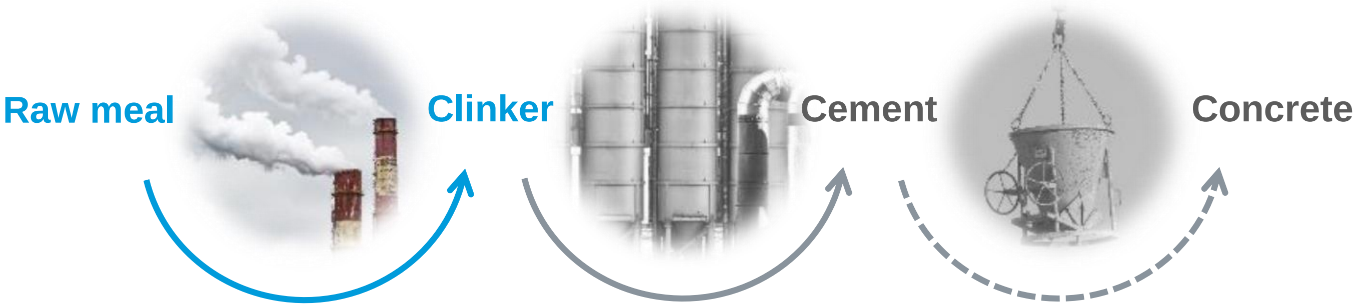
Economics of Decarbonizing Cement

Gernot Wagner
gwagner@columbia.edu
gwagner.com

Clinker production accounts for ~90% of cement emissions

Cement production process



	Calcination of limestone	Fuel combustion for kilns	Non-clinker related cement emissions
Description	The calcination process that extracts **lime (CaO) from limestone ($CaCO_3$)** is a **chemical reaction** that produces CO_2 as a byproduct.	Emissions from **the combustion of fuels** used to heat the kilns where limestone calcination takes place **up to 1,450°C.**	Emissions associated with powering the mill that crushes raw materials, the clinker cooler, cement mill, and the transportation of materials.
% of cement emissions	 ~50-60%	 ~30-40%	 ~5-10%
Annual emissions, *~1.6 Gt CO_2 total*[1]	~0.9 Gt CO_2/year	~0.6 Gt CO_2/year	~0.1 Gt CO_2/year
Average energy intensity[2]	~3-3.6 GJ/t clinker (thermal)		~100 kWh/t cement (electricity)

[1] Scope includes cement manufacturing only; full concrete value chain emissions total ~2.5 Gt CO_2 annually. [2] Assumes dry kilns, which have widely replaced wet kiln processing globally.
Sources: IEA, Cement Tracking (2023); CATF, Recasting the Future (2025); ACM, Roadmap to Carbon Neutrality (2021); CEMBUREAU, Key Fact & Figures (2024); DoE, Liftoff Report (2023).
Credit: Jessica Cong, Isabel Hoyos, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Kim *et al*., "Decarbonizing Cement" (2 June 2025).

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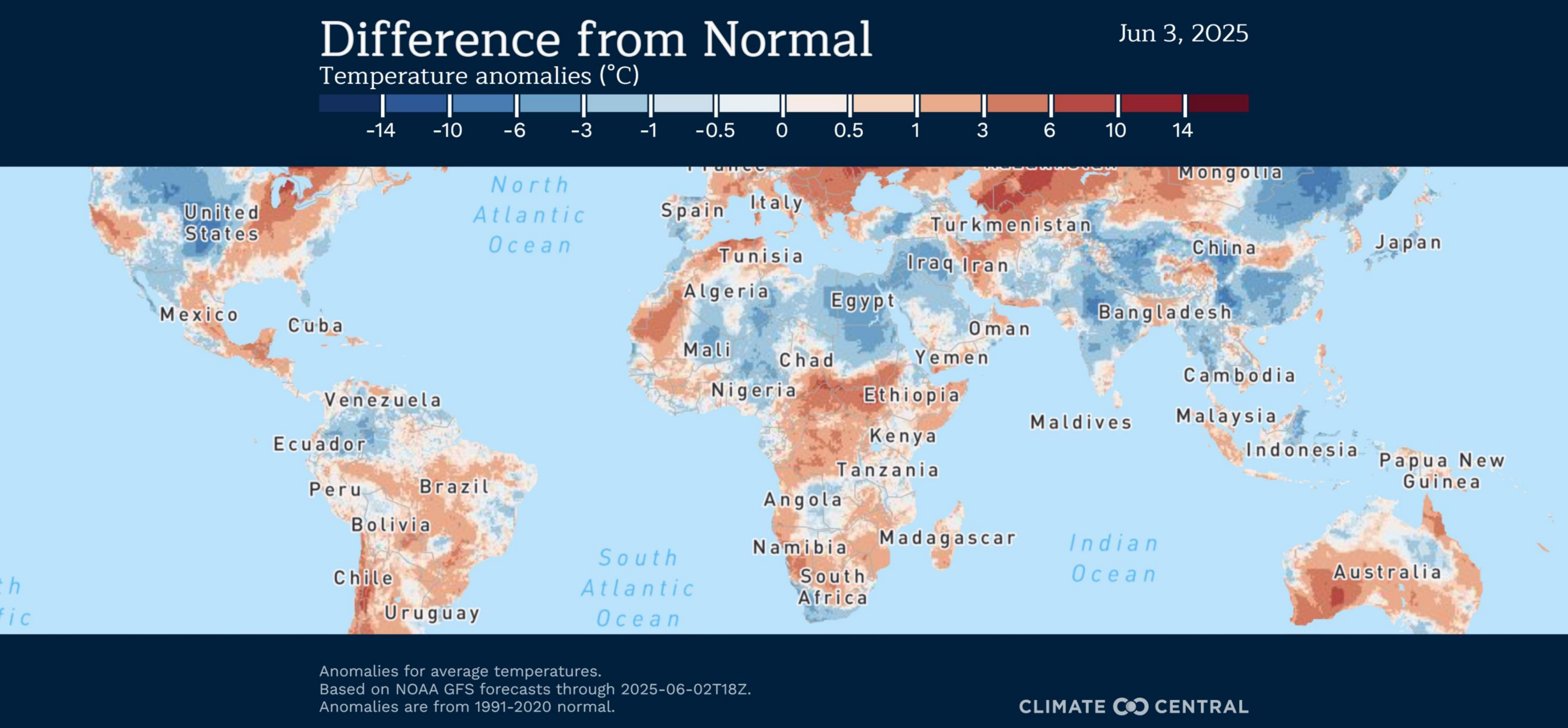
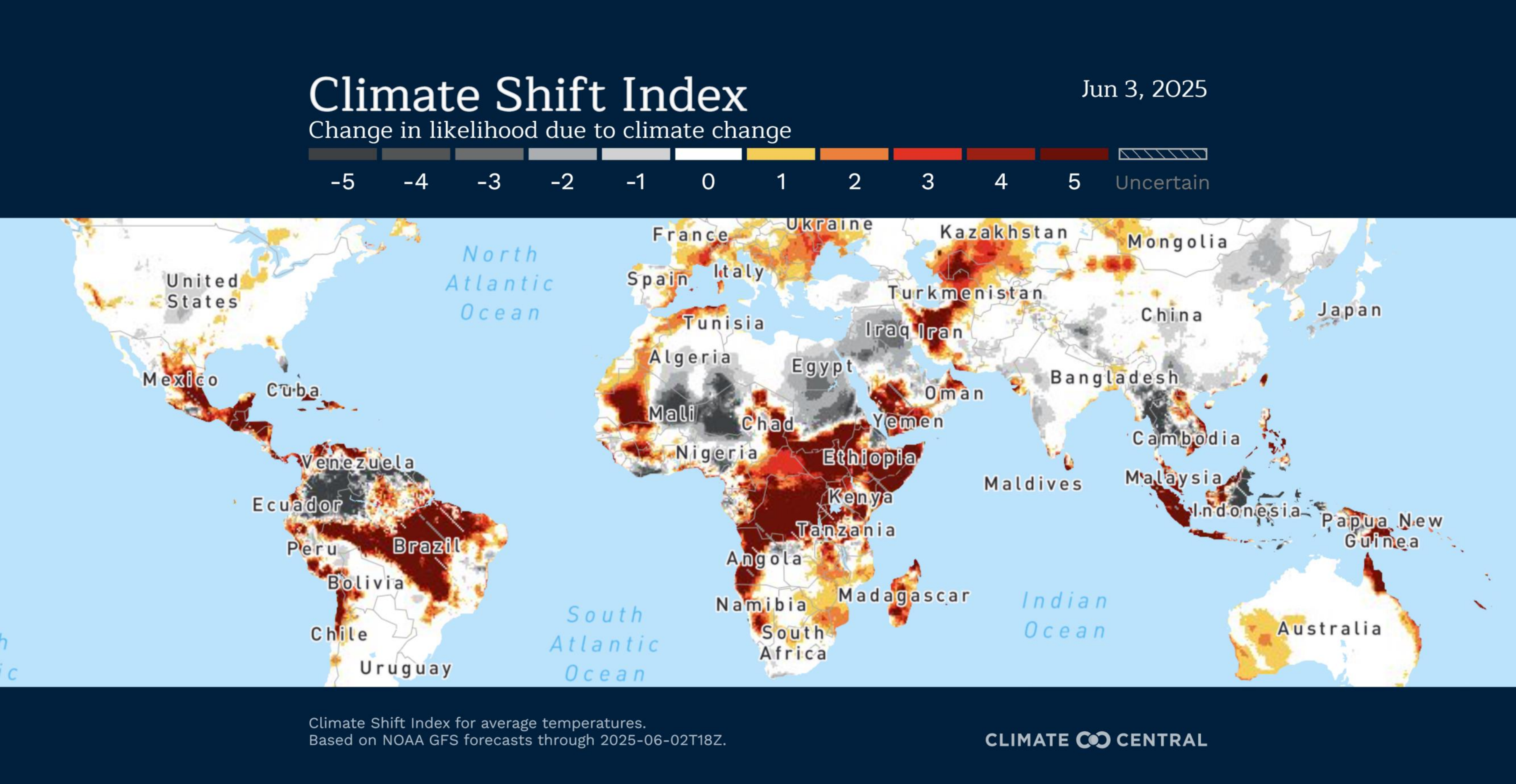
Blatten, Switzerland, 28 May 2025

Flin Flon, Manitoba (*NPR*, 30 May 2025)

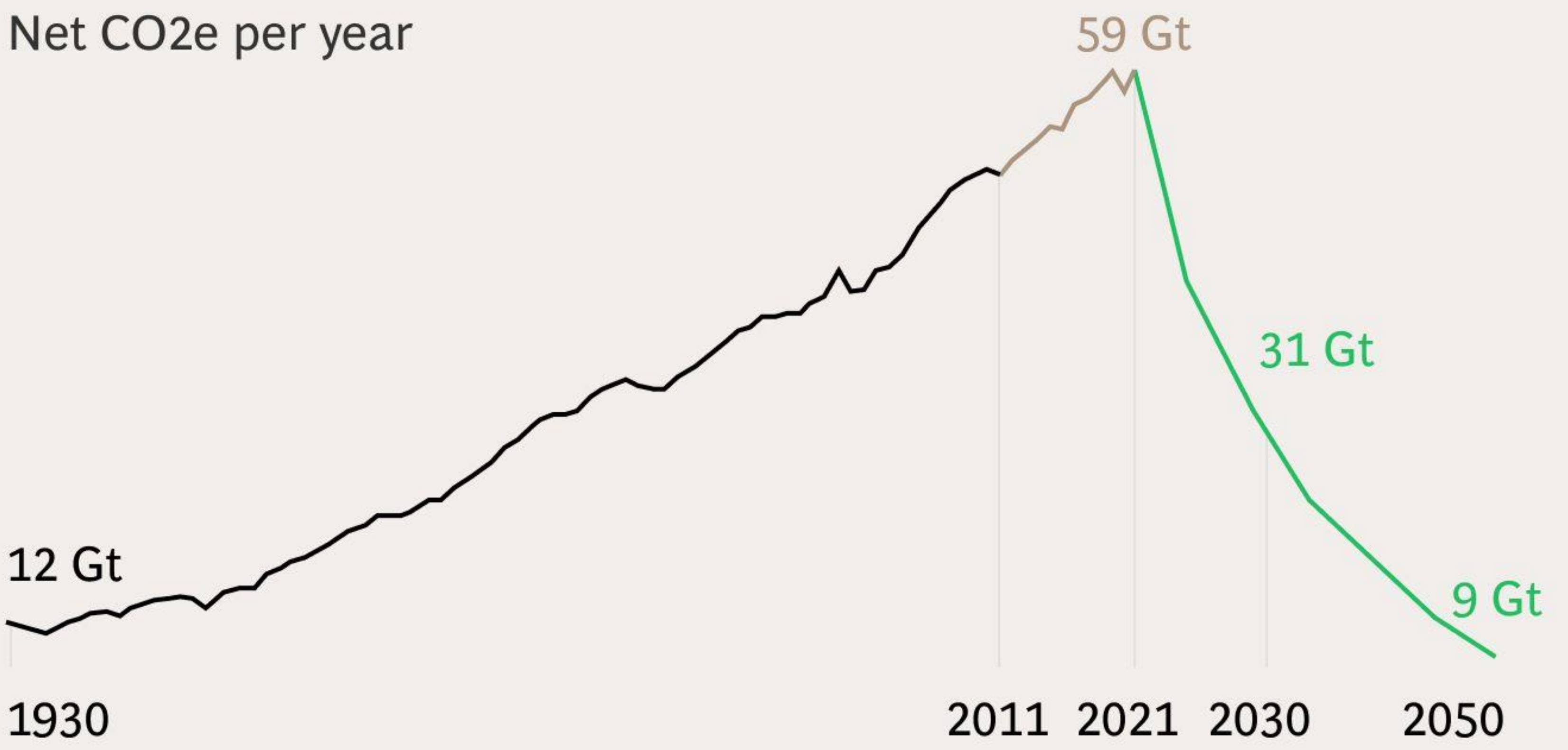


Source: climatecentral.org/climate-shift-index



Source: climatecentral.org/climate-shift-index

Major course correction needed to achieve the 1.5°C ambition



-7%
annual reduction in emissions needed by 2030 to meet the 1.5°C pathway

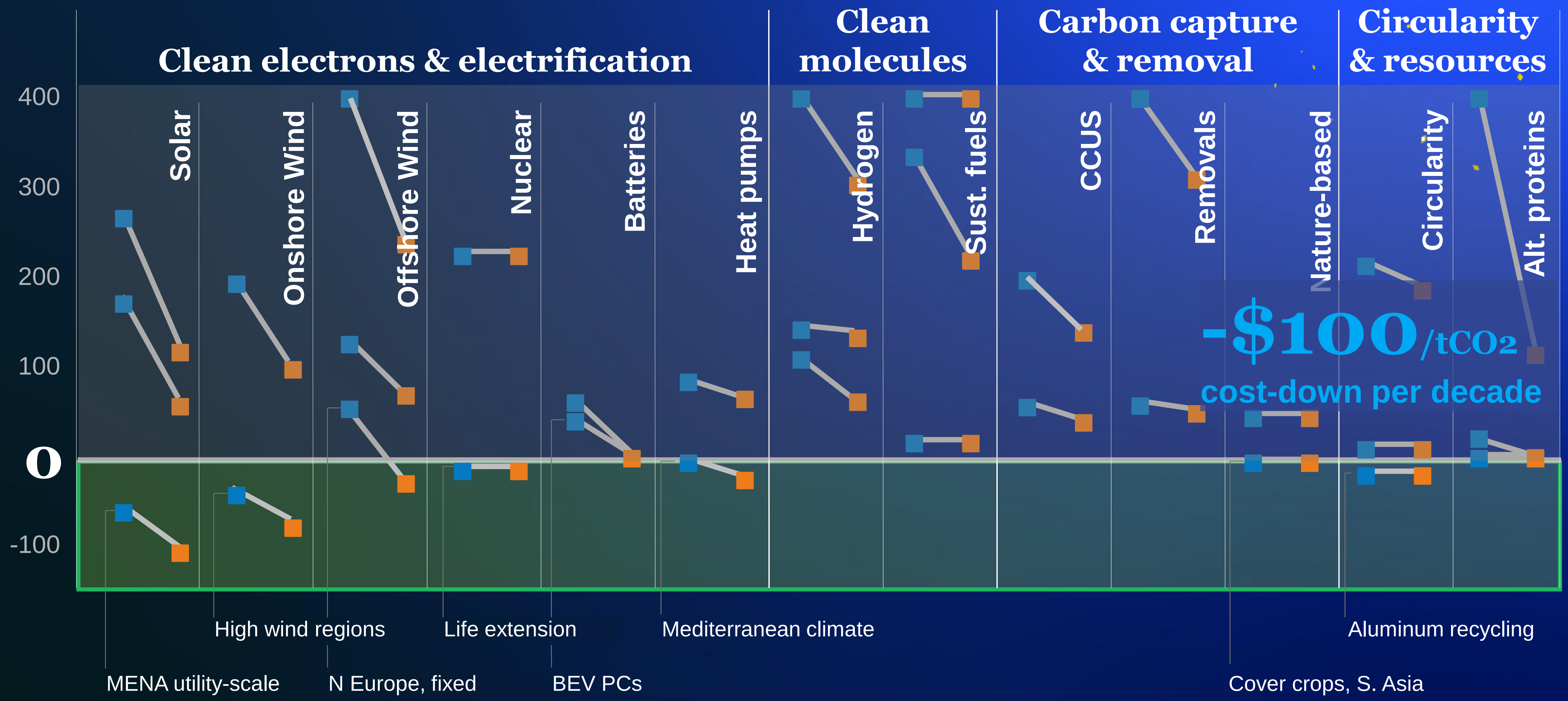
+1.5%
recent annual increase in emissions from 2011-2021

Sources: IPCC, PIK, BCG analysis

Bernd Heid, Senior Partner, McKinsey, at Columbia Business School, 18 November 2024

10 % of techs in the money today – steep cost-down to 2030

Estimated abatement costs, USD/tCO_2e



Source: McKinsey Global MACC with regional/product estimations

McKinsey & Company

100$/tCO$_2$ carbon tax would make most techs competitive

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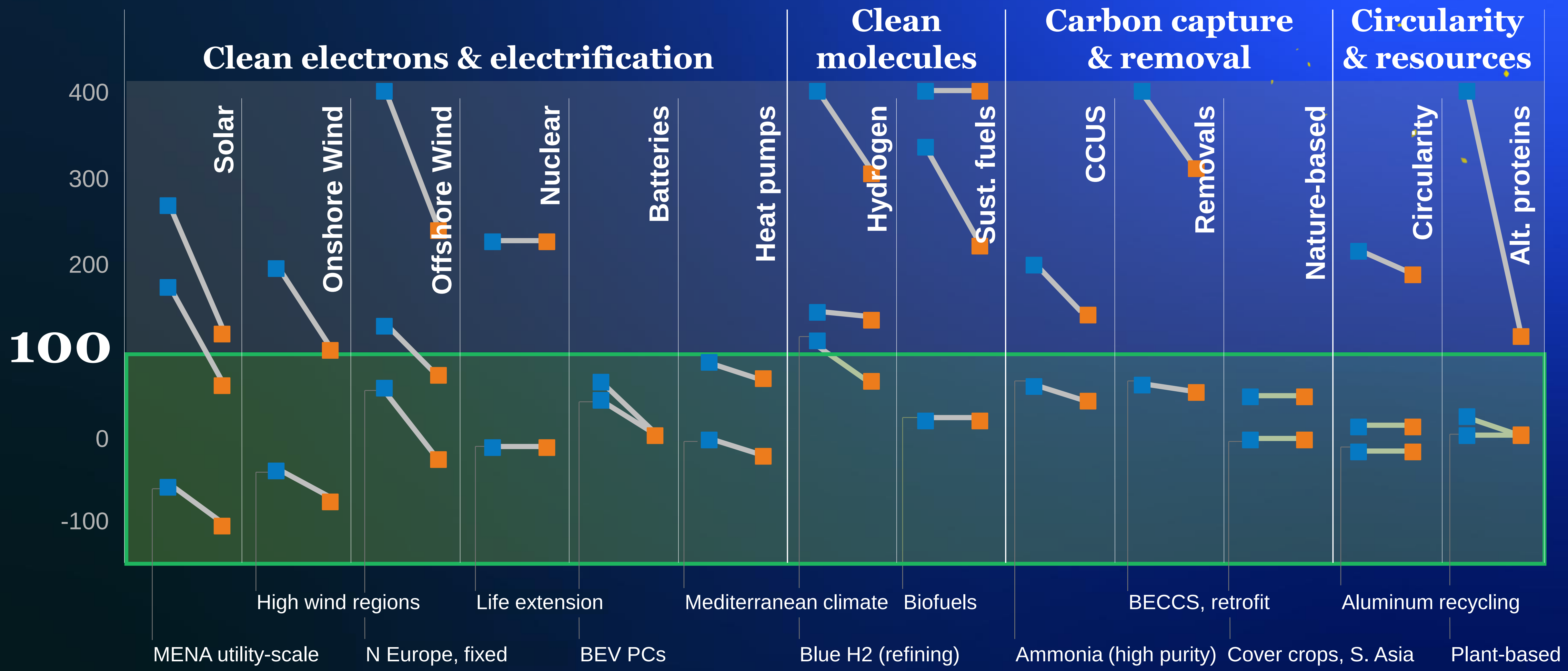


Source: McKinsey Global MACC with regional/product estimations

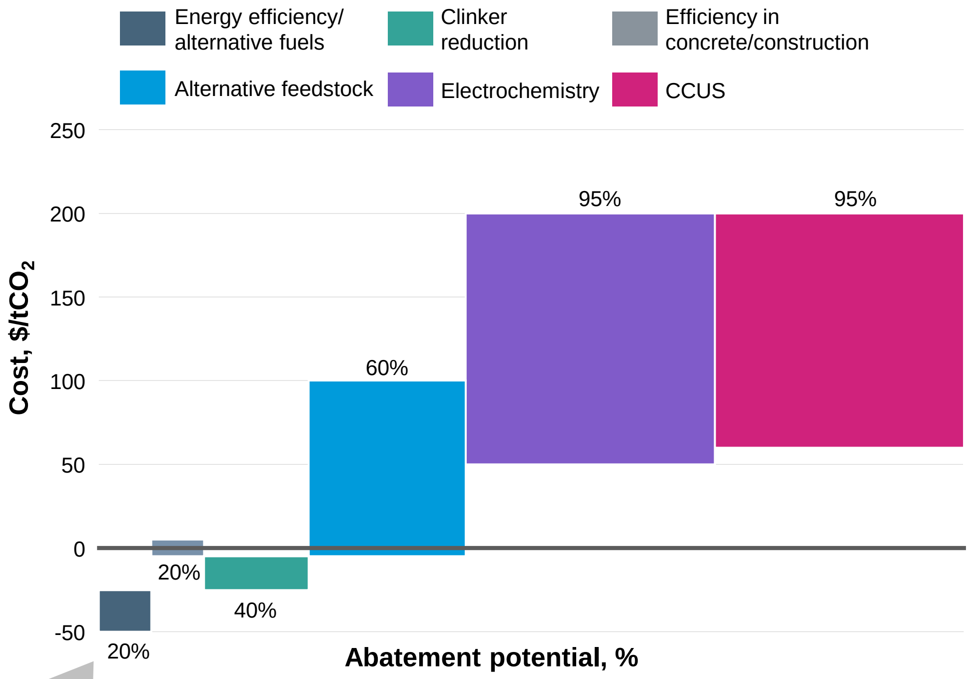
McKinsey & Company

Clinker reduction can abate up to ~40% cement emissions; emerging technologies have higher abatement potential and cost

Key pathways for cement decarbonization

	Clinker reduction (SCMs and LC3)	Alternative feedstock	Electrochemistry	CCUS
Abatement potential[1]	15-40%	Up to 60%	Up to 95%	Up to 95%
Cost, $/t CO_2$	-5 to -25	~-5 to ~100	(high)	~60 to 200
Technology readiness	High	Low	Low	Medium
Pathway to commercial scale	Rapid scale-up driven by large buyer demand and accelerated validation of blended cements.	Enabled by cost reductions and coordinated procurement to create investment signal.	Enabled by cost reductions and coordinated procurement to create investment signal.	Enabled by tax credits, policy support, and cost reductions as deployments ramp.
Key Players	**Eco Material Technologies** transforms fly ash into highly reactive pozzolans, creating SCMs that can substitute higher quantities of clinker.	**Brimstone** produces OPC and SCMs using non-carbonate calcium silicate rock, eliminating process emissions from limestone calcination.	**Sublime Systems** uses electrochemistry and non-carbonate feedstocks to produce calcium silicate cement, avoiding CO_2 from limestone and fuel combustion.	**Fortera** developed a bolt-on technology that captures CO_2 from cement production and mineralizes it into cementitious material.

Abatement cost vs. potential for key pathways[2]



Energy efficiency and alternative fuels are **currently deployable solutions** with abatement potentials between ~8 and 20%.

[1]Unconstrained theoretical abatement potential for a given tonne of cement produced for each approach in isolation. [2] Upper bounds of abatement potentials used.
Source: DoE, Liftoff Report (2023); Mission Possible, Net-Zero Concrete and Cement (2023); CATF, Recasting the Future (2025) ACM, Roadmap to Carbon Neutrality (2021); GCCA, Concrete Future (2022); Climateworks Foundation, Low-carbon cement (2023).
Credit: Adele Teh, Hoshi Ogawa, Sho Tatsuno, Isabel Hoyos, Jessica Cong, Shailesh Mishra, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Kim *et al*., “Decarbonizing Cement” (2 June 2025).

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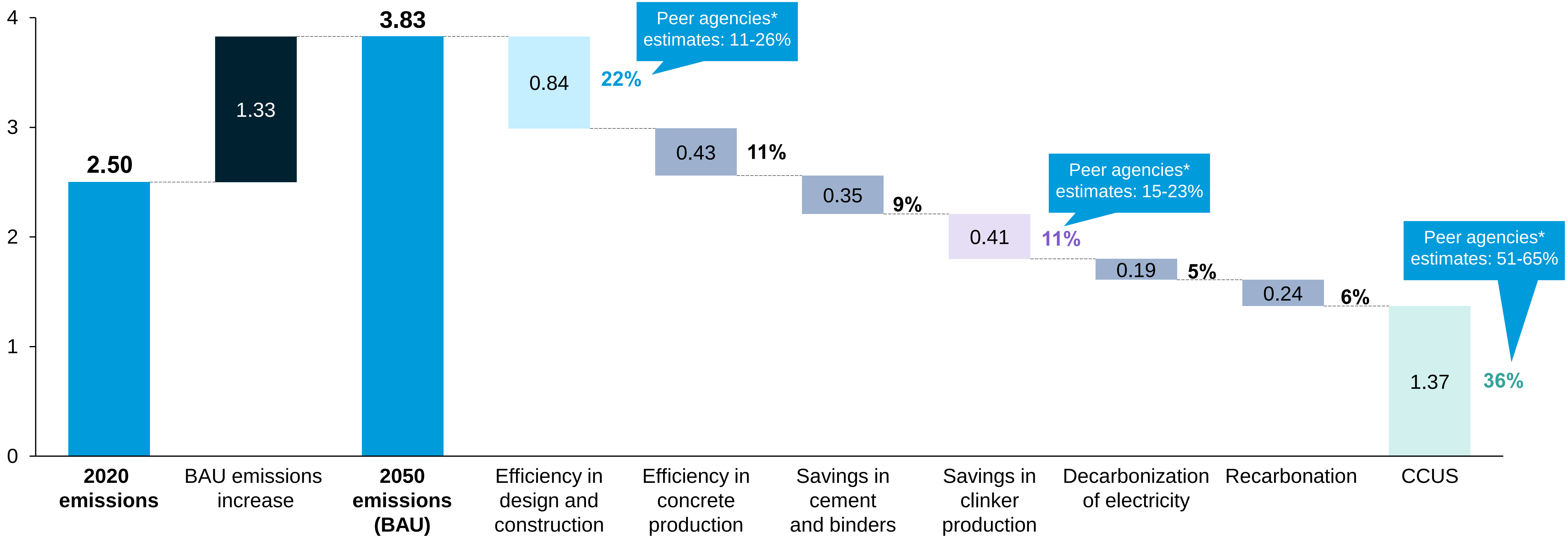
❶ Not if, *when*

Wagner, "Who pays for cutting carbon out of making cement?" (*Financial Times*, 19 May 2025)

GCCA's Net Zero Roadmap presents CCUS and improved material efficiency as the key levers for decarbonizing the concrete sector

GCCA decarbonization roadmap, 2020-50, Gt CO_2



*Peer agencies estimates include ACA, CEMBUREAU and DoE

Source: GCCA Concrete Future (2022).

Credit: Adele The, Shailesh Mishra, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Kim *et al*., “Decarbonizing Cement” (2 June 2025).

❶ **Not if, *when***

❷ **Innovator’s Dilemma**

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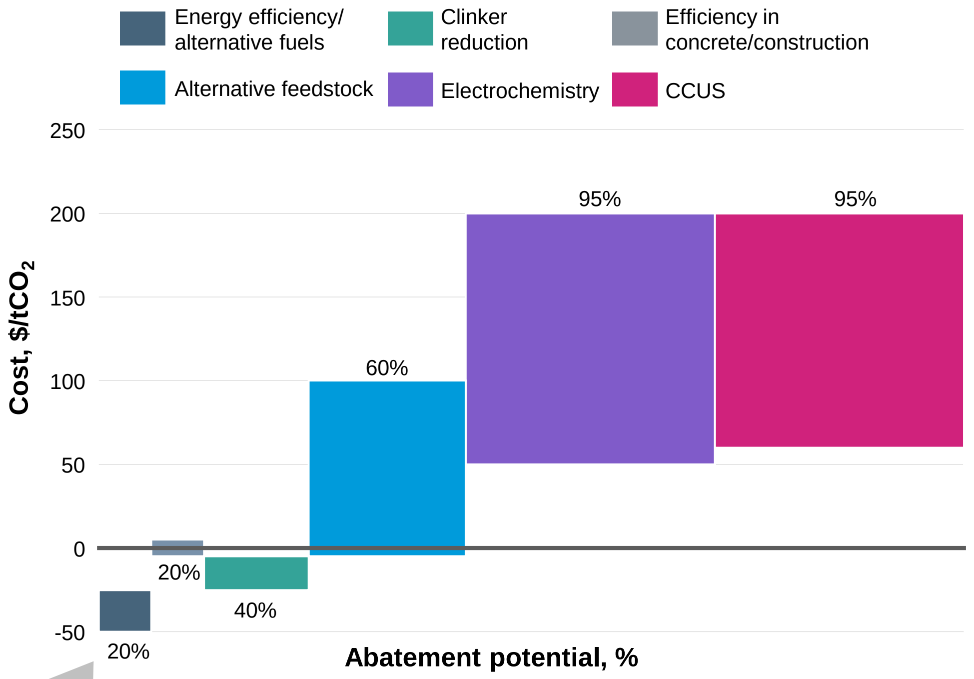

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❶ **Not if, *when***

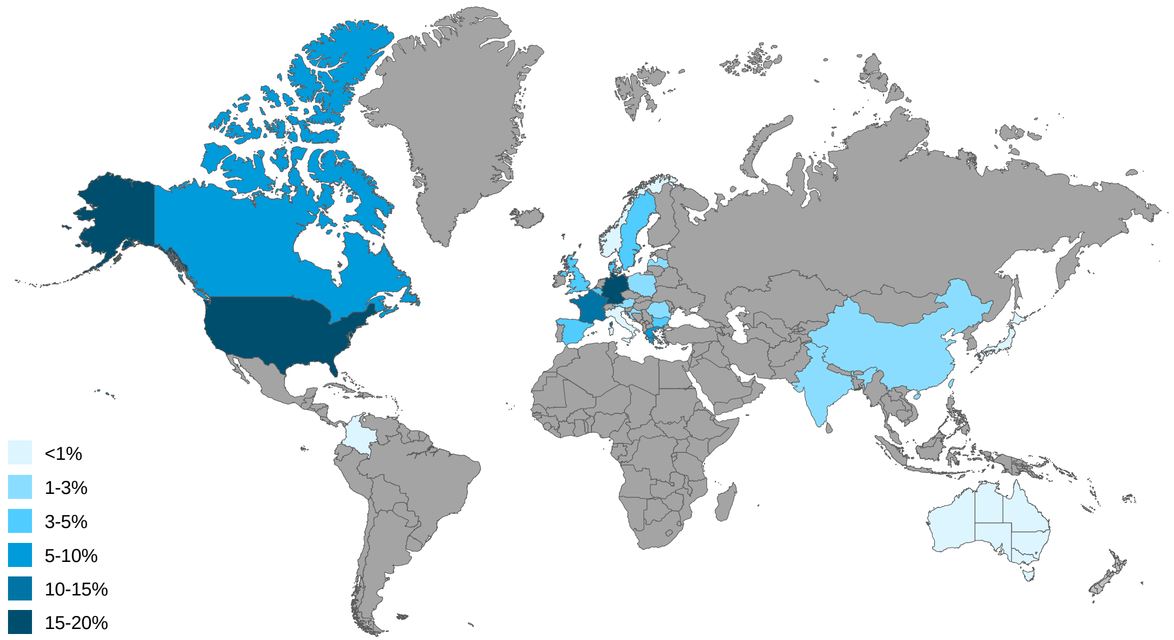
❷ **Innovator's Dilemma**

❸ **Who pays?**

Wagner, "Who pays for cutting carbon out of making cement?" (*Financial Times*, 19 May 2025)

Investment capacity and infrastructure drive CCUS in Global North; clay reserves and capital constraints drive LC3 in Global South

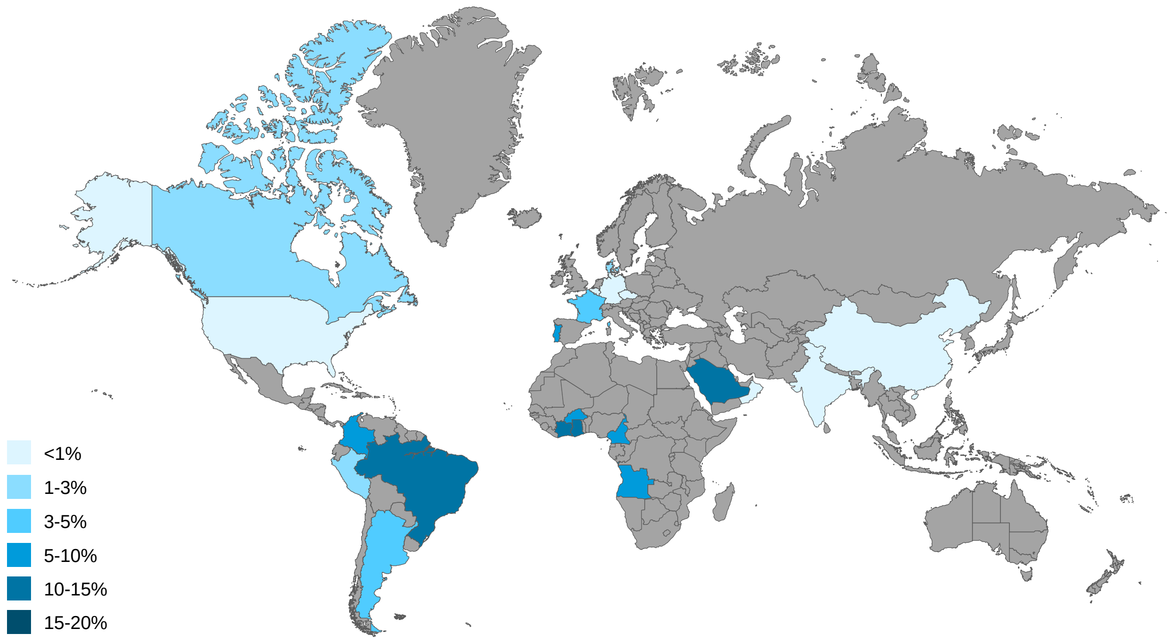
Cement CCUS capacity*, global distribution (Dec 2024)



Observations

- **North America and the EU account for 92%** of stated capacity from announced cement CCUS projects.
- **High capital needs and strong policy support** (e.g. U.S. 45Q tax credit) drive CCUS deployment in high-income countries.
- **Existing oil & gas infrastructure** in developed markets (e.g. pipelines, storage facilities, geological data) enable faster roll out. For example, Norway's Northern Lights project utilizes existing North Sea oil infrastructure to store CO_2.

Clay calciner capacity*, global distribution (Dec 2024)



Observations

- **Africa** accounts for **44%** of stated capacity from announced clay calciner projects.
- Clay calcination kilns are **less capital-intensive** and easily integrated into existing cement plants than CCUS installations, making them more attractive option for countries with limited industrial investment capacity.
- Many developing countries have **abundant clay reserves** but rely on imported clinker due to scarce high-grade limestone. Clay-based alternatives offer a **cost-effective solution** to meet rising cement demand amid rapid urbanization in developing countries.

*Expected at full operation based on stated disclosed carbon capture capacity for CCUS and stated disclosed installed capacity for clay calciner
Source: GCCA and LeadIT, Green Cement Technology Tracker (2024).
Credit: Adele Teh, Isabel Hoyos, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Kim *et al*., "Decarbonizing Cement" (2 June 2025).

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Performance-based standards, public support, and market mechanisms key to overcoming barriers to decarbonization

Barriers and solution mechanisms for cement decarbonization

● Effectiveness of solution mechanisms

		Regulatory mechanisms			Market mechanisms		
		Performance-based standards	Tax incentives	Green public procurement	Carbon accounting	Contracts for difference	Securitization
Financing	High capex		◕	◑		◕	◕
Financing	Tech uncertainty	●	◔	◑	◕	◕	◑
Financing	Risk aversion	●	◑	◑	●	◕	◑
Operating	Complex value chain			◑			
Operating	Lack of SOPs	◕		◔	◑		

Source: DOE, Liftoff Report (2023); WRI, Insights (2025) Green Cement Technology Tracker (2024); Columbia Center for Sustainable Investment, Green Public Procurement (2024); Climate Bonds Initiative, Securitization (2023).
Credit: Adele Teh, Isabel Hoyos, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Kim *et al*., "Decarbonizing Cement" (2 June 2025).

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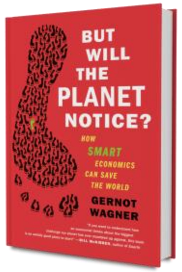
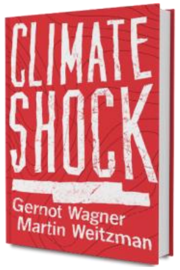
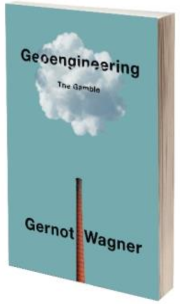
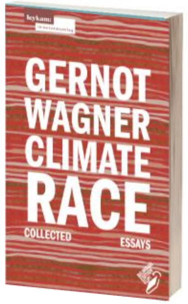




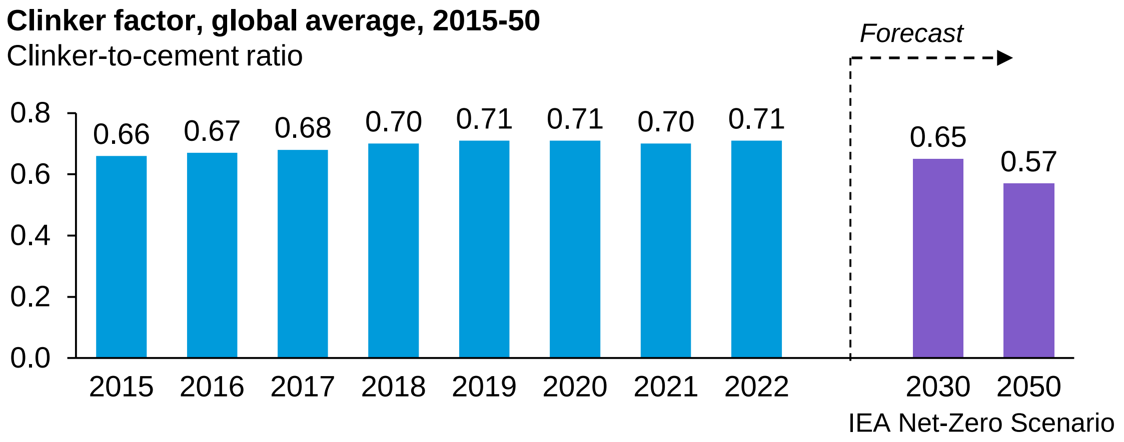


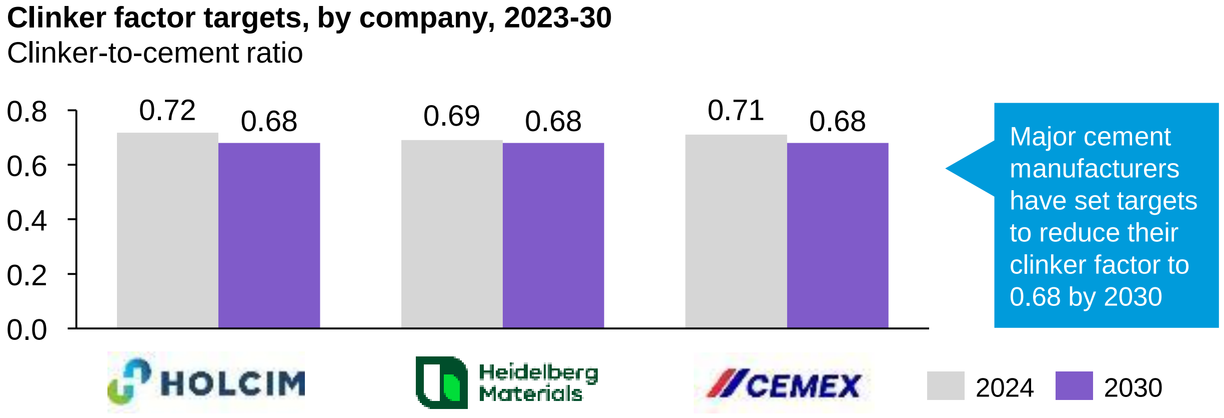


Gernot Wagner
gwagner@columbia.edu
gwagner.com

Partially substituting clinker can reduce up to ~30% of emissions with minor changes to the production process or added costs

Clinker substitution technologies





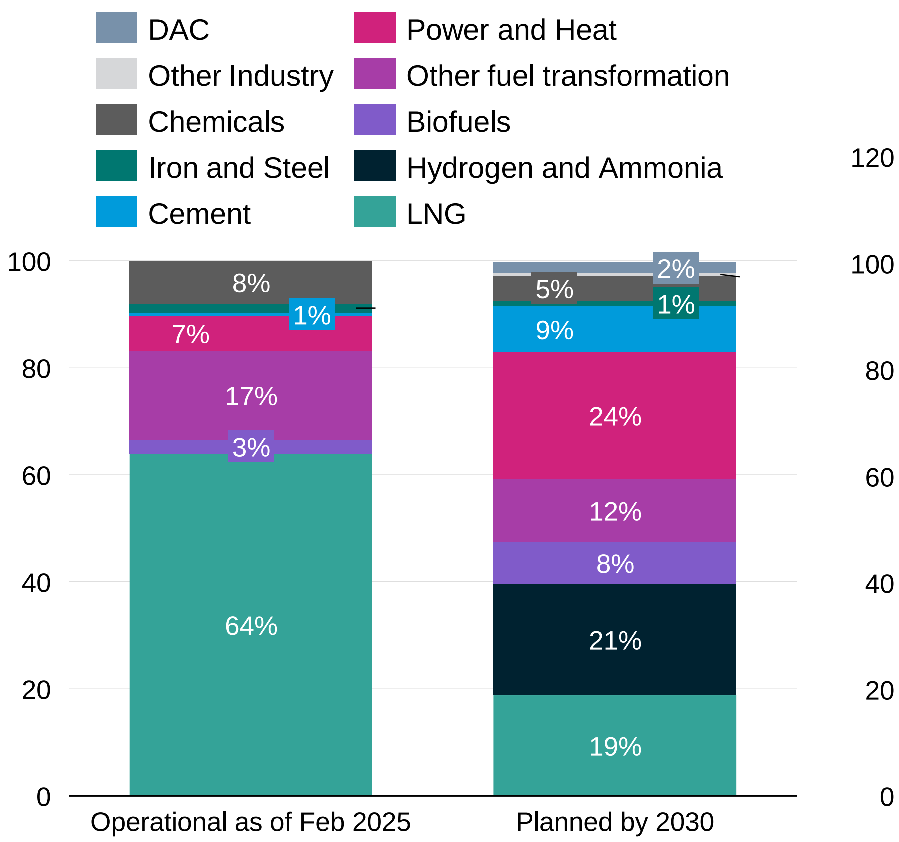
Observations

- **Blended cements** partially substitute clinker with **supplementary cementitious materials (SCMs),** including fly ash, blast furnace slag, silica fume, and pozzolans.
  - Availability of industrial byproducts will decline as these industries decarbonize.
- **Limestone Calcined Clay Cement (LC3)** is a leading blended cement with clinker ratio of 0.5 that combines limestone, calcined clay, and gypsum. Compared to OPC, it has:
  - **40%** less CO_2 emissions
  - **25%** lower overall costs
- Clinker-to-cement ratios vary considerably by region due to the **material availability and local regulations.**
  - China**: ~0.65**
  - Europe: **~0.77**
  - Canada: **~0.86**
  - US: **~0.89**

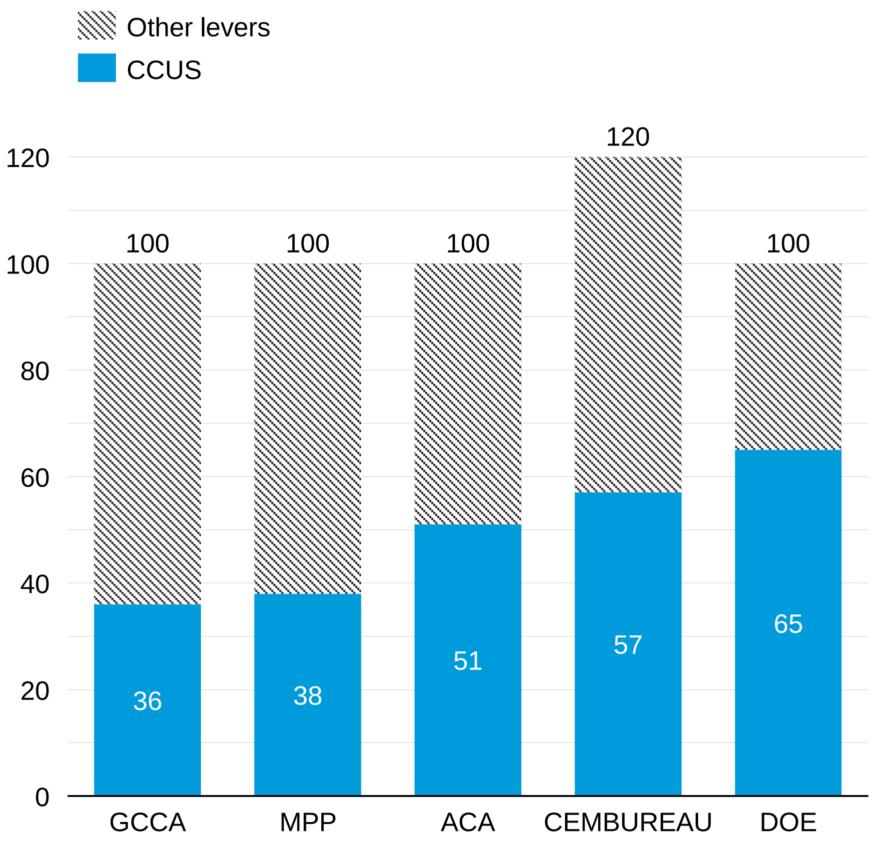
*In some countries, SCM substitution occurs during concrete manufacturing rather than cement manufacturing.
Sources: IEA, Cement (2023); Congressional Research Service, Cement (2023); Heidelberg, 2024 Annual Report (2025); Cemex, 2024 Annual Report (2024); Holcim, 2024 Annual Report (2024); IEA Net Zero by 2050 (2021); RMI, Unleashing the Potential of LC3 (2023).
Credit: Adele Teh, Hoshi Ogawa, Sho Tatsuno, Isabel Hoyos, Jessica Cong, Shailesh Mishra, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Kim *et al*., "Decarbonizing Cement" (2 June 2025).

Carbon capture, utilization, and storage (CCUS) expected to play critical role in reducing hard-to-abate emissions in cement industry

Operational and planned CCUS capacity by industry, %



Cement abatement from CCUS by roadmap, 2050, %



Observations

- The majority of current CCUS operations target **point-source emissions from oil & gas.** However, as the energy industry continues to phase out fossil fuels, CCUS will play **a bigger role in decarbonizing hard-to-abate industries** like cement and steel.
- As of Q1 2025, **global CO_2 capture and storage capacity in operation reached over 50 Mt.** By 2030, capture capacity is expected to reach 430 Mt based on current project pipeline, while storage capacity 670 Mt.
- **Current cement CCUS plants:**
  - **Brevik CCS, Norway (Heidelberg):** First industrial-scale **CCS cement plant.** Designed to capture up to **400k tonnes CO_2 annually.** As of May 2025, the plant captured and stored first 1k tonnes of CO_2.
  - **Lengfurt Cap2U, Germany (Heidelberg & Linde):** First industrial-scale **CCU cement plant.** Designed to capture up to 70k tonnes **CO_2 annually.**

Sources: IEA, Net Zero by 2050 (2021); IEA, CCUS Projects Explorer (2025); IEA, Demand and Supply Measures for the Steel and Cement Transition (2025); International Cement Review (2024); Cement, China Starts CCUS Focus (2023); Heidelberg, Brevik CCS (2025), GCCA, Concrete Future (2021); MPP, Making Net-Zero concrete and Cement Possible (2023); PCA, Roadmap to Carbon Neutrality (2024); DoE Industrial Decarbonization Roadmap (2022); CEMBUREAU, From Ambition to Deployment (2024).

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Demand-side levers key for material efficiency

Levers for concrete decarbonization

	1 Efficiency in design and construction	2 Efficiency in concrete production	3 Recarbonation
Concrete decarbonization lever	• Optimizing use of concrete in construction using material-efficient design and construction (e.g., smart design systems, choice of concrete floor slab geometry, concrete column spacing, optimization of concrete strength)	• Transitioning from small-project site batching of concrete using bagged cement to industrialized processes offers emissions savings because of the adherence to mix specifications and quality control.	• Recarbonation is a natural process of CO_2 uptake by concrete. Concrete reabsorbs a significant amount of CO_2 over its lifetime as a permanent CO_2 sink. • **12 to 23%** of process emissions released during cement production can be absorbed.
Pathway to decarbonization	• CO_2 emissions would need to become a design parameter for construction projects • Can be applied with current standards and regulations	• Transition to industrialized production has been implemented in some countries. • Use of admixtures improved processing of aggregates.	• Would need to facilitate access to concrete demolition waste to enable the industry to maximize CO_2 uptake.
% contribution to achieve net zero in 2050 (GCCA)	22%	11%	6% (recarbonation only)
CO_2 emissions savings in 2050 (GCCA), 3,830 metric tonnes (total)	840 Mt CO_2	430 Mt CO_2	242 Mt CO_2 (decarbonation only)

Observations

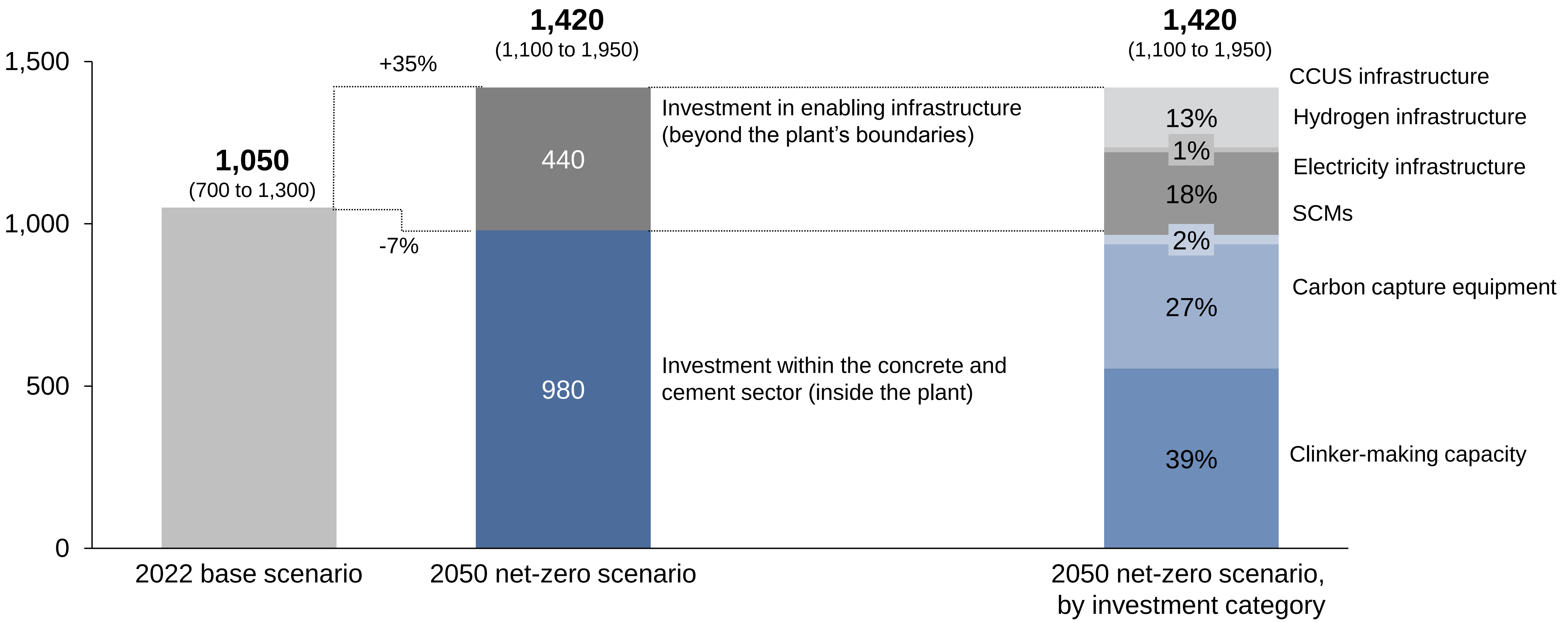
- **Efficiency strategies in design and construction** can be a significant lever to reduce overall consumption of cement.
- **Optimization of concrete production** through a transition to industrialized production can reduce demand for cement.
- **Decarbonation** and improved management of end-of-life materials could offer additional mitigation opportunities for circular concrete.

Sources: Climate Works (2021), GCCA Concrete Future (2021), IVL methodology (2021), Nature Communications (2024)

Credit: Jessica Cong, Isabel Hoyos, Shailesh Mishra, Hyae Ryung Kim, and Gernot Wagner. : Kim *et al*., “Decarbonizing Cement” (2 June 2025).

Delivering a net-zero scenario requires a 35% investment increase against base case

Cumulative investments, 2022-50, Billions of dollars, midpoint



Sources: Mission Possible Partnership (2023).
Credit: Shailesh Mishra, Jessica Cong, Hyae Ryung Kim, and Gernot Wagner. Share with attribution: Kim *et al*., "Decarbonizing Cement" (2 June 2025).