratios by 70%
- **The California Department of Transportation:** series of pavement projects that used a mix of fly ash and slag to reduce clinker ratio of pavement mix by 40%, reduced overall emissions for the projects by 10%, and saved over 1K metric tons of waste material from landfills
- **Bullitt Center (Seattle, WA):** 6-story building using concrete with a 30% lower clinker ratio and 100% recycled steel
- **3 World Trade Center (New York, NY):** 80-story skyscraper using BF slag and fly ash to reduce clinker ratio of concrete mix by 50%
- **East Side Access Project (New York, NY):** construction of a new train station and tunnel connections that is using fly ash and BF slag, resulting in a 40% reduction in CO_2 emissions compared to traditional concrete
- **The Port Authority of New York and New Jersey:** updated plan for all future construction projects that will require 25% reduction in clinker ratios below traditional concrete mixes, significantly reducing its carbon intensity and allowing for lower-carbon alternatives

European Union

- **Gulliver Business Center (Milan, Italy):** 33-story skyscraper that used concrete mixes that were 40% fly ash and BF slag
- **Brenner Base Tunnel (Austria and Italy):** tunneled road going through the Alps using a concrete mix that incorporates fly ash, slag, and calcined clay, resulting in a 50% reduction in CO_2 emissions compared to a traditional concrete mix
- **Alkmaar Bridge (Netherlands):** bridge constructed using a concrete mix that incorporated BF slag and fly ash, resulting in a 70% reduction in CO_2 emissions compared to a traditional concrete mix

Australia

- **Hallett Group (Adelaide):** Hallett Group, the state's largest integrated supplier of building and construction materials and manufacturer of supplementary cementitious materials (SCM), launched a $125M project supported by a $20 million federal government grant to deliver 30M metric tons of SCMs to the Australian market over the next 20 years
- **Alexandria Road Replacement:** Alexandria City Council replaced a section of roadway with low-clinker cement, using fly ash and BF slag and reducing emissions to 30% of what a traditional concrete mix would produce
  - The government is using this road replacement as a test case to update Australian cement and concrete standards

Note: Title quote is from Global Sustainability Lead, Utility company #5
Source: Lit. search, Corporate interviews

"We need dynamic standards that can evolve with technology - they are fundamental for construction and our ability to bring innovations to market"

The **United States** is increasing clinker substitution through demand-side standards and supply-side financial support

- **LEED Certification** encourages lower clinker mix use in building projects
- **ASTM C-150** standards outline cement types with clinker ratios and use cases
- **Individual states (incl. CA, OR, NY, CO) have set maximum limits for clinker in concrete and cement** based upon carbon emissions and set minimum limits on use of SCMs in cement and concrete mixes
- **The Federal government provides tax incentives and credits** for low-emissions cement production and construction via EPAct and ITC
- **The Federal government has production efficiency programs that fund producers to reduce emissions,** supplemented with significant R&D funding via the NSF, DOE, DOT, FHWA, and academic collaborations with MIT

The **European Union** is focused on the supply-side in its clinker substitution policies through standards, disclosure, pricing, and direct funding

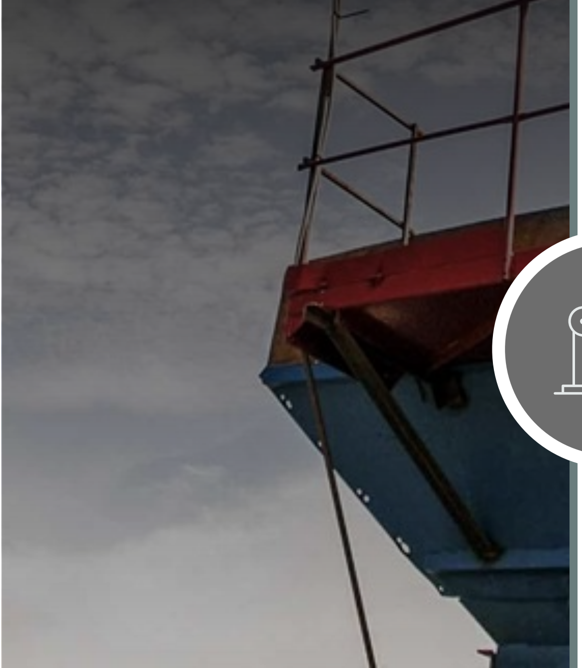
- **EPBD, CPR, and member state production standards** encourage lower clinker mixes
  - **These are supplemented by CEM I-V standards** which outline cement types with clinker ratios and use cases
- **The EU ETS places emissions limits** on many businesses and incurs fines for those exceeding their limits, including cement producers
- **The EU 2020 Horizon program and SILC initiative fund R&D** for low-carbon practices
  - **Includes AETHER2 program** for cost-effective, industrial-grade, low-carbon clinker (40+ projects in last 10 years)
  - **Includes green public procurement (GPP) guidelines** and member state R&D funding (e.g., CNRS, SFIC, ANR, ADEME, and EcoCite in FR and DCA, RVO in Netherlands)
- **EU Cement CO_2 and Energy protocol** mandates cement producers to monitor and reduce emissions, use alternative fuels, and lower clinker ratios
  - Includes lifecycle assessments on all public construction

China is focused on the demand-side in its clinker policies through building standards and rebates

- **The government has provided guidelines for low-carbon building materials** that encourage lower clinker ratios and use of substitutes
  - **Includes LEED Certifications** that encourage use of lower clinker mixes in buildings and **"low carbon" tags** from China Building Materials Federation for low clinker mixes
  - **Circular economy promotion laws** also encourage builders to use fly ash and slag with ready-mix cements, with new standards requiring SCMs be 20% of those mixes
- **The government provides VAT rebates** for the portion of mixes above 30% made from SCMs
- **The government's Green Industry Fund provides financing for construction projects aimed at emissions reduction** including green concrete and cement
  - **Includes public procurement policies** that prioritize use of low-carbon products
  - **Supplemented by R&D funding**, pilots, demonstrations for high-volume fly ash (HVFA) and limestone calcined clay (LC3) production for government projects

Note: Title quote from VP Group Affairs and Government Relations, Cement producer #4
Source: Lit. search; Corporate interviews

Lower clinker ratios will reduce emission intensity, but substitutes' lack of supply and market acceptance pose barriers



Access to supply of proven clinker alternatives

- **Cement producers have proven that clinker alternatives like fly ash and BF slag** can reduce clinker ratios
- **Supply of these alternatives - which are not consistently available across geographies -** will reduce in some regions as the coal and steel processes that produce them continue to decarbonize
- As fly ash and BF slag supply decreases in industrialized economies, **calcined clays, ground limestone, and other pozzolans can serve as clinker alternatives, but producers are still assessing their viability given the cost to procure and utilize these alternatives**

~60% of business leaders consider availability of inputs to be a top barrier to clinker substitution

Market acceptance of clinker substitution

- **Cement producers have optimized clinker substitution rates** in many places given cost incentives to employ fly ash and BF slag - additional clinker substitution would add cost and complexity
- **Consumers are cost conscious and need to maintain insurability of their buildings,** so there is limited market demand or acceptance for additional clinker substitution and lower clinker mixes
- **Incentives are not aligned across the value chain** - even if asset owners benefit from low-carbon mixes, engineers and infrastructure bodies tend to prioritize known mixes

~50% of business leaders consider customers' willingness to adopt lower clinker mixes to be a top barrier to increasing clinker substitution rates

Alternative technologies to clinker

- **Some producers are pursuing clinker-free cement mixes,** but known clinker substitutes are supply constrained and new technologies suffer the same **market acceptance concerns** as other lower clinker mixes
- Without breakthrough technology, **the increased adoption of clinker substitutes by clinker-free cement producers would increase emissions from other producers,** given limited supplies of clinker substitutes

"Many are investing significant R&D in clinker-free cement, but when you consider the supply needed to support these mixes, they do not seem viable."

VP Sustainable Development, Cement materials producer #1

To spur higher rates of clinker substitution, governments should place mandates around cement producers and in parallel provide support to bolster demand

Governments must start by procuring low-emissions mixes themselves

- Governments are a **critical enabler to bolstering demand for green concrete and cement mixes,** as they own 20%+ of the built environment globally and are the primary financing source for 30%+ of concrete and cement procurement globally
- Government procurement policies around low- and zero-emissions mixes are critical, including **public procurement commitments (e.g., offtakes) for green cement and use of low clinker mixes in government construction projects** to facilitate broader market acceptance

Then they can implement policies to encourage other asset owners to shift

- With governments driving the first wave of low- and zero-emissions mixes, **policy can then turn to assuring demand from private actors** including asset owners, architects, engineers, construction companies, etc.
- **Introducing green building code certifications** that encourage lower clinker cement and concrete use, which would ideally be mandatory but could be voluntary
- **Adopting lifecycle assessments of construction projects** to disclose their emissions footprints, which would also ideally be mandatory but could be voluntary
- **Carbon pricing schemes on concrete and cement purchasing and usage** could further encourage adoption of lower-carbon

With demand secured, governments can prompt producers to transition

- Even with demand assured, governments should **support producers in shifting their product mix entirely to low- and zero-emissions mixes**
- **Fund R&D to develop lower clinker mixes** to encourage producers to explore additional SCMs past those that have already been adopted and optimized across the industry, **including bespoke applications via customer collaborations**
- **Offer tax and tariff incentives, credits, or rebates** for negative emissions via BECCS accounting system

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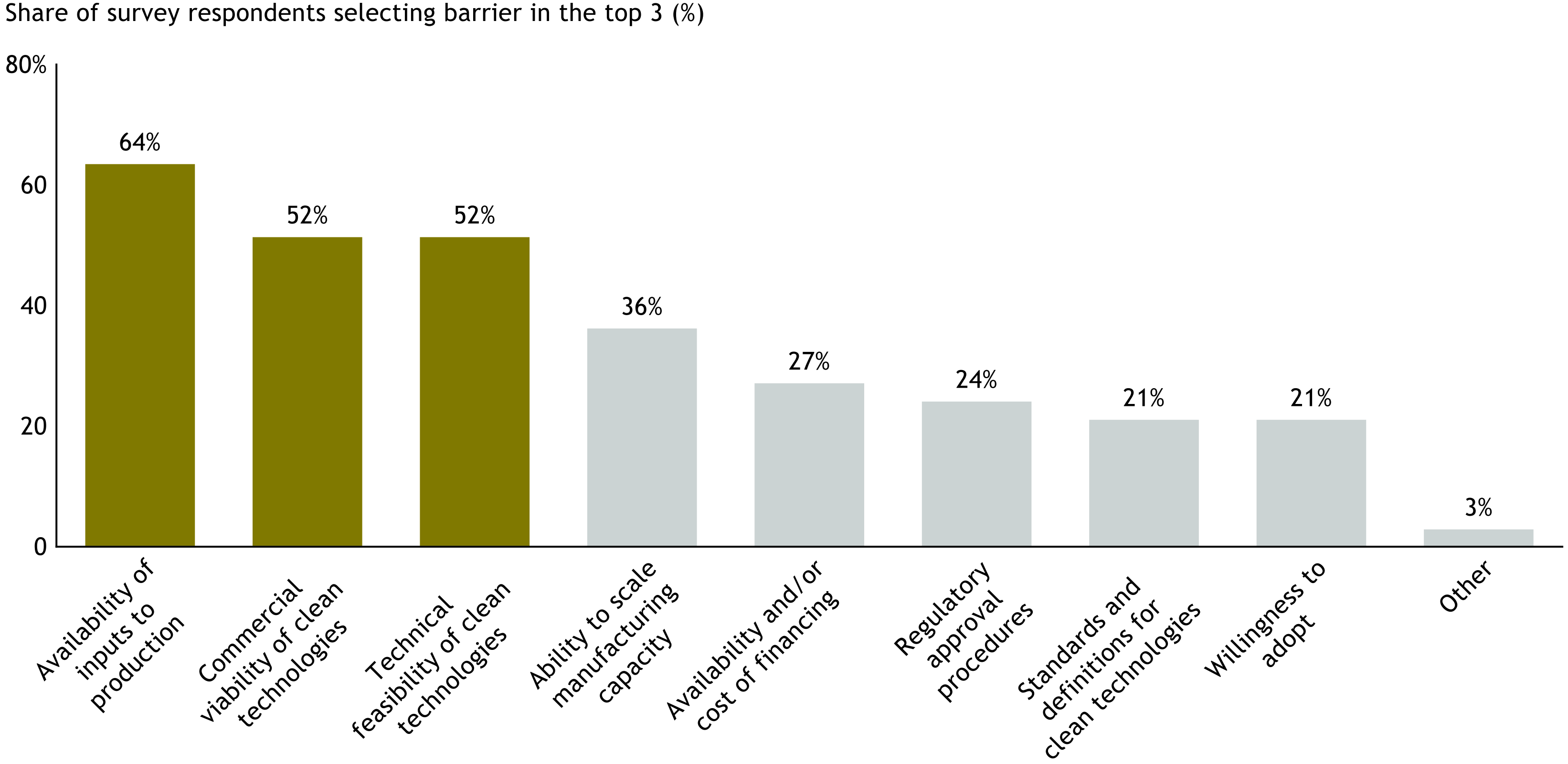
Business leaders are most concerned with access to the supply of fossil fuel alternatives but also cite concerns with technical and commercial feasibility

*Which of the following do you view as the **greatest barriers to transitioning toward fossil fuel alternatives?** Please select the top 3 most impactful barriers.*



Note: Chart includes data from energy consumers with expertise in the cement sector (N = 33)
Source: Bain / WMBC Global Stocktake Survey (N = 215)

Commentary

- In the near term, many cement producers are pursuing biomass and waste substitutes as alternatives to coal, but both have **limited supply and competing demand from other sectors like aviation and shipping**
- In the long-term, business leaders may increase adoption of green hydrogen and kiln electrification. Today both are challenged by high upfront investment, ongoing operational costs, and supply constraints.

"You can minimize the footprint from the energy used for heating and creating cement by employing alternatives to coal and petcoke"

Legend Company performance vs. IEA: Most favorable (green) · Mixed favorability (yellow) · Least favorable (red)

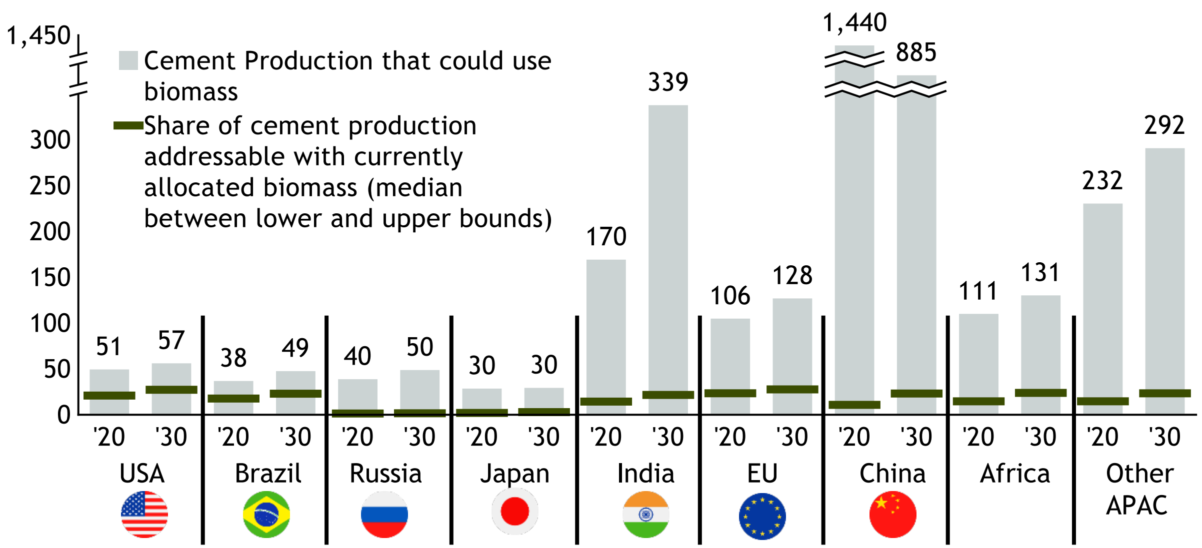
	Fossil Fuels	Shorter-term solutions		Longer-term solutions	
	Coal, NG, and petcoke	Biomass	Waste	Green hydrogen	Electrification
Description	• Coal and petcoke (82% of fuel use) and natural gas (9% of fuel use), are burned in order to heat cement kilns to high temperatures	• Generated from burning wood, plants, and other organic matter that can replace coal as a fuel for kiln heating	• Wastes include sources like oils, solvents, tires, and sludge, which would otherwise be sent to landfills and serve as a fuel for kiln heating	• Hydrogen, when produced renewably, can be used as an alternative fuel to heat cement kilns	• The high temperatures required in the cement process can be achieved through electricity powered from renewable energy
Carbon emissions	~2-3 t carbon / t coal (Least favorable)	Near-zero: biomass itself is carbon-neutral but requires supplementary coal to heat (Mixed favorability)	Near-zero: CO_2 emissions depend on the material, composition, and life cycle (Mixed favorability)	Zero (Most favorable)	Zero (assuming renewable generation) (Most favorable)
Supply constraints	• Widely available (Most favorable)	• Cement will compete with increasing demand from shipping and aviation • Biomass availability varies by region, hindering its commercial viability as a solution in places with insufficient supply (Mixed favorability)	• Without anti-dumping policies, waste can be expensive and inaccessible • Using waste substitutes often requires a permit and adherence to strict standards • Collection networks vary by geography, challenging access in some regions (Least favorable)	• Most hydrogen today is supplied using fossil fuels - zero-carbon hydrogen requires renewable power sources • Cement will compete with increasing demand from steel, shipping, and road transport (Least favorable)	• Electrification would require large amounts of electricity and energy, which vary in access and price across regions (Mixed favorability)
Technical constraints	• Most coal has appropriate combustion characteristics to heat kilns to the required temperature • Coal is traditional fossil fuel that has been used to heat cement kilns for a long time (Most favorable)	• Biomass can only account for 60% of kiln fuel, but producers need to supplement with coal or other alternatives to satisfy calorie requirements • Biomass loses 15% of its energy in conversion processes (Mixed favorability)	• Using waste safely and cleanly requires identification and classification of suitable materials, and collection and treatment processes should comply with standards • Waste materials are largely heterogenous, requiring a pre-processing system (Mixed favorability)	• Electrolyzers produce green hydrogen and oxygen and could be installed in cement plants - but currently, electrolyzer supply is limited • Electrolyzers are both expensive to install and require significant amounts of energy to operate (Least favorable)	• Technical viability has only been proven at the laboratory level • Kiln electrification is also prohibitively expensive in its current form in terms of upfront investment and ongoing operational costs that further technical development is required to bring the technology down the cost curve (Mixed favorability)
Total costs	Low (Most favorable)	Low (Most favorable)	Low (Most favorable)	High (Least favorable)	Medium (Mixed favorability)

Note: Title quote is from Head of Design Innovation and Property Solutions, Building owner #1; Total costs include procurement and operational costs as well as other associated expenditures for using alternatives
Source: Specify Concrete; GCCA; IEA; Malico, I., et al., "Current status and future perspectives for energy production from solid biomass in the European industry"; EPA; International Cement Review; Global Cement, Corporate interviews

While biomass is a fossil fuel alternative, it cannot fully replace coal and does not project to be sufficiently available across cement-producing geographies

The US, Brazil, and EU are most able to leverage biomass, while other regions like China, India, and other APAC have an insufficient supply to meet cement production

Annual cement production (in M of MT)



	USA '20	USA '30	Brazil '20	Brazil '30	Russia '20	Russia '30	Japan '20	Japan '30	India '20	India '30	EU '20	EU '30	China '20	China '30	Africa '20	Africa '30	Other APAC '20	Other APAC '30
% of domestic biomass supply needed for 100% of cem. prod.	5%	4%	5%	4%	62%	66%	32%	22%	25%	33%	10%	10%	280%	80%	16%	12%	33%	26%
Expected % increase in biomass from 2020 to 2030		30%		30%		19%		45%		51%		18%		114%		63%		59%

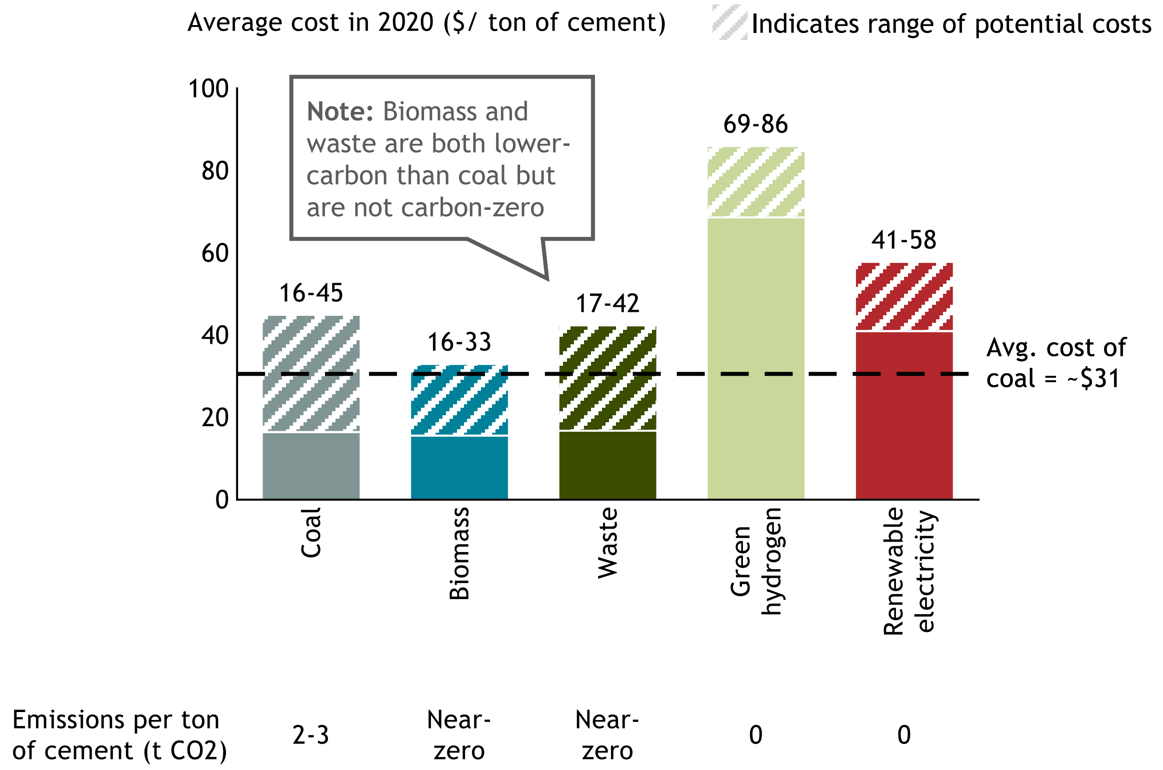
Biomass supply is increasing, but not fast enough to catch demand

- **Low shares of biomass are currently allocated to the cement industry** due to its many use cases across sectors
  - Cement is both a hard-to-abate and price sensitive sector, meaning **securing access to and financing for biomass will be more challenging than other sectors**, such as aviation
- Biomass **supply is particularly low in markets with the highest expected growth for cement**, such as India and other APAC
- Biomass supply will increase from 2020 to 2030, but **it will still be insufficient for most regions**

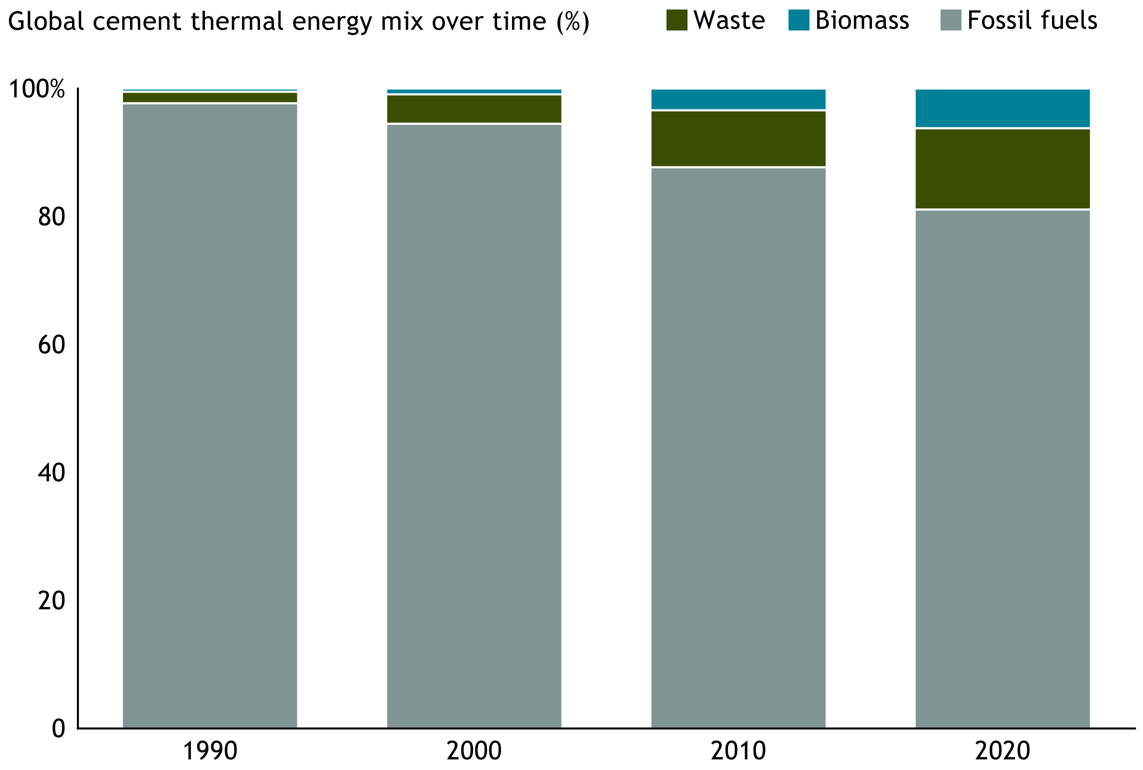
Note: Process and assumptions laid out for this analysis in appendix
Source: IEA – World Energy Outlook extended data; US Geological Survey; IHS Global Insights; Biomass Thermal Energy Council; US Energy Information Administration; Mokhtar, A., et al., "A decision support tool for cement industry to select energy efficiency measures"; Malico, I. et al., "Current status and future perspectives for energy production from solid biomass in the European industry"; Taibi, E. et al., "The potential for renewable energy in industrial applications"; Sector Policies and Programs Division at the EPA, "Available and Emerging Technologies for Reducing Greenhouse Gas Emissions from the Portland Cement Industry"

Cost competitive alternatives are displacing fossil fuels, but supply and infrastructure vary regionally

Biomass and waste are already cost competitive with coal today



Biomass and waste usage have increased over time



Note: Cost of carbon capture assumes CO_2 usage in cement is .59t CO_2 / metric ton of cement per IEA 2021 report; A 0.8 metric tons of clinker / 1 metric ton cement ratio was assumed; the average of high and low estimated bounds was used as projection; CCUS cost per metric ton was removed from cost estimates at a flat rate across all FF alternatives based on RMI cost estimates for CCUS; other alternatives have ranged 2020 price estimates, to reflect regional differences in pricing
Source: RMI; World Cement; IEA 2021 report; GNR; Kahawalge, A. “Opportunities and challenges of using SRF as an alternative fuel in the cement industry”

Many are investing R&D in kiln heating; with aggregated efforts, green hydrogen or electrification applications may come to market more quickly

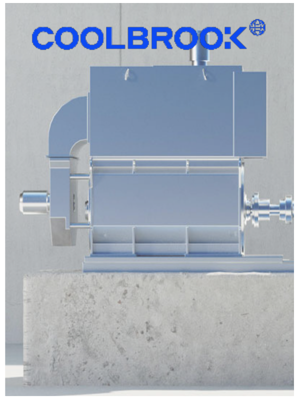
Electric kilns

- Kiln electrification technology has been tested in laboratory settings but **has yet to see commercial-scale applications**
- **Kiln electrification is often more expensive than coal or natural gas** and varies in cost across regions

Green hydrogen

- **Green hydrogen** entails high production costs and relies on limited existing electrolyzer capacity
- Many industries have competing demands green hydrogen to decarbonize their own operations, so **further limiting its potential for kiln heating**

CEMEX — **Cemex, a leading concrete and cement producer, is investing in both renewable electricity and green hydrogen kiln heating technologies**



- Cemex, along with South Asian producer Ultratech, is **partnering with Coolbrook,** an industrial technology provider whose **RotoDynamic technology is used to electrify kiln heating,** replacing coal and natural gas
- Coolbrook estimates that industry wide adoption of their technology **could cut 1B t CO2 emissions from concrete and cement each year**

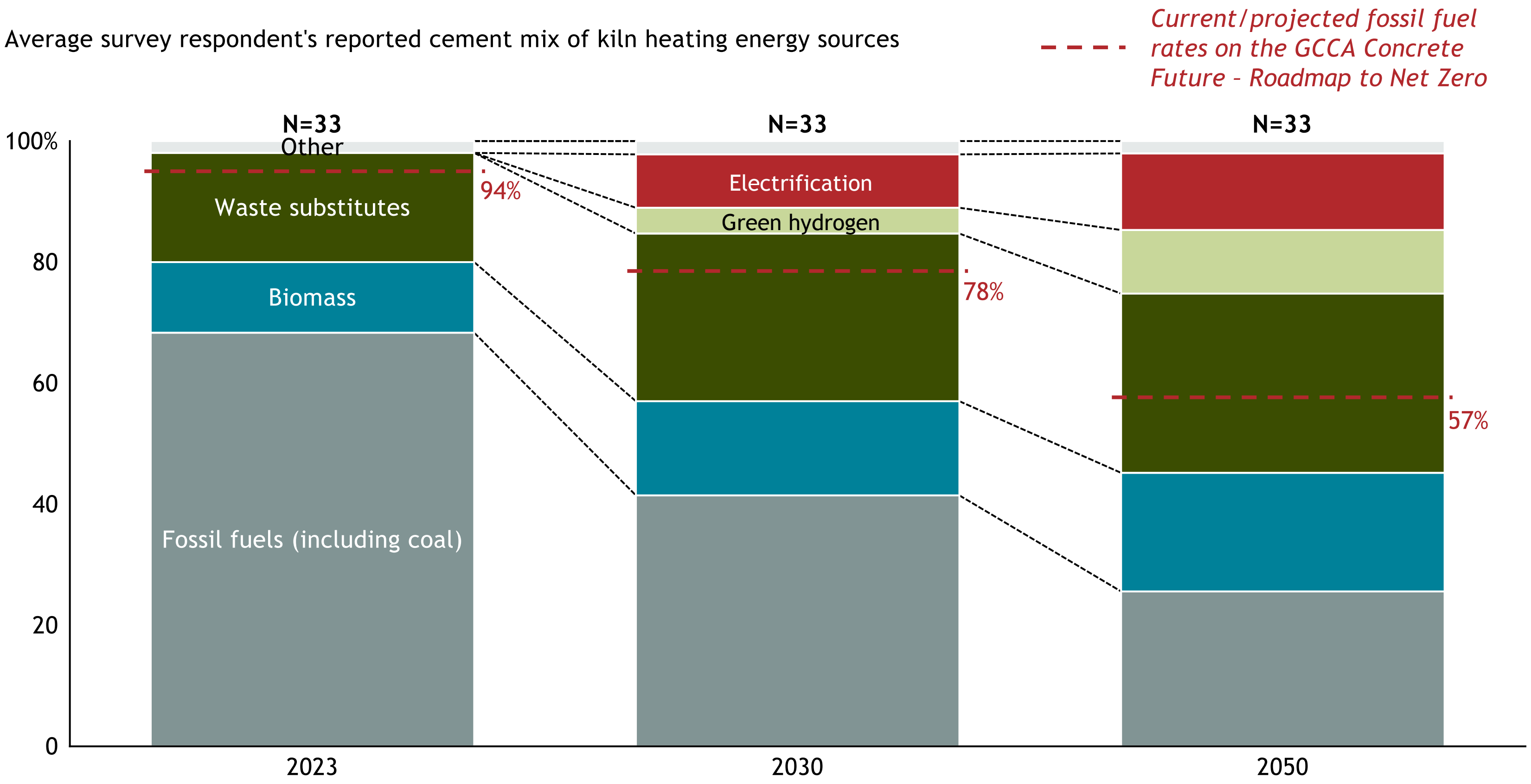
- In parallel to its Coolbrook partnership, **Cemex has also partnered with HiiROC,** which has developed a patented plasma technology **to produce low-cost, zero-emissions hydrogen**
- The partnership is intended **expand green hydrogen usage as an alternative to coal and natural gas in kiln heating**
  - Cemex has been using small amounts of green hydrogen in kiln heating since 2019

Note: Cost of carbon capture assumes CO_2 usage in cement is .59t CO_2 / metric ton cement per IEA 2021 report; A 0.8 metric tons of clinker / 1 metric ton cement ratio was assumed; the average of high and low estimated bounds was used as projection; CCUS cost per metric ton was removed from cost estimates at a flat rate across all FF alternatives based on RMI cost estimates for CCUS; other alternatives have ranged 2020 price estimates, to reflect regional differences in pricing
Source: RMI; World Cement; IEA 2021 report; GNR; CEMEX; Ultratech; Specify Concrete; Coolbrook; HiiROC

Vast majority of kiln heating is currently through fossil fuels; FF share expected to drop to ~60% by 2050 with some companies expecting rates as low as ~30%

Which of the following do you view as the ***greatest barriers to transitioning toward fossil fuel alternatives?*** *Please select the top 3 most impactful barriers.*

Average survey respondent's reported cement mix of kiln heating energy sources



Note: Chart includes data from energy consumers with expertise in the cement sector (N = 33)
Source: Bain / WMBC Global Stocktake Survey (N = 215); Corporate interviews

Commentary

- While popular today, **share of production leveraging biomass is expected to hold steady** as demand from other sectors scales (e.g., aviation, shipping)
- **Waste substitutes continue to be supply-constrained,** but as policies around anti-dumping and alternative fueling evolve, business leaders expect to increase their use
- **Green hydrogen and electrification are in their nascency as kiln heating options and are still far from being able to be used industry-wide.** Business leaders currently only anticipate scaled adoption towards 2050

*"**Cement producers are each embarking on their own R&D journeys related to kiln heating.** With more aggregated efforts, it is possible that we could see green hydrogen or kiln electrification applications come onto the market more quickly."*
VP Sustainable Development, Cement materials producer #1

*"There are **no technical barriers to kiln electrification.** In fact, electricity can reach much higher temperatures than coal. The problem is that **electricity is ~20x the cost per GJ vs. coal.**"*
CEO, Cement producer #3

Austria is a top country for alternative fuel use, enabled by world leading waste management systems and policy support

Case Study: Austria

Overview

- Austria has an **excellent waste management system**, which assures the collection, sorting, and fractioning of waste
  - As such, waste is tracked and can be reused by cement and concrete players rather than dumped
- Austria, like most countries in Europe, is a **relatively compact country without a lot of space for landfills**
  - As such, Austria has **high dumping costs**, encouraging the reuse of waste rather than dumping waste directly into landfills

Targets

2022
- Holcim announced a construction, demolition, and excavation waste center at its Mannersdorf production facilities

2030
- Austrian concrete and cement manufacturers commit to reducing emissions by 30%
- EU-wide goals set to reduce emissions in ETS sectors (including cement) by 43% vs. 2005 levels

2040
- Austrian concrete and cement manufacturers are carbon neutral

Activities

Reducing use of carbon-intensive fuels

- In 2018, the Austrian cement industry **replaced more than 81% of the fuels** needed for production of clinker with alternative fuels
- By increasing alternative fuel use, CO_2 emissions from fuel combustion in the Austrian cement industry has **dropped by 23% from 85 to 65 kg CO_2/GJ** over the last 21 years
  - The most common alternative fuels in Austria are waste substitutes such as waste ceramics, bricks, tiles and construction products, foundry sand, and lime waste

Driving adoption of waste as a fuel alternate

- The Austrian government is now addressing obstacles to drive further use of waste substitutes as a fueling option:
  - **Increasing public acceptance:** Adopting guidance and standards around the safety of using waste substitutes as a fuel
  - **Accelerating permitting processes:** Modifying permitting regulations to allow some waste substitutes to become legally usable alternatives to coal for kiln heating
  - **Improving economics of waste:** Optimizing dumping costs in order to improve the economics of pursuing waste substitutes as a fueling alternative

Source: Lit. search, European Parliamentary Research Service Report

Some new cement plants have embedded emissions reductions strategies into construction plans

Case Study: Dangote

Overview

- Dangote Cement, based in Nigeria, is the largest cement producer in Africa
  - The company manages 48.6M MT of annual cement production capacity, ~13% of total capacity in Africa
- Dangote's **Ibese Cement Plant in the Ogun State of Nigeria** was commissioned with 6M MT of capacity in 2012 and doubled to 12M MT in 2014

Technology overview

Alt. fuels

- Alternative fuels will substitute ~25% of fossil fuels in Dangote kilns by 2025, expected to replace 330 metric tons of coal per day and reduce emissions by 650 t/CO2 per day

Energy efficient

- Vertical roller mills reduce energy requirements for milling by 40-50%
- Materials transfer system using conveyors and bucket elevators reduce energy requirements for materials transfer by up to 90%
- Fans with variable frequency drivers (VFD) to vary ventilation rate by demand reduce energy requirements of fans by 40-50%

Activities

Setting best practice for early-stage CO2 mgmt.

- Championed by the United Nations, Dangote Cement established a team with **sustainability, alternative fuel, and environmental experts to drive emissions reduction** efforts
- The team **identified potential cement production plant locations with an abundance of renewable energy sources**, prioritizing locations that were ideal to reduce landfill use and well-positioned to leverage waste as an alternative fuel to heat kilns
- Leaders at the Ibese Plant have encouraged **the use of alternative fuels, namely Palm Kernel Shells (PKS), as they are an abundant and cost-effective resource in Nigeria** that can be used to replace fossil fuels to reduce total plant emissions by more than 5%

Planning for use of alternative fuels and CCUS from the onset

- **Dangote plans to continue emissions reductions strategies** as it expands its production footprint outside of Nigeria, selecting plant locations positioned to adopt alternative kiln heating fuels and CCUS from initial buildout

Source: Dangote company website, Lit. search

Beyond transition thermal energy sources, concrete and cement producers can also invest in other energy efficiency practices like Excess Heat Recovery

Excess heat recovery can help reduce energy needs outside of the kiln, but are cost prohibitive to install

- Excess heat recovery (EHR) is the process of **capturing excess heat during production** processes and then reusing the heat or converting it to electricity
- **EHR can be deployed at multiple points** during the production process:
  - During kiln heating, capturing flue gases as they are released
  - After kiln heating, capturing excess heat as the mix cools after being removed from the kiln
- Regardless of where the excess heat is captured, **the most common re-use of the excess heat is to pre-heat raw materials** before they enter the kiln
  - This practice reduces heating and subsequent energy needs once material is in the kiln
- While EHR has been proven to be technically viable at multiple points during production, it is **prohibitively expensive to install and operate**
  - **Upfront investment and installation costs are too high** relative to the energy cost savings that are realized

EHR Example: The TASIO Project demonstrates the viability of EHR in concrete and cement production

Overview of the TASIO project

- The TASIO Project was **launched as part of the EU's Horizon 2020 research and innovation program** to develop solutions to recover the waste heat produced in energy-intensive processes of industrial sectors
- The TASIO project targeted select sectors:
  - Concrete and Cement
  - Glass
  - Steel
  - Petrochemicals

TASIO's application in concrete and cement

- The TASIO project's first concrete and cement EHR installation was the Cementi Rossi plant in Piacenza, Italy in 2019
- **At this facility, all waste heat** generated before, during, and after kiln heating **was turned to electricity,** resulting in a 7% reduction of electricity purchased from the grid

Source: Technology Roadmap – Low Carbon Transition in the Cement Industry; Cementi Rossi Plant (Piacenza, Italy, 2019)

Lower clinker ratios will reduce emission intensity, but substitutes' lack of supply and market acceptance pose barriers

Technical concerns with long-term alternatives

- **Some business leaders in the concrete & cement sector are planning to leverage a combination of hydrogen and kiln electrification** as alternatives to fossil fuels used in kiln heating today
- While **kiln electrification** development is underway, it **remains technically tested only at the laboratory level; commercial deployment is currently challenging due** to high upfront investment and ongoing operational costs
- **Green hydrogen use in kilns is technically feasible, but supply of green hydrogen is constrained, and deployment will also be commercially challenging,** though there are select exceptions such as hydrogen injection in waste incineration

~50% of business leaders consider technical feasibility to be a top barrier to fossil fuel adoption

~50% of business leaders consider commercial viability to be a top barrier to fossil fuel adoption

Access to supply of near-term alternatives

- **Biomass and waste substitutes present meaningful opportunities** to substitute fossil fuels out of kiln heating today, though neither is fully carbon-zero
- That said, the supply **of biomass and waste substitutes is limited, regionally varied, and difficult-to-track, and** cement is not a priority use case for biomass's limited supply compared to applications like sustainable aviation fuels (SAFs)
- Some cement producers are installing other technologies to reduce the need for fuels for kiln heating, namely **excess heat recovery (EHR),** which uses thermal energy of kiln flue gases to preheat raw material through a series of cyclones before entering the kiln

~65% of business leaders consider availability to inputs to production to be a top barrier to adoption of fossil fuel alternatives

Government should ensure proper access and tracking of near-term thermal energy alternatives, with funding to support R&D into longer-term alternatives

Removing technical and commercial barriers to long-term kiln heating alternatives

- Today, there are **insufficient incentives for producers to invest in kiln electrification and green hydrogen**
- Governments can help to **facilitate the transition via tax incentives or direct funding of R&D projects associated with improving the efficiency and subsequent commercial viability** of these options

Facilitating stronger access to short-term kiln heating alternatives

- Today, there is supply of **waste substitutes** that could serve as alternative thermal energy sources for kiln heating, but waste is **regionally varied in its supply**
- To facilitate the use of waste substitutes, governments should **ensure robust waste management** so that waste can be tracked and traced for re-use, and in conjunction, **anti-dumping laws such as high dumping costs** can encourage reuse of waste rather than dumping in landfills

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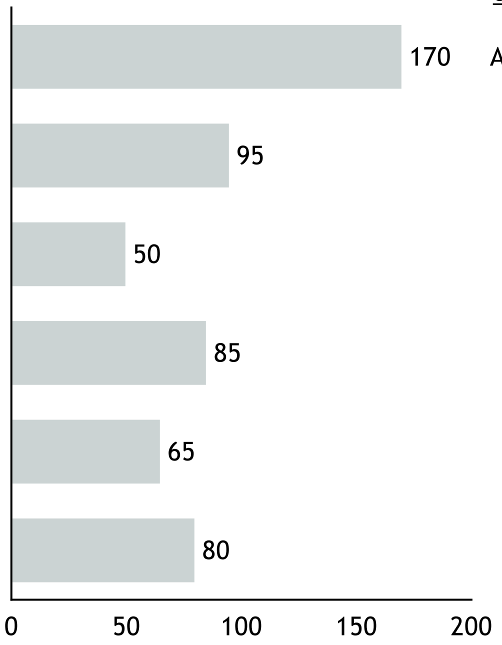
Carbon capture, utilization and storage (CCUS) projects could have an important role to play in reducing cement emissions

CCUS is a critical enabler for decarbonisation

- CCUS is a necessity in the cement sector, as **limestone, the key base ingredient, has significant carbon content** that is released when heated
- While CCUS has applications across sectors, CCUS in cement **is the process of trapping the CO_2 produced during kiln heating**
  - CCUS is known to be technically challenging in the kiln, in part due to the low density of CO_2 in kiln flue gases
- Once trapped, the greenhouse gas can then be:
  - Piped into permanent underground **storage facilities**
  - Used to **re-carbonate concrete mixes**
  - **Carbonation hardening of concrete**
  - **Sold to industries who make use of carbon** for their production

Absorption is the most advanced CCUS technology for the sector today, but alternative technologies present potential benefits



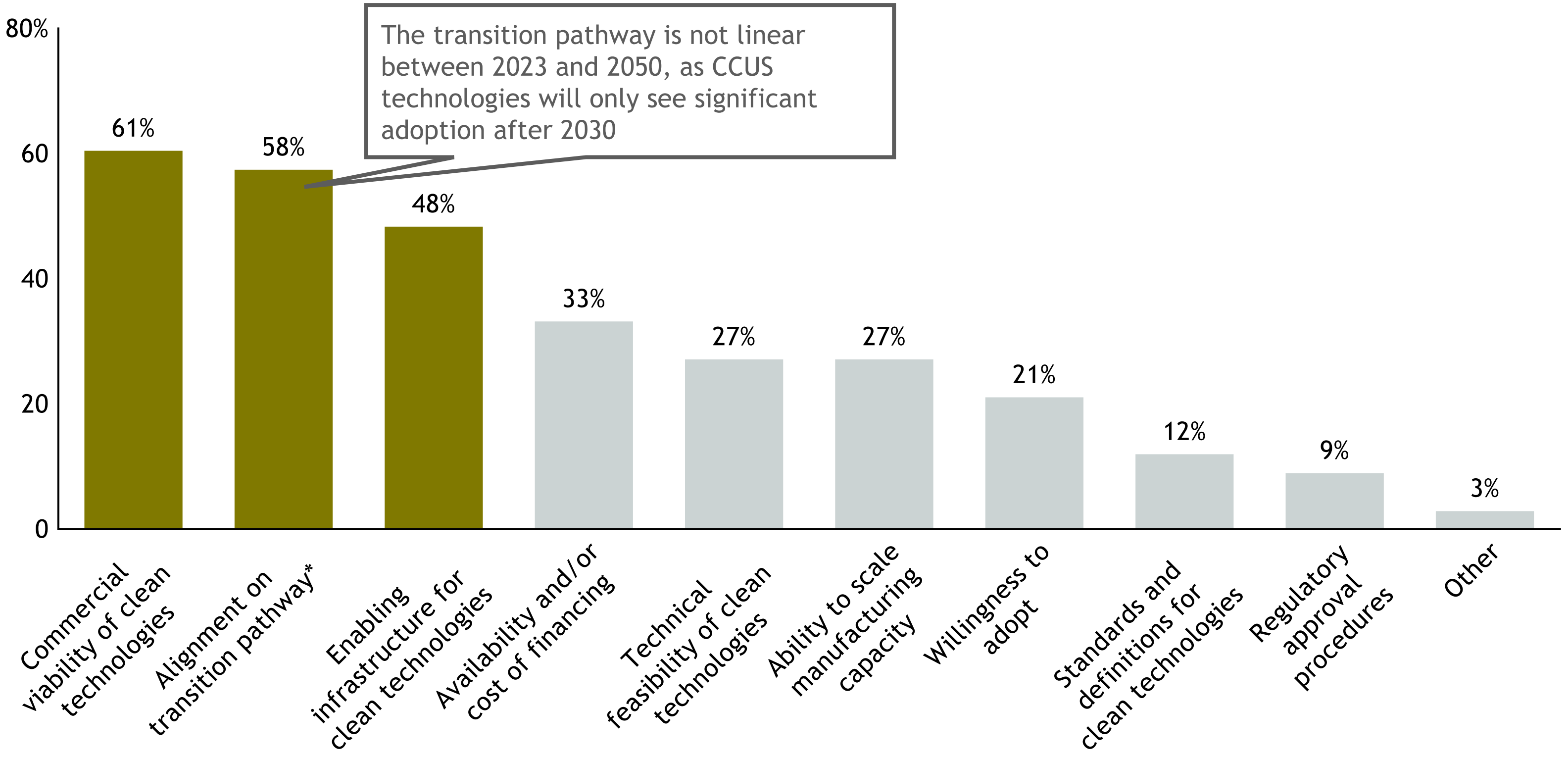
Technology	2035 cost per ton of clinker (in 2023 $ USD)	Expected deployment year	Energy consumption (MJ/kg CO2)
Absorption is a common capture process based on the reaction between CO2 and a chemical solvent	170	Already deployed	7
Oxyfuel burns fuel in oxygen rather than in air, which generates a purer CO2 concentration	95	2025	2
Indirect calcination indirectly heats the calciner to keep the heat and process emissions separated	50	2025	1
Absorption & cryogenic is a process in which a material attracts CO2 molecules to its surface	85	2030	3
Calcium looping removes CO2 from the flue gases using a calcium oxide (CaO) sorbent	65	2030	5
Membranes can separate gases based on the permeability difference between different gases	80	2030-40	3

Source: IEA Tech Report (2018); A review of the technologies, economics, and policy instruments for decarbonising energy-intensive manufacturing industries (2014); QZ; Resources for the Future Resources for the Future (RFF); Mission Possible Partnership "Making Net Zero Concrete and Cement Possible: An industry backed, 1.5˚C-aligned transition strategy"; ECRA Technology Papers

Cement business leaders cite sector alignment, commercial viability, and infrastructure as the biggest barriers to CCUS adoption

*Which of the following do you view as the **greatest barriers to the implementation of CCUS technology?** Please select the top 3 most impactful barriers.*

Share of survey respondents selecting barrier in the top 3 (%)



Commentary

- Those who favor CCUS acknowledge there are major **barriers to industry-wide adoption:**
  - Prohibitive upfront investment costs
  - Ongoing operational costs that yield a significant "green premium" for construction customers who view cement as a commodity
  - Infrastructure to store and transport carbon once it is captured

*"There are many CCUS technologies under development, such as post combustion, oxyfuel, direct separation and others, and each of them will contribute to some extent. That said, **our main challenges lie in finding suitable framework conditions for CCUS projects, such as funding opportunities and the infrastructure to support carbon capture, transport and storage.**"*

Senior Manager Sustainable Construction & Public Affairs, Cement producer #2

Note: Chart includes data from energy consumers with expertise in the cement sector (N = 33); (*) Refers to whether business leaders in the sector are in agreement on which decarbonization pathways are the most viable
Source: Bain / WMBC Global Stocktake Survey (N = 215); Corporate interviews

“We see CCS as the second step to decarbonization after product development and process optimization”

Heidelberg Materials

Case Study: Heidelberg Materials

Overview

- **Description:** Heidelberg Materials is one of the world’s largest integrated manufacturers of building materials, providing aggregates, cement, and ready-mixed concrete
- **Founded:** 1873
- **Headquarters:** Heidelberg, Germany
- **Ownership:** Public (OTCMKTS:HDELY)
- **Revenue (2022):** €21.1B

Targets

- **2024**
  - CCUS plant operation in Brevik, NO
- **2025**
  - CCUS pilot plants in testing phase in Hanover, DE and Mergelstetten, DE
- **2026**
  - CCUS operational in Edmonton, CA
- **2028**
  - CCUS operational in Padeswood, UK, Devnya, BG, and Antoing, BE
- **2030**
  - CCUS operational in Slite, SE, Mitchell, Indiana, US, and 2 sites in Eastern Europe
  - Reduce net CO2 emissions to 400 kg/t of cementitious material
  - Save 10M MT of CO2 from the 12 cumulative CCUS sites to be operational
- **2050**
  - Net-zero company

Activities

Opening first CCUS-enabled cement plant and first carbon-neutral cement plant

- Heidelberg is leading the industry by opening a cement production facility in Brevik, Norway as the **world’s first carbon capture facility at a cement plant**
  - Plans for the facility include carbon capture technology installations covering 50% of the plant’s production capacity
    - > Expected to **capture 400,000 metric tons of carbon per year**
  - Captured carbon will be **transported by ship to Northern Lights storage field,** where it will be injected underground for permanent storage
- Targets to **expand the existing plant in Sweden** by building an adjacent **carbon-capture facility** to capture emissions equivalent to the plant's total emissions (~1.8 M MT CO_2 p.a.)

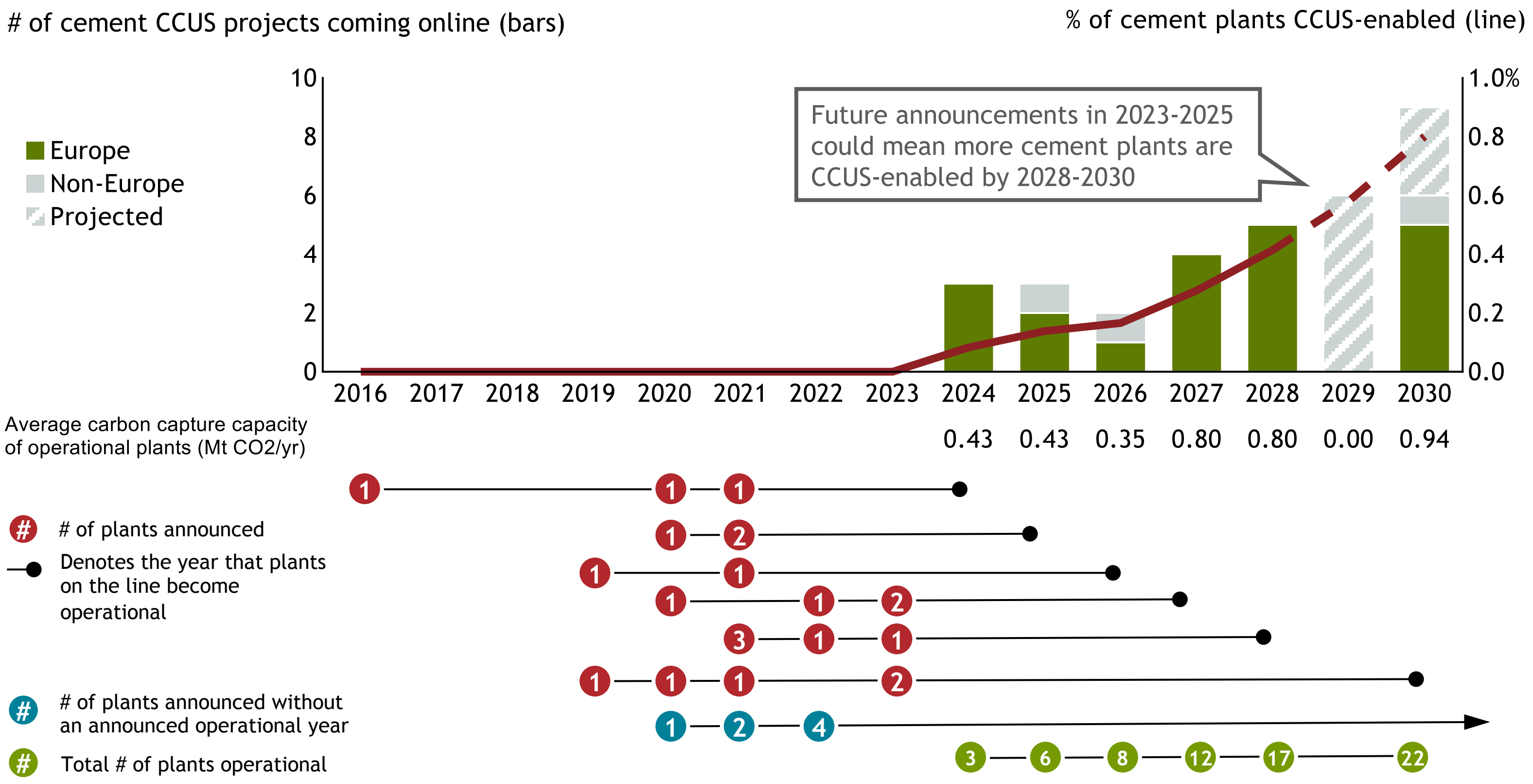
CCUS pathway is pushing industry to follow

- Heidelberg has made agreements and is securing funding for additional CCUS projects through 2030
- The success of CCUS installations in Brevik have **prompted CCUS demonstration projects and feasibility studies globally**
  - **13 Cement producers in 5 EU countries, Switzerland, and China have formed an initiatives called CLEANKER** with the goal of demonstrating the viability of calcium looping (a form of CCUS) in Cement production
  - The European Cement Research Academy has begun conducting **research on the application of CCUS technology in the Cement industry**
  - **CEMEX committed to partner with the EU** in funding the **C3-Capture project** whose goal is to develop CCUS applications in the Cement sector
  - **The US Department of Energy (USDOE) has committed funding to build out a Cement production plant in Monterrey, California** incorporating calcium looping (a form of CCUS)

Note: Title quote is from Chief Sustainability Officer, Cement producer #2
Source: Heidelberg Materials company website, Lit. search; Corporate interviews

Many have been talking CCUS for awhile without any action; as pressures mount to decarbonize, however, CCUS installations are likely to accelerate

Plans for CCUS-enabled cement plants are increasing, though less than 1% of plants are scheduled to be CCUS-enabled by 2030



CCUS is particularly challenging in cement, contributing to slow adoption

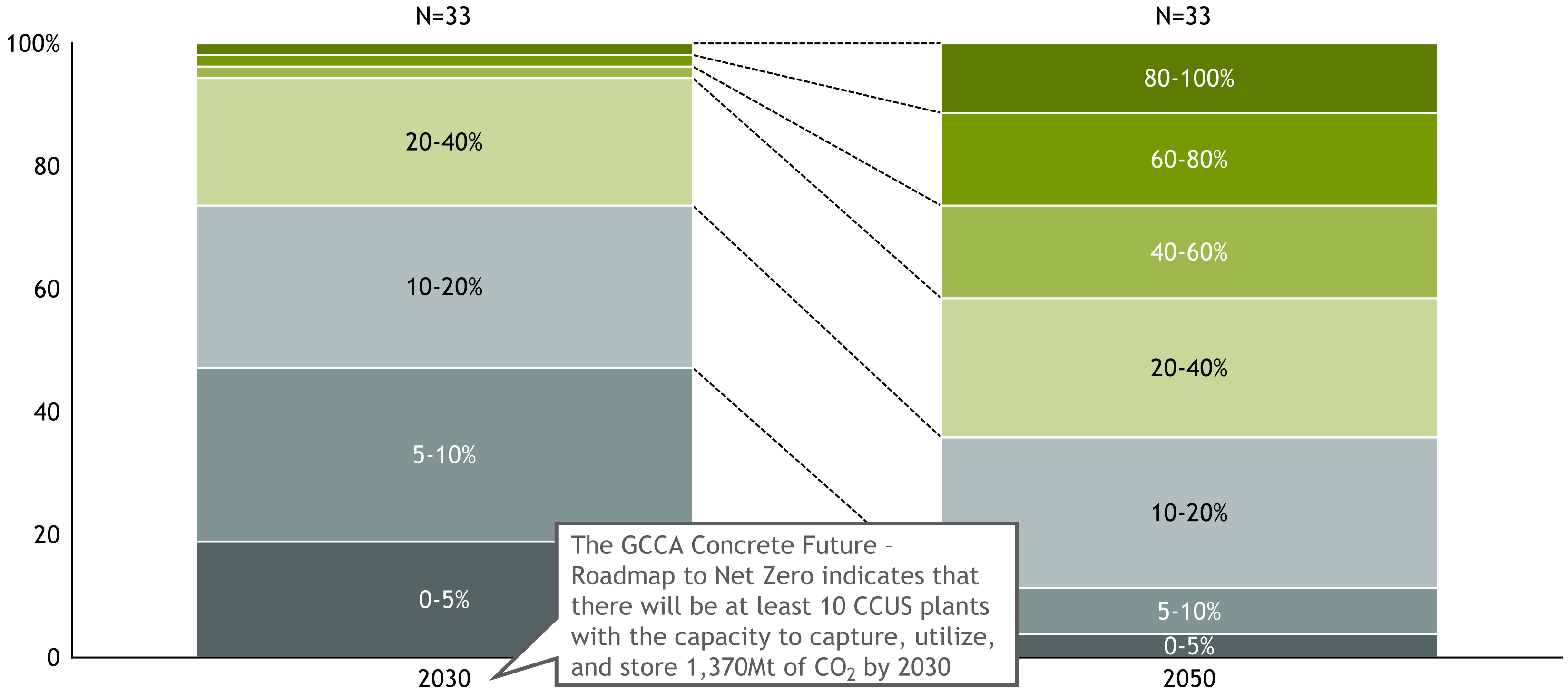
- **Capturing carbon in cement is challenging** due to emissions getting released directly in the cement kiln from the calcination process
  - This process requires capture within the system itself as opposed to outside the emitting system as in other CCUS applications
  - These challenges contribute to slower adoption of CCUS in cement applications
- The average time between a **plant being announced and it coming online is 6.18 years**
  - Significant financial investment is required to support CCUS in cement plants
  - Regulatory barriers (e.g., difficulty achieving permits to build pipelines and other infrastructure) slow the adoption of CCUS
- Other CCUS projects are underway, including **7 pilot projects and 6 demonstration projects**, but were excluded since they do not have plans for full-scale operationalization

Note: Data includes all operational, under construction and planned CO2 capture facilities with an announced capacity of more than 100 000 t per year (or 1000 t per year for direct air capture facilities). 7 CCUS projects do not have an operational year -- those plants have an announced average capacity of 1.247 MT CO_2/yr; 4 of the plants without operational years were outside Europe; 2 CCUS projects do not have announced capacities; lower bound estimates used for announced capacity of plants | Source: IEA CCUS Projects Database; GECD; GCCA; Leadit

Few business leaders expect meaningful CCUS capacity in the sector by 2030, but >25% expect significant CCUS installations by 2050

*We want to understand more about cement producers planning to install CCUS technology to abate emissions inherent in clinker production. What **share of your cement production capacity do you estimate will be CCUS-equipped** by 2030? By 2050?*

Share of survey respondents by % of CCUS-equipped capacity (%)



Note: Chart includes data from energy consumers with expertise in the cement sector (N = 33)
Source: Bain / WMBC Global Stocktake Survey (N = 215); Corporate interviews

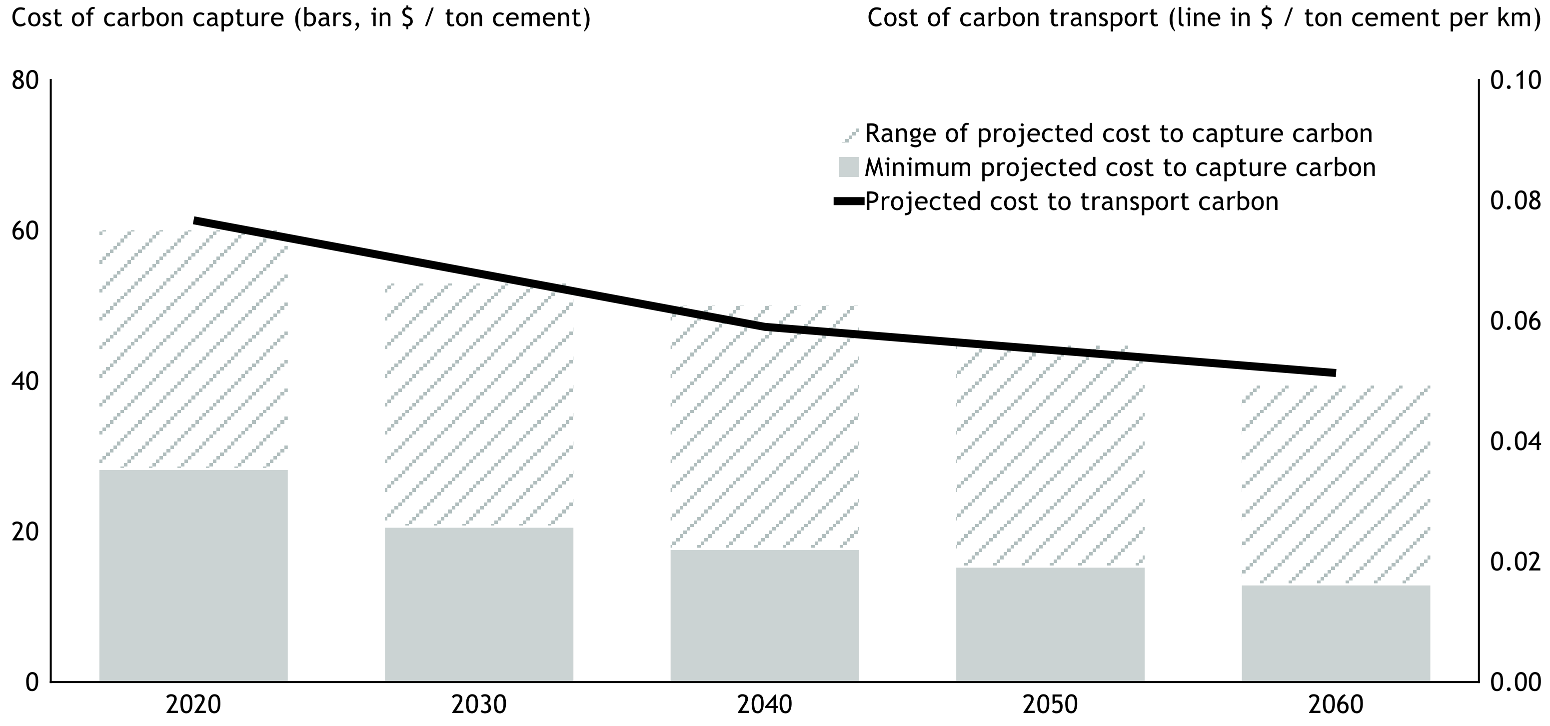
Commentary

- While no cement facilities have deployed CCUS as of 2023, many CCUS facilities have been announced in the sector. And the technology is top-of-mind for business leaders for the years ahead
- Given **upfront investment costs and timelines for permitting and installations,** only ~25% business leaders expect more than 20% of their cement production to be CCUS-enabled by 2030
- **By 2050, most business leaders expect that more than 20% of cement production will be CCUS-enabled,** with some believing production could be more than 80% CCUS-enabled

*"We are pleased with the support from the EU to kickstart CCUS developments. **We need this momentum to carry over to the required regulatory frameworks and to accelerate CCUS.** Funding programs must now switch focus on full deployment by reinjecting revenues from the EU emission trading into major decarbonization projects."*
Chief Sustainability Officer, Cement producer #2

Significant investment is still required to develop CCUS to the point that it can be adopted across the sector

While CCUS is an expensive addition for a commodity, capture and transport costs will decrease >30% by 2060



CCUS will be the main driver of price premiums for zero-carbon cement

- CCUS is a novel technology in the cement process, so there is little data supporting exact price estimates today
  - In general, carbon capture costs are expected to decrease mainly due to **technological developments, economies of scale, and potential for carbon utilization on site**
  - Transport costs are expected to decrease as **infrastructure development will allow for transport optimization,** such as more efficient routes and closer proximity to storage sites
- Even so, there will still be a price premium for lower-carbon cement, **driven largely by the cost of CCUS and alternative fuels**

Note: Cost of carbon capture assumes cost CO_2 usage in cement of .59t CO_2 / metric ton cement per IEA 2021 report; cost of carbon capture given as high and low bounds to signify projections
Source: RMI; China Cement Association; IEA

Although CCUS' impact on cost of clinker is high, end-users could achieve impact with limited increase on the entire cost of a construction project

+300-400%
cost of clinker

- CCUS costs drive up the cost of clinker significantly, primarily as a function of **operational costs for carbon capture, transport, and storage costs of carbon after capture.** Other decarbonization levers (e.g., clinker substitution) can be implemented at lower or negative costs

+40-120%
cost of cement

- The effect of CCUS costs on the cost of cement is smaller given **clinker is only one of many drivers of cement cost**
- The **cost is further offset by the fact that other SCMs are integrated with clinker to make cement mixes,** limiting the impact of higher clinker costs

+15-40%
cost of concrete

- Similar to the change in cost impact from clinker to cement, **cement is only one of many drivers of concrete cost**
- Also similar to cement, **cost is further offset by the fact that other SCMs are integrated with cement to make concrete mixes,** limiting cost impacts

+1.5-3%
cost of finished asset

- Ultimately, the cost impact of CCUS for end-users is small, **as most costs are concentrated in the emissions-intensive clinker-making process** - clinker is only a small percentage of the cost of a construction project

Note: Ranges driven by variation in underlying costs of product and range of costs of abatement. Design levers mostly represent pre-casting levers, but also includes lean design and topology optimization
Source: MPP analysis; ECRA (2022); Hipages; Cembureau; Corporate interviews

The main barriers to CCUS adoption lie in identifying the infrastructure to support carbon transport and storage

Access to carbon storage

- Captured carbon needs a place to go once it is captured – **carbon sinks, which are natural, or engineered reservoirs that can absorb carbon, are a critical enabler for CCUS adoption to be feasible**
- Carbon sinks include underground geological formations like depleted oil and gas reservoirs, saline aquifers, basalt formations
- Leaders across sectors, including Cement, are **working to identify geographies with the greatest access to carbon sinks**
- Over 40% of the optimal locations are in North America
- Cross-sector efforts to identify carbon sinks can centralize work to build carbon storage capacity and transport infrastructure

Regulatory guardrails to support storage and transport access

- There are **significant barriers to permitting and siting for CCUS,** and significant planning is required to file and receive authorization
- In the US, approvals are needed for land use, surface water discharge, dredge discharge, endangered species, GHG reporting, air permits, carbon pipeline safety, siting carbon pipelines, pore space ownership, mineral rights, and carbon injection
- In Germany, there are limitations around where carbon can be stored (e.g., today, carbon can only be stored off-shore, though many claim on-shore and underground carbon storage options will be crucial to enabling broader CCUS adoption)
- Despite tax benefits to technologies like CCUS, siting and permitting costs can be high, deterring some companies to justify the investment
- In some regions, there have **been targeted attempts to help companies with CCUS siting and permitting**
- The CCS Infrastructure Fund and the CCS Knowledge Centre in the EU provide companies with assistance and funding to overcome these obstacles

Source: Wood Mackenzie; White House Council on Environmental Quality (CEQ); CCS Knowledge Centre; CCS Infrastructure Find

“To deploy CCUS at scale, we need a framework that provides enough flexibility to develop industrial value chains that, today, are largely nonexistent”

The United States is pursuing a series of standards and supplementary funding to encourage producers to adopt CCUS

- **Council on Environmental Quality (CEQ) delivered guidelines** to Federal agencies to ensure CCUS is executed in a responsible way
- **The DOE has provided ~$10B over the past two years for CCUS** deployment, infrastructure, and broader carbon management support
- **The IIJA has allocated ~$12B to CCUS** over the next 5 years, and the CHIPS Act allocated ~$1B for CCUS R&D
- **Federal GHG reporting programs** require high-emissions industries with opportunity for CCUS installations to report emissions (e.g., steel, iron, cement, etc.)
- **IRA provide tax credits for carbon management** ($60-$180 / metric ton of carbon stored or used depending on circumstances) with additional tax credits for CCUS installations to come online prior to 2033

The European Union is focused on increasing carbon prices to encourage CCUS adoption, supplemented with significant funding for installations

- **The EU’s ETS increases prices on carbon,** progressively decreasing number of free carbon allowance and thereby promoting adoption of CCUS
  - Associated CBAM will enforce carbon price on emissions
- **The government has a regulatory framework** for the environmentally sound storage of carbon
- **Horizon Europe (€95.5B), The EU Innovation Fund (€20B), and the Connecting Europe initiative (€20B)** allocate funds for CCUS installations
- **The EU Investment Bank provides favorable rates** on long-term financing for CCUS projects
- **The EU’s $2B Just Transition Scheme** supports high-emissions industries with subsidies

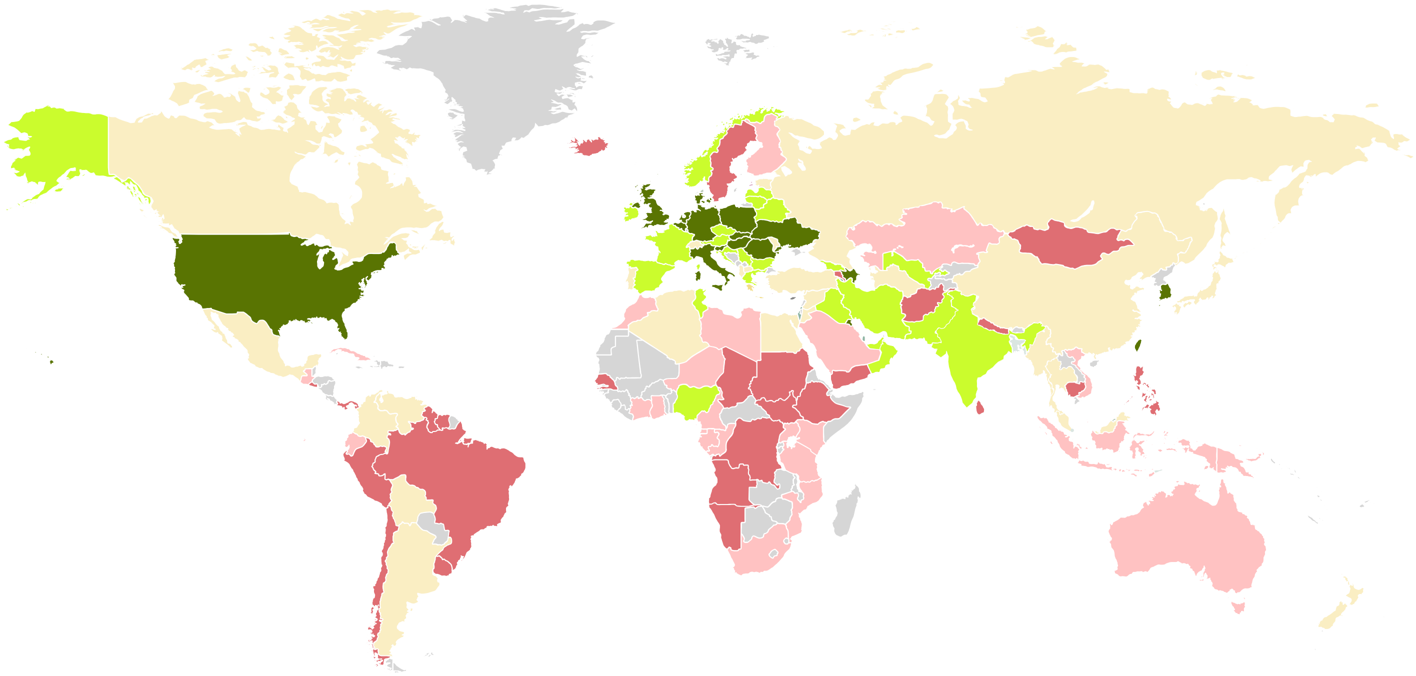
Australia is enforcing ad-hoc requirements for CCUS but is beginning to introduce funding and subsidies to support this transition

- The government sets **project-specific requirements for CCUS**
- E.g., Chevron must sequester >80% of emissions from its Gorgon LNG plant
- **CCUS Hubs and Technology program** allocated $250M to CCUS R&D, gov’t maintains $50M CCUS grant fund, and gov’t has granted ~$1.1B in ad-hoc project funding for CCUS installations and infrastructure buildouts
- **National Greenhouse and Energy Reporting Scheme (NGERS)** requires corporations meeting certain thresholds of emissions, energy production, or energy consumption to report emissions and energy data
- **Emissions Reduction Fund (ERF)** provides credits for CCUS projects per metric ton of carbon sequestered

Note: Title quote from VP Group Affairs and Government Relations, Cement producer #4
Source: Lit. search; Corporate interviews

Existing oil and gas infrastructure can be repurposed for CCUS, helping to transfer captured carbon to be stored or utilized

The US, EU, Middle East, and India have the highest density of pipelines today



Legend

Degree of Piping:	Low	Low-medium	Medium	Medium-High	High	
M of piping per km² of land area:	0 to 2.5	2.5 to 10	10 to 25	25 to 50	More than 50	No data

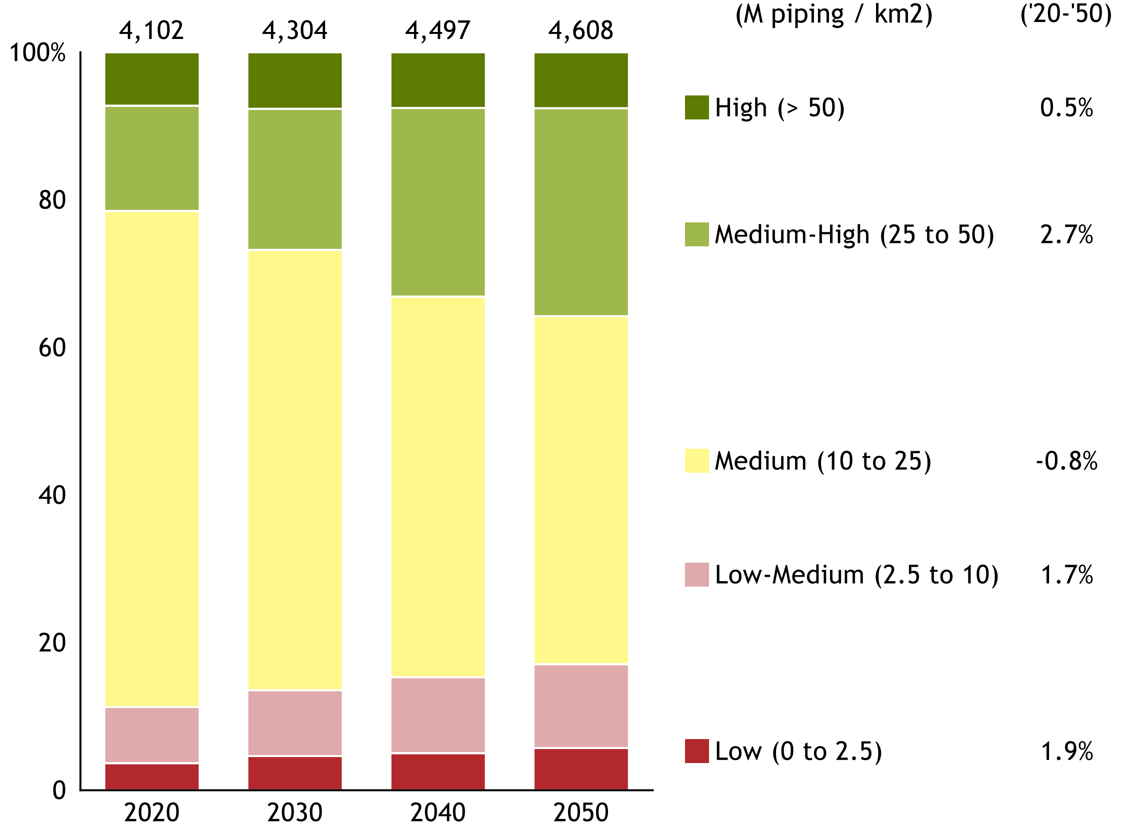
Note: Oil and gas piping for each country was calculated by summing the piping from all projects that start in that country
Source: Globaldata; World Bank; ESRI; Carbon Herald; IEA

Existing oil and gas pipelines are an important enabler for CCUS adoption

- Oil and gas pipelines are ideally suited for CO_2 transport because they are built to **transport fluids or gases long distances** and have **necessary safety and monitoring systems**
  - The Alberta Carbon Trunk Line in Canada has a pipeline capacity of 14.6M MT CO_2 and has already begun transporting carbon to storage or to oil and gas reservoirs for use
  - The Acorn Project in the UK takes captured CO_2 and transports it directly to a gas terminal, utilizing existing pipelines
- **Utilizing existing infrastructure allows for lower costs and easier implementation** of CCUS
  - Also **bypasses some regulatory considerations,** as oil and gas lines are already subject to regulatory oversight
  - Thus, countries with more oil and gas pipelines have an **easier transition to CCUS adoption**

In the regions where cement production is expected to grow the fastest, pipeline infrastructure tends to be most limited

Cement production growth by pipeline infrastructure tier (in M of MT)



Carbon transport infrastructure is a critical enabler to decarbonization in growing clinker and cement markets

- **Regardless of geography, existing oil and gas infrastructure will likely remain for its current purpose into the 2040s**
- **That said, ~80% of 2020 cement production was in places with medium or lower density of oil and gas pipeline infrastructure**
  - Countries with low and low-medium piping, where the least CCUS infrastructure exists today, are some of the countries with the highest expected growth in cement production
  - By 2050, ~65% of cement production will still occur in places with medium or lower density of oil and gas pipeline infrastructure
- For facilities without local carbon sinks or pipelines, **many have explored using ships, trucks, and trains to transport their captured carbon, which is viable but expensive**

*"Every CCUS project is different. **Every project will have to develop a value chain and industrial partnerships from scratch.**"*

VP Group Public Affairs and Government Relations, Cement producer #4

Note: 2020 cement production data was used from USGS; projections used on a regional level, meaning all countries were projected to experience the average growth of their region
Source: IEA; ACTL; The Acorn Project; USGS

CCUS has significant emissions reduction potential but requires further financial and technical investment

CCUS technology development

- CCUS is imperative to cement & concrete sector decarbonization, hence **governments should continue to support technology development to overcome technological challenges** posed by the difficulty of capturing low concentration emissions before, during, or after kiln heating
- **There are limited but growing examples of CCUS being deployed** commercially and at industrial scale; for example, a facility in Brevik, Norway is expected to be the first commercial scale application of CCUS in Cement

"It's also important to find the right partners. We can't do these things [CCUS] alone."
Chief Sustainability Officer, Cement producer #2

Financial requirements for CCUS

- **Applying CCUS in large scale in the short term is prohibitive for heavy industries today** when considering the large upfront CapEx for retrofitting, and OpEx requirements, as well as investments required to install the underlying transport infrastructure, with low carbon procurement, green premiums and a carbon price it would be possible to make a commercial case

~60% of business leaders consider commercial viability to be a top barrier to CCUS adoption in Cement today

Underlying infrastructure to support CCUS

- **Given geographically dispersed production, availability of local carbon sinks or transport and storage infrastructure varies significantly by region,** limiting implementation of CCUS where cement production is needed
- While **there is opportunity to convert oil and gas pipelines that will be retired with the energy transition into carbon transport pipelines,** it is unclear how quickly pipelines will be retired, and pipelines are scarce in many high cement production geographies
- For those without access to local carbon sinks or transport pipelines, **many facilities have explored using ships, trucks, and trains to transport their captured carbon, which is viable but expensive**

~50% of business leaders consider enabling infrastructure to be a top barrier to CCUS adoption in Cement today

Government must pave a pathway to technical and commercial viability for business leaders in high-emitting sectors to adopt CCUS

Governments should establish international targets and standards for CCUS operations

- **Governments must start with creating international agreements and commitments to CCUS adoption targets,** as there is insufficient economic incentive for governments to fund CCUS adoption policies absent international commitments to drive adoption globally
- Governments can then **establish standardized regulatory frameworks for carbon sequestration practices** to coalesce efforts around streamlined technologies
- **Established standards for carbon storage, including both on- and off-shore storage options,** can also be introduced to ensure flexibility for how businesses store carbon
- **Established standards for carbon transport, including pipelines, trains, ships, trucks, and other forms of transport will also be critical,** to ensure flexibility for transporting carbon

Once governments illuminate the path, they can help fund CCUS development

- Even with a clear set of guidance, **CCUS is still prohibitively expensive** for most businesses today, both in terms of initial installation (CAPEX) and heightened energy costs once operational (OPEX)
- Governments can provide financing to help operationalize CCUS, including **funding programs for CCUS R&D, installation, and storage and transport infrastructure development and subsidies and tax credits** for those operating CCUS facilities

With clear standards and financing, gov’ts can mandate adoption

- With standards and financing in place, governments can then **compel business leaders to action with a series of standards and mandates to ensure adoption**
- **A carbon pricing scheme** will place a cost on high-emitting businesses and help to justify the cost of CCUS installations and **can be paired with cap-and-trade systems** to allow able to install CCUS to expand CCUS operations
- **Disclosure programs would hold businesses accountable for emissions footprint** and compel them to explore options like CCUS

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