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Oil & Gas Practice

The world needs to capture, use, and store gigatons of CO_2: Where and how?

Strategically building carbon capture, utilization, and storage hubs near clusters of large emitters can lower costs and accelerate scale-up.

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April 2023

Countries and companies around the globe are committing to net zero by 2050. One suite of technologies—collectively called carbon capture, utilization, and storage (CCUS)—offers solutions for many hard-to-abate sectors such as aviation, cement, and hydrogen production from fossil fuels. However, global CCUS uptake needs to expand 120 times from current levels by 2050, rising to at least 4.2 gigatons per annum (GTPA) of CO_2 captured, for countries to achieve their net-zero commitments.[1]

There are two routes for captured CO^2: permanent storage (CCS) or utilization by converting into products (CCU). The potential for CCUS is highly dependent on factors including the emissions source, industry, capture technology, transportation, as well as location and type of storage. Thousands of CO_2 point source facilities exist that could be suited to carbon capture and storage (CCS), with varying concentrations of CO^2 in the flue gas and differing proximity to storage sites, which can affect the viability for CCS for these facilities. Future emission sources may exist near facilities that use captured CO^2 to create products such as fuels, chemicals, and building materials, and near oil and gas wells where they can be used for enhanced oil and gas recovery (EOR/EGR). Utilization has the added benefit over CCS of generating revenue to offset the cost of capture and transport.

However, many, if not most, CCUS projects are economically challenged today, with high costs of capture for dilute point sources and a limited number of revenue streams available.[2] For CCUS to reach levels needed to achieve net-zero commitments, lowering costs may be vital. Developing cross-industry hubs that share CCUS infrastructure and resources across multiple companies could reduce the risks associated with the upfront investment capital that individual emitters may be unable to burden alone.

This article explores potential CCUS hubs, five emerging hub archetypes, and three key steps to accelerate the development of CCUS hubs.

Creating CCUS hubs can accelerate development

A CCUS hub is a cluster of emission facilities that share the same CO_2 transportation and storage or utilization infrastructure. There have been several recent government funding calls for hub developments in Canada, Europe, and the United States to address industrial emissions and accelerate the development of both carbon-removal technology and infrastructure.[3] There are approximately 15 CCUS hubs globally under various stages of development, with many more being planned.[4]

In the United States, CCUS has recently been boosted by the Inflation Reduction Act, which offers an increased tax credit for captured point source CO_2 from $50 to $85 per ton.[5] Many industrial use cases such as ammonia production, ethanol plants, and natural gas processing facilities are now economically "in the money" in the United States with the increased 45Q tax subsidy.[6] This subsidy provides $85 per ton for sequestered industrial or power emissions, and $180 per ton for emissions captured directly from the atmosphere and sequestered.

Shared transportation, utilization, or storage infrastructure could lower costs, increase savings through economies-of-scale, provide additional options for managing or sharing risks, and strengthen regional visibility for support by governmental entities. Hubs may, however, bring companies together from different sectors that do not normally work together, which can introduce project complexity as there are multiple collaborators across different industries, all with different timelines and objectives.

We developed a macro-model to assess the viability of future CCUS hubs (see sidebar, "Our methodology"). This model considers a range of factors, including point source industries and purity of the emissions streams (which determines their potential for utilization or storage, or both), the

[1] "Scaling the CCUS industry to achieve net-zero emissions," McKinsey, October 28, 2022.
[2] Ibid.
[3] "Safely reducing emissions in the industrial heartland," Government of Alberta, March 31, 2022; "Integration of CCUS in hubs and clusters, including knowledge sharing activities," European Commission, April 8, 2022; "Notice of Intent No.: DE-FOA-0002746," US Department of Energy, May 13, 2022.
[4] McKinsey Energy Insights Global Emissions and Storage Database; McKinsey analysis.
[5] Alejandro de la Garza, "The Inflation Reduction Act includes a bonanza for the carbon capture industry," *Time*, August 11, 2022.
[6] Matt Bright, "The Inflation Reduction Act creates a whole new market for carbon capture," Clean Air Task Force, August 22, 2022.

Our methodology

We developed a perspective on optimal locations for CCUS hubs that match global storage potential with CO_2-emitting facilities across countries. Our cross-industry global database of CO_2 point source emissions spans 11 sectors, covers over 25,000 individual facilities, and accounts for 19.5 gigatons (GT) of CO_2 emitted per year. Analysis of this data allowed us to identify potential locations for approximately 700 CCUS hubs globally.

The analysis is based on an optimized view with direct links between the CO_2 source and the closest sink location with enough storage capacity. Actual storage and access will depend on geological assessments and geographical or political boundaries (for example, mountains and cities) and drilling feasibility, among others. This model does not explicitly account for external drivers such as local regulations and cross-border limitations.

Our global database of potential CO_2 storage reservoirs consolidates over 1,100 saline aquifers and 16,000 oil and gas fields, representing up to 20,000 GT of global capacity. Utilization of all this capacity could represent over 700 years' worth of global annual emissions at today's emissions rate. Utilization opportunities, apart from EOR/EGR, were not considered explicitly in the model, which could lead to an underestimation of overall CCUS potential. According to McKinsey analysis, utilization is projected to account for approximately 5 percent of the captured CO_2 volume in 2050, compared to approximately 95 percent for storage. Further, the model did not account for transport and storage savings in hubs that focus on utilization rather than storage, which may lead to more conservative results for emissions savings in the different cost buckets.

physical proximity of the emitters to potential storage sites, and the potential for shared infrastructure costs, operating costs, and other commercial synergies within a cluster.

Our analysis suggests that approximately 700 CCUS hubs could be established globally. Most of these hubs are located on, or close to, potential storage locations and EOR/EGR sites, with more than 60 percent located within 50 miles from potential storage sites (Exhibit 1). East Asia could become a hub hotspot since the region's high emission volume could be covered by its high storage capacity (Exhibit 2).

For each potential hub consisting of five nearby emitters or more, we have calculated a total carbon-abatement cost, which includes the cost of capture, compression, transportation, and storage. Additional variable costs such as financing, vendor margins, and contingency are project specific and not included here, but need to be factored in to understand real-world cost of abatement.

Capture costs are typically the largest cost in the CCUS value chain and vary considerably between technologies and industries.[7] One of the key factors here is the concentration of CO_2 in the emissions stream. High concentration streams, such as those from ethanol and ammonia processes, where CO_2 is 50 to 90 percent of the emissions, are the cheapest to capture.[8] However, such sources represent less than 5 percent of the worldwide emissions volume. Low-concentration sources, such as power generation, cement, and petrochemical production, with CO_2 concentrations in emissions streams of between 5 and 15 percent, represent the greatest share of emissions and are also the costliest to capture.[9]

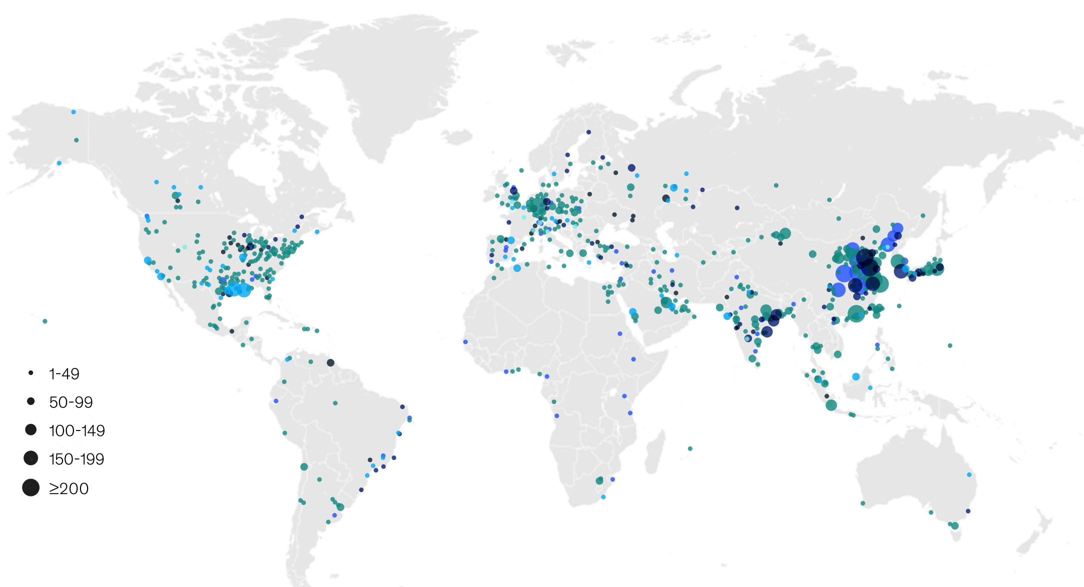
[7] Adam Baylin-Stern and Niels Berghout, "Is carbon capture too expensive?" IEA, February 27, 2021.
[8] Ibid.
[9] Ibid.

Exhibit 1

There is a potential to establish approximately 700 CCUS hubs globally, most of which are located on, or close to, potential storage locations.

Emissions | Storage capacity

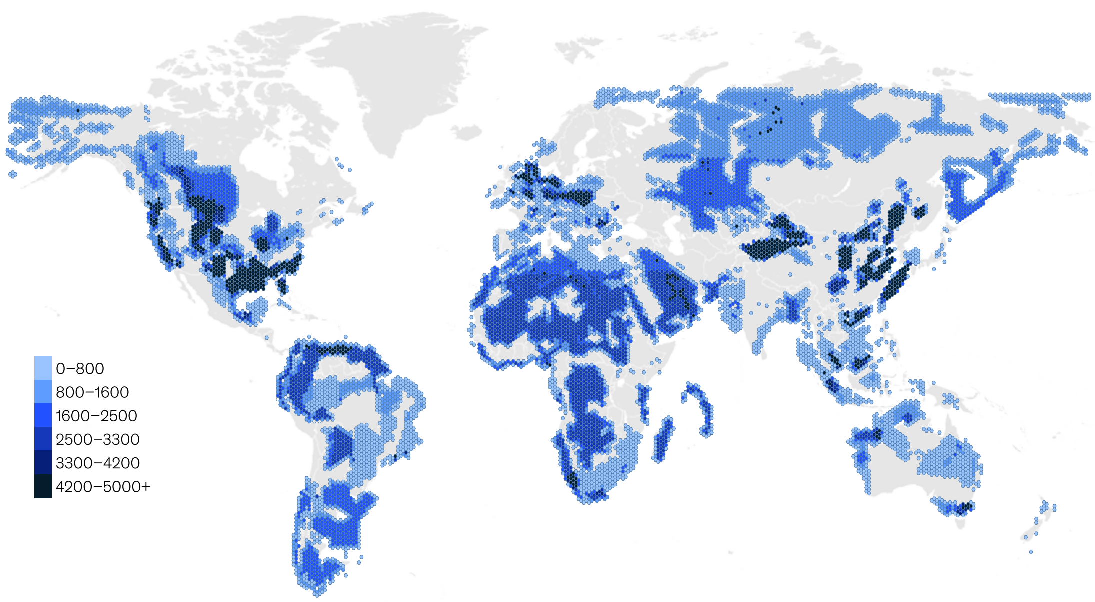
Map of global emission hubs, CO_2 emission, Mt



Disclaimer: The boundaries and names shown on maps do not imply official endorsement or acceptance by McKinsey & Company.
Source: McKinsey Energy Insights Global Emission and Storage Database, Energy Insights Carbon Hub Explorer

Emissions | Storage capacity

Map of potential sink locations, CO_2 storage capacity, Mt



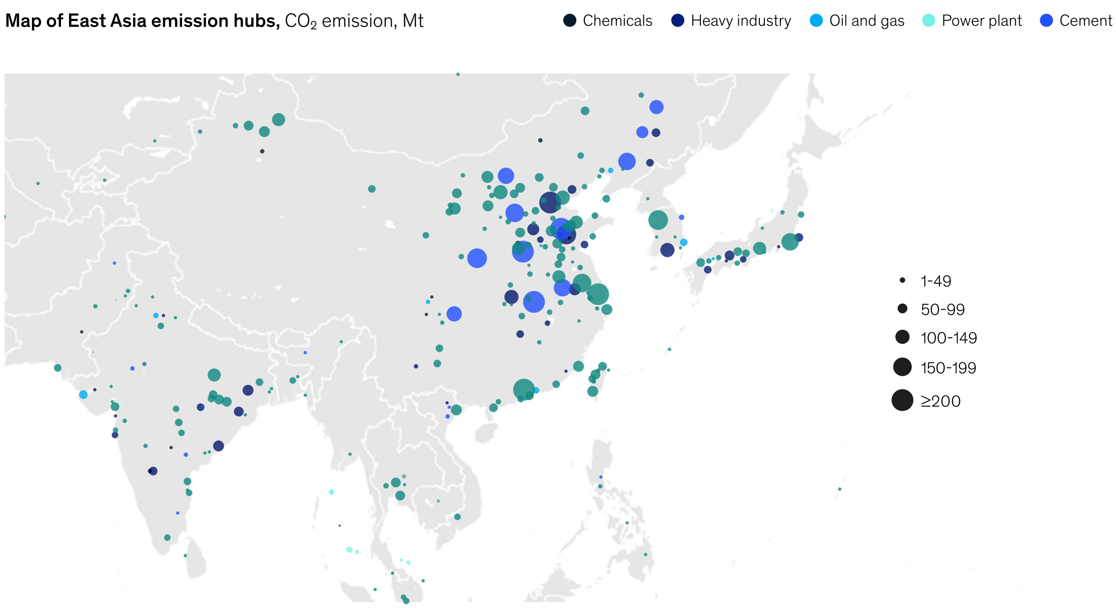
Disclaimer: The boundaries and names shown on maps do not imply official endorsement or acceptance by McKinsey & Company.
Source: McKinsey Energy Insights Global Emission and Storage Database, Energy Insights Carbon Hub Explorer

Exhibit 2

East Asia could become a hub hotspot, as the region’s high emissions could be covered by its high storage capacity.

Emissions | Storage capacity

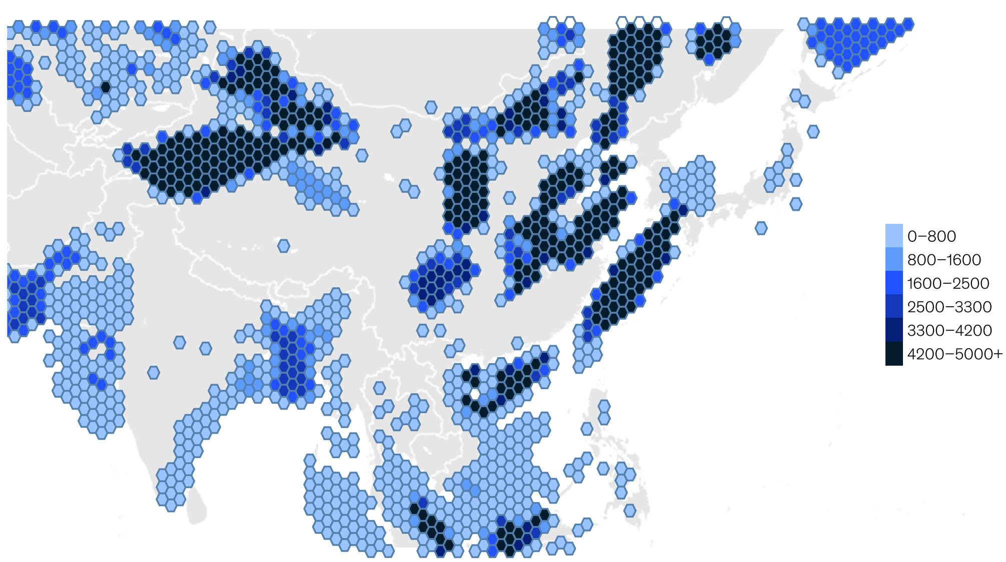
Map of East Asia emission hubs, CO_2 emission, Mt



Disclaimer: The boundaries and names shown on maps do not imply official endorsement or acceptance by McKinsey & Company.
Source: McKinsey Energy Insights Global Emission and Storage Database, Energy Insights Carbon Hub Explorer

Emissions | **Storage capacity**

Map of potential East Asia sink locations, CO_2 storage capacity, Mt



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Source: McKinsey Energy Insights Global Emission and Storage Database, Energy Insights Carbon Hub Explorer

As compression is a mature and well-established process, this cost element is typically well-understood and less variable between operations. Transportation cost is highly dependent on proximity to storage sites, transport mode, terrain, and whether sites are located on land or offshore. Finally, storage cost is dependent on the type of storage used (onshore, offshore, reservoir, geologic, etcetera).

The resulting emission-abatement cost curve shows that if 440 hubs are developed, 9 GTPA to 10 GTPA of existing emissions could be abated at a cost of less than $100 per ton CO_2 (Exhibit 3). Furthermore, the world could reach its 4.2 GTPA net-zero goal by 2050 through the development of approximately 160 CCUS hubs at costs of less than $85 per ton CO_2.

While the total addressable CO_2 abatement from CCUS is based on clusters of emission point sources, we should note that much of the decarbonization may come from other levers (for example, increased energy efficiency, fuel switching, or electrification) prior to CCUS being adopted. Some of the high-emitting facilities included in the model may be nearing their end of life and will simply be decommissioned, or there is a potential for disruptive new technologies to decarbonize their supply chain, such as electric arc furnaces for steel production. In many situations and use cases, CCUS serves as a backstop for emissions that are difficult or impossible to decarbonize using other means.

Five emerging hub archetypes

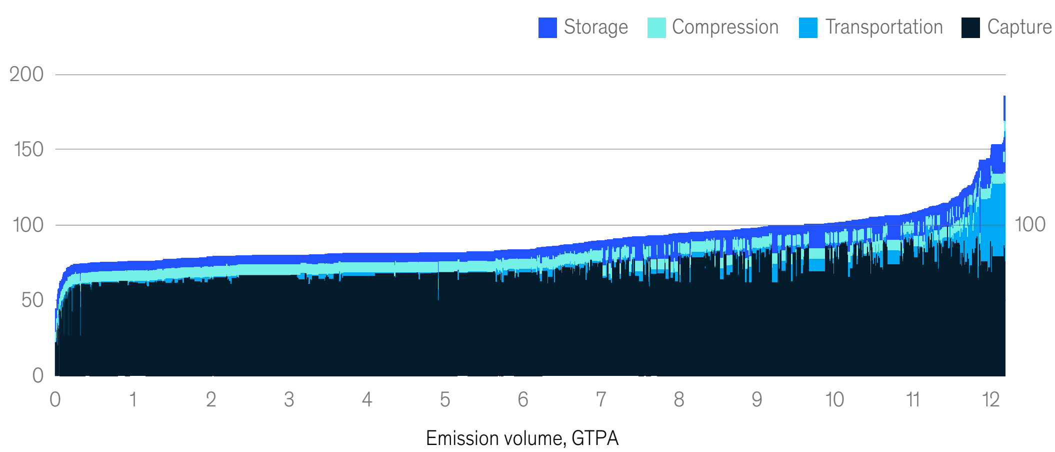
Five hub archetypes sharing common features across regions and sectors emerge when the industrial make-up of an emissions cluster drives the formation of these hubs. These archetypes each have unique characteristics that will likely shape their business case, operating model, governance, and potential impact.

1. *Large emitter-dominated hub*s are characterized by the presence of multiple emission point sources greater than 1 million tons per annum (MTPA). Sometimes these

Exhibit 3

With the development of 440 hubs, 9–10 GTPA of existing emissions could be abated at a cost of less than $100 per ton CO_2.

Global CO_2 emission-abatement cost curves across selected CCUS hubs,[1] $/tons



[1]Based on current emission profiles; assumes midpoints of cost estimates across capture and storage, excludes hubs or facilities with CCS cost above $200/ton; based on an optimized view with approximately 50 percent additional transportation cost to account for actual pipeline routes; actual storage (and access) will depend on geology, and geographical and political boundaries (such as mountains, cities, regulations, and drilling feasibility). Does not include cost of financing, project execution, or margins from vendors. Selected hubs based on emission size of more than 1 MTPA and facility count no less than five.
Source: McKinsey Energy Insights Global Emission and Storage Database; McKinsey Energy Insights Carbon Hub Explorer

facilities may be so large that they require their own dedicated CCUS infrastructure and can afford the capital expenditures to deploy CCUS. They may still be open to partnering with other smaller emitters to create a hub. These facilities are primarily power plants, but may also be large iron, steel, or cement facilities. Point sources are typically lower purity with higher costs, making them better suited to storage than utilization, but lower project complexity due to the reduced number of players may lead to faster execution. Smaller emitters that would not be able to afford the build-out of CCUS infrastructure may benefit from proximity to a large emitter as a bolt-on. While there are large CCUS facilities in operation today, there have yet to be hubs that have formed around existing infrastructure.

2. *Cross-industry hubs* are built around industrial parks with a mixture of high and low-emission facilities with varying costs across different sectors and industries (for example, a cement facility located near an ammonia production plant and a refinery). These industry-balanced hubs are typically centered around common CCUS infrastructure, such as a transport pipeline that collects CO_2 from various sources. A combination of utilization and storage may work at such hubs, with different purity streams used for different purposes. Cross-sectoral collaboration between industries not accustomed to working together may lead to higher project complexity. An example of a cross-industry hub is the Alberta Carbon Trunk Line (ACTL), which captures CO_2 emissions from an oil refinery and fertilizer facility that shares a pipeline to storage for EOR. The ACTL was designed with a larger capacity to accommodate future emitters.

3. *Storage-led hubs* are strategically located near ports for shipping or near geological storage to reduce the need for onshore and offshore pipeline transportation. Creating hubs that are located close to storage can reduce costly transportation infrastructure. In locations where onshore geological storage may be limited due to regulation or public acceptance, such as in Europe, offshore storage-led hubs are more likely to emerge. An example of a storage-led hub is the Porthos CCUS project, which captures CO_2 emissions from facilities in the Port of Rotterdam and then stores them in gas fields under the North Sea.

4. *Smaller, higher-purity emitter hubs* consist of a higher number of facilities with relatively high-purity CO_2 streams (such as ethanol production plants) and therefore typically lower capture costs. However, aggregation across multiple facilities is required to achieve economies of scale and share the capital burden to build transport, storage, and utilization infrastructure. Such hubs may be better suited to utilization than storage, to take advantage of high-quality streams of CO_2. Due to the larger number of smaller facilities, there is likely to be increased project complexity, which may slow progress or complicate operations. An example of a smaller, higher-purity emitter hub is the CCUS pipeline network in the Midwest that will capture emissions from ethanol biorefineries and is being developed by companies like Summit Carbon Solutions, Navigator, Wolf Carbon Solutions, and ADM.

5. *Carbon-removal-led hubs* are built around direct air capture (DAC) or bioenergy carbon capture and storage facilities. Since a DAC facility could theoretically be deployed directly around carbon removal-driven hubs, and could also overlap with a storage-driven hub, the infrastructure built for carbon-removal technology (such as pipelines, CO_2 compression, and monitoring and measurement subsurface technologies) could be shared by other nearby emitters. The CO_2 captured from the atmosphere by these hubs is also well suited for utilization to produce synfuels such as sustainable aviation fuels. The US Department of Energy's Office of Clean Energy Demonstration announced $2.5 billion for the development of regional DAC hubs, with

applications due in March 2023.[10] An example of carbon-removal-led hubs is the recent announcement from Occidental Petroleum and King Ranch to remove and store up to 30 MTPA of CO_2 using DAC.[11]

Large emitter-dominated hubs may have improved deployment speed due to organizational simplicity with one dominant stakeholder. However, cross-industry or storage-led hubs may be more resilient as the success of the hub is diversified across multiple organizations and the fate of the entire hub is not dependent on one facility. Hubs that have some form of utilization may also emerge faster than those focused on storage alone, as utilization provides a stream of revenue to offset the costs.

Ultimately, proximity to storage, availability of renewable energy for powering carbon removals, opportunities for utilization, and willingness of parties to cooperate will likely drive the business cases for the formation of many of these hubs. Integration with other emerging climate technologies, such as hydrogen production and sustainable aviation fuels, may also drive adoption.

How can we accelerate the development of CCUS hubs?

Our recent research shows that an annual global investment in CCUS technology of $120 billion to $150 billion by 2035 is required to achieve net zero.[12] To scale CCUS effectively, greater coordination across the value chain may be needed. The following three key actions could speed up CCUS-hub development worldwide:

1. **Identify no-regrets activation projects within regions that are feasible under existing economic conditions and around which hubs can begin to form**. Building hubs around high-purity sources with lower CO_2 capture costs may allow for quicker learning that can be applied to larger-scale sources of CO_2 emissions that are more expensive to capture. These initial hubs can be designed to accommodate modularity and flexibility for expansion to take advantage of potential future economies of scale or cost compression from technological advances.

2. **Build market mechanisms to ensure value and risk are apportioned appropriately across the hub.** It is important to understand the value and risk across capture, transportation, storage, and utilization in different regions and situations. Sharing learnings and best practices from the development of hubs can facilitate risk sharing, improve safety, standardize storage monitoring, and ensure governance and business models follow best practices. Creating standards around the capture, utilization, monitoring, and measurement of CO_2, and end-of-life liability management, could give investors confidence in capitalizing on CCUS hubs.

3. **Design hub networks to be resilient and adaptable to change.** Developing a CCUS hub is a multistep process that can require significant collaboration between industry players that are often not accustomed to working together. The network between capture and storage may need to be carefully designed. For example, a hub may choose a trunk line model that aggregates many emissions into one pipeline with one storage location, or it may choose a network approach with multiple sequestration and transportation options and flexibility across sinks and sources.

Carbon capture, utilization, and storage offers a way to reduce the emissions of our existing

[10] "Biden-Harris Administration announces $2.5 billion to cut pollution and deliver economic benefits to communities across the nation," US Department of Energy, February 23, 2023.
[11] "Occidental and 1PointFive, King Ranch reach lease agreement to support up to 30 direct air capture plants on leased acreage," Oxy, October 31, 2022.
[12] "Scaling the CCUS industry to achieve net-zero emissions," McKinsey, October 28, 2022; *Global Energy Perspective 2022*, McKinsey, April 26, 2022; McKinsey Energy Insights.

infrastructure, especially for hard-to-abate sectors, while we continue to improve renewables and electrification. By working together, pooling resources, and sharing critical infrastructure, CCUS hubs could lower the costs associated with capturing, transporting, utilizing, and storing CO_2. Considerable volumes of CO_2 remain to be captured, and we can accomplish significantly more by working together than laboring alone.

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The authors wish to thank Krysta Biniek, Alastair Hamilton, and Clint Wood for their contributions to this article.