Long-term transformations in national pathways to net zero

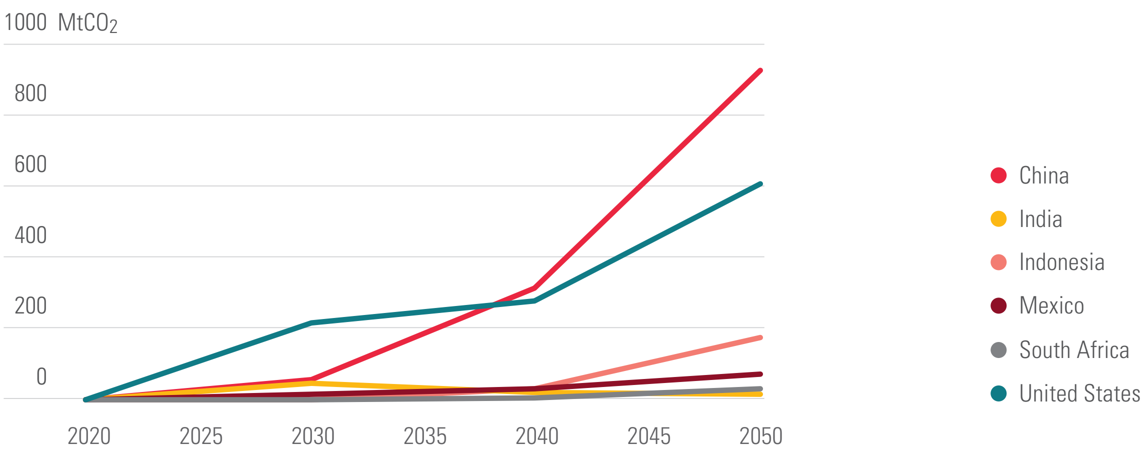
CARBON CAPTURE AND STORAGE

Due to constraints on its potential and challenges affecting the deployment timelines, Carbon Capture and Storage (CCS) will make a limited contribution to cumulative emissions reductions by 2050 across all national pathways to net zero. In some countries, it may be able to serve as a supplementary mitigation strategy around the mid-century to achieve carbon neutrality.

When examined at the country level, it becomes clear that several barriers limit the true potential of Carbon Capture and Storage (CCS). These constraints include geological factors, such as limits to effective national storage capacities or leakage risks related to uncertainties about long-term storage stability; technical factors, such as the energy penalties associated with large-scale sequestration and water use in absorption systems at power plants; spatial characteristics, including the effective localization of emission sources and storage capacity, which can create transport challenges, necessitate significant infrastructure, and lead to negative externalities; and economic considerations, such as the investment costs of capital-intensive infrastructure needed to transport and store carbon, as well as the operational cost resulting from energy penalties. A country-driven assessment of these constraints showed that several of the countries studied identified national pathways to net zero without any reliance on CCS, such as Brazil, Argentina and Nigeria, or assign it a very limited role as is the case for South Africa.

Furthermore, even in countries where constraints would not prevent substantial deployment of CCS, its effective role until 2050 is limited by obstacles that affect the timing of its deployment. As of today, there are very few cost-competitive CCS facilities in operation and they are dedicated to specific uses (e.g. natural gas processing and bioethanol production). The development of commercially viable and mature large-scale applications for the power sector and energy-intensive industries would require significant technical progress through research and development, including prototypes and pilot projects. It would also require massive investment to build the infrastructure needed to capture, transport (potentially internationally, especially as large volumes of carbon are likely to be transported, creating a demand for capital-intensive port installations) and store carbon. These innovations and infrastructure processes are characterized by considerable inertia, which means that, even if CCS is deployed, this CCS deployment will be gradual. This temporal constraint means that, even in countries that envisage the potential for CCS technology, it can only be implemented in most countries after 2040 and would not start to play a significant role until around the mid-century (**Figure 8**). Even in China and the US, which have an earlier deployment of CCS capacities, it mitigates only 22% and 27% of CO_2 emissions from energy and industry by 2050, respectively. Moreover, CCS plays an even smaller role in earlier periods, with only 6% and 13% from energy and industry, respectively, in 2040. CCS is therefore an additional mitigation option to reach carbon neutrality by the mid-century, complementing other solutions that provide more substantial emission reductions, such as LULUCF (see message 1.3).

Figure 8. Annual CO_2 captured and stored ($MtCO_2$)



Given the constraints and challenges discussed above, CCS can play this role around the mid-century only if targeted actions are taken to proactively promote it throughout the period. This is, for example, the underlying assumption behind CSS deployment in the US pathway to net zero (see part Enabling long-term emission reductions - Case study US). In other countries, CCS has an even more limited role or is concentrated on very specific uses, such as in South Africa and Mexico, where CCS targets clearly defined industrial emissions (Case study - CCS in Industry). In some countries, the need to integrate CCS with CO_2 utilization pathways has been highlighted as critical for the long term (cf. Mexico).
This analysis highlights the systemic consequences of the limits and delays in CCS deployment on mitigation strategies across different timeframes, as well as its indirect feedback effect on the overall role of CCS in national pathways to net zero. These constraints necessitate significant efforts to reduce emissions through other mitigation actions in the first decades, particularly by accelerating the reduction of fossil fuel use (cf. message 1.2). This in turn leads to a diminished role for CCS when it becomes available, around the mid-century.

As a result, CCS could play only a very limited role in reducing cumulative emissions up to 2050 within national pathways to net zero (**Figure 9**).

CASE STUDIES

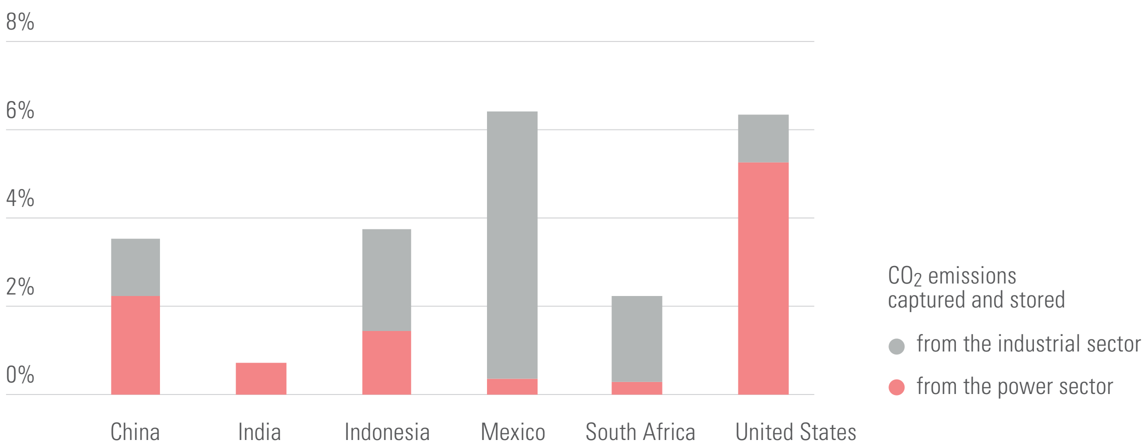
CCS in industry

South Africa

South Africa's underground storage capacity is primarily located offshore, at least 600km from the regions with the highest CO_2 emissions activity, namely the central and eastern provinces of Gauteng and Mpumalanga. The assessment of the capacities of potential geological storage formations, their injectivity, the localization of CO_2 sources and of all necessary infrastructures, along with the related total cost estimates, all derive from World Bank (2017)[20].
Based on these cost estimates, our modelling showed that CCS will only be necessary for specific industrial uses and processes that are difficult to decarbonize. CCS will be deployed from 2040 and will increase by 2050, with the cement industry needing approximately 15Mt of CO_2 capture, ferroalloys and iron and steel requiring around 9Mt of CO_2 capture, and gas power plants needing around 5Mt of CO_2 storage by 2050. CCS capacities can also be considered, albeit to a very limited extent, for gas power plants that continue to operate at a minimum level due to the intermittency of renewable energy production.

20 https://documents1.worldbank.org/curated/en/247631518158856551/pdf/123200-JRN-PUBLIC-World-Bank-CCS-Program.pdf

Figure 9. Share of CO_2 emissions captured and stored over total 2020-50 cumulated energy & industrial CO_2 emissions



Mexico

Mexico's decarbonization scenario plans to roll out Carbon Capture, Utilization and Storage (CCUS) over the 2030-2050 timescale, primarily targeting emissions from the cement industry, which are expected to grow alongside continued economic development. By 2050, it is predicted that 71 Mt of CO_2 will be captured, 90% of which originating from the industrial sector.

Although the current status of CCUS technologies – both post-combustion and from chemical processes – require further development to achieve widespread availability and affordability, the production of clinker in cement manufacture produces a high-purity CO_2 stream, making its capture technically easier and more cost-effective than post-combustion CCUS, which is often considered for applications such as power generation.

Prioritizing CCUS for the cement industry within Mexico's industrial policy can help drive a faster and more effective adoption of CCUS compared to alternative approaches. Furthermore, Mexico has sufficient renewable resources to transition its power generation away from fossil fuels, making this the primary strategy for electricity decarbonization.

CCUS should be feasible in Mexico as soon as the technology becomes competitive and reliable. The cement industry can provide predictable volumes of easy-to-capture CO_2, while depleted oil fields can provide reliable geological storage. Existing pipelines may facilitate transport, and potential applications could include enhanced oil recovery in the short to medium term, as well as the production of synthetic hydrocarbons in the medium to long term.

Pursuing synthetic hydrocarbon production can provide decarbonized fuels for aviation and freight, and it should be developed in conjunction with a green hydrogen strategy to ensure that the whole value chain for these fuels remains low-carbon. This highlights the clear synergies in developing CCUS and green hydrogen simultaneously. Achieving these goals will require the development of carbon-focused chemical industries, which should be established urgently to create and pilot practical options, enabling technologies to mature and be rolled out at scale in time to facilitate deep decarbonization by 2050 (as discussed in part 2.1).