

Scaling the CCUS industry to achieve net-zero emissions

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Carbon capture, utilization, and storage can help hard-to-abate industries achieve net-zero emissions. Scaling the industry will require action by governments, investors, and industrial players.

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Over the past 30 years, many industry experts have predicted that [carbon capture, utilization, and storage \(CCUS\) technologies](#) would be required to decarbonize industries such as energy, chemicals, cement, and steel production, yet the CCUS industry has struggled to find its footing. Today, however, the nationally determined contributions (NDC)^[1] of governments and

corresponding industry commitments, technological innovations, and demand for green consumer products have made scaling CCUS not only possible but necessary.

To meet their emissions reduction commitments, governments have begun enacting policies to support the development of CCUS. For example, the recent Inflation Reduction Act (IRA) in the United States includes an enhanced tax credit for the permanent sequestration of CO₂, which could rapidly boost adoption and help scale CCUS facilities.^[2]

According to McKinsey analysis, CCUS uptake needs to grow 120 times by 2050 for countries to achieve their net-zero commitments^[3], reaching at least 4.2 gigatons^[4] per annum (GTPA) of CO₂ captured, with some estimates ranging from 6.0 to 10.0 GTPA. This could lead to CCUS decarbonizing 45 percent of remaining emissions in the industry sector. Even in conservative scenarios, CCUS demand would reach approximately two GTPA by 2050—a 60-fold increase over today’s pipeline of projects.

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CCUS is recognized as a necessary and relatively low-risk piece of the decarbonization puzzle, but the technology is not moving fast enough to achieve a 1.5° or even 2.0° pathway. This article explains

what the CCUS industry can do to overcome historical challenges and reach the scale required for net-zero emissions. Specifically, we map how the industry can generate revenues and move beyond a subsidy-only business model, and we discuss what governments, investors, and industry players can do to help scale the technology. Future articles will discuss other scaling requirements, such as lowering the costs of implementing CCUS and developing hubs and clusters.

An overview of CCUS: Will it finally arrive?

There are three main types of technological carbon capture today (with many more in development): industrial-point-source CCUS, direct air capture (DAC), and bioenergy with carbon capture and storage (BECCS). Industrial-point-source capture is most important for short- and midterm decarbonization because the technology is ready today and has the potential to capture large volumes of CO₂ emissions from hard-to-abate industries that have few other decarbonization options. Predicated on achieving significant cost reductions, DAC has the potential to unleash decentralized carbon removals at scale in combination with a multitude of revenue-producing technologies from sustainable aviation fuel (SAF) to hydrogen production. BECCS will be critical as the net-zero transition progresses, particularly as attention further shifts to scaling carbon removal from the atmosphere and nature-based solutions reach their

capacity.

That said, several challenges must be overcome before industrial-point-source CCUS can reach scale, especially around policy and regulatory support, cost, and public acceptance. Based on the current CCUS project pipeline, approximately 110 million tons per annum (MTPA) of CO₂ are expected to be captured annually by 2030. To achieve the net-zero commitments pledged by 64 governments at COP26, approximately 715 MTPA are required by 2030 and 4,200 MTPA by 2050.^[5]

Our research shows that more than 25,000 global industrial CO₂ emitters across 11 industrial sectors could be decarbonized through CCUS. These facilities are distributed all over the world, with China, Europe, India, and the United States accounting for more than 60 percent of industrial-point-source emissions. The highly distributed nature of emissions means that these challenges will be solved not through the formation of a small number of decarbonization hubs but by deploying capital at scale across a large number of projects around the world.

Doing so, however, requires tackling the following underlying challenges:

- *Policy is uneven and uncertain.* CCUS projects are generally still first-of-a-kind and therefore unproven, not because the technology is unknown but because the various components have not yet been combined repeatedly at scale. As a result, the policy to enable these projects is complex and still evolving. It requires a blend of

direct incentives (such as support for shared infrastructure), indirect incentives (such as carbon prices or voluntary markets), regulatory enablement (such as permitting), and risk management (such as monopoly, offtaker, or subsurface risk assumption). The current policy landscape is quite varied and, in many instances, is in the process of being actively shaped.

- *Revenue streams are not well established, making business cases challenging.* Building on the previous point, most business cases for CCUS currently rely on specific policy enablement. Without that, it is difficult to make economical business cases. Nonsubsidy revenues, which will be critical to scaling the industry, are currently immature. Given estimates that scaling the CCUS industry will require \$130 billion per year from now until 2050,^[6] it is unlikely that governments would be either willing or able to cover all costs (exhibit). To put things into perspective, the required investment by 2050 is on par with global liquefied natural gas (LNG) (\$120 billion per year), electric-vehicle (EV) charging (\$140 billion per year), and hydrogen (\$140 billion per year), according to McKinsey analysis. Companies have been willing to develop plans but are hesitant to commit capital without regulatory certainty, which has led to cautious approaches to spending on project development beyond feasibility studies. That said, CO₂ prices (whether as a mandate or from companies internalizing a price) can determine that a product equipped with CCUS, such as cement, becomes cost competitive with its high-emitting equivalent.
- *Projects are large and unproven.* CCUS projects take a long time to

stand up, and there have been many early failures. According to one study, 263 CCUS projects with the ability to process at least one ton of CO₂ per day were undertaken from 1995 to 2018. Of those with a project size greater than 0.3 MT CO₂ per year, or about half the sample size, 78 percent have been canceled or put on hold. [7] Essentially, every CCUS project to date has been unique, creating all the delivery challenges of first-of-a-kind projects, but they are also commercially fragile, making success all the harder to achieve.

- *Cost benefits of scaled projects come with coordination complexity.* Carbon capture through CCUS-anchored industrial hubs is only effective at scale if all components of the value chain are developed in a synchronized way. For instance, capture projects need transportation and storage networks or end users of CO₂ to come online to meet the export demand. As a result, these projects require collaboration between partner organizations that typically aren't used to working together. They often have different corporate decarbonization objectives or timelines, asset life cycles, investment hurdles and requirements, and tolerances for sharing risk across projects (for example, delivering the various parts of a project or comingling CO₂ streams in shared sequestration infrastructure). When compounding different business models—as well as the desire to build real options and phases of projects that come online at different times—making decisions on shared infrastructure build-out options can be quite challenging.
- *Controversial public perception.* Although serious analyses and

pathways to achieve net-zero commitments by 2050 require CCUS as a solution, many still see CCUS as enabling the continuation of the fossil-fuel industry and do not perceive it as a “clean” technology in the way that they see renewable power or EVs, for example. In this sense, companies and governments have not been effective in highlighting the necessity and benefits of CCUS technologies or clearly articulating guidelines for where CCUS should (and should not) be deployed. In some quarters this has led to public hostility, making development more challenging, especially in projects that require initial public subsidies to build and operate.

Exhibit

Despite these historical challenges, there is good reason to believe that the current push will be different. The NDC commitments made late last year at COP26 in Glasgow, which brought net-zero coverage of global emissions to more than 90 percent, provide a clear basis for governments to get serious about regulatory enablement of the industry.^[8] And some early clusters in Canada, Europe, and the United States are showing how to overcome the complexity of projects.

New investments will depend on

four future revenue streams

Although CCUS is currently seeing significant innovation, especially in the capture stage, it is unlikely in the short to medium term that costs will come down across the value chain as they did with technologies such as electrolyzers for hydrogen. Many CCUS technologies, such as compression and pipelines, are already mature, while others rely on bespoke brownfield projects that can be difficult to standardize. This means revenues will need to balance out business cases. Such revenues fall into four categories, and each will likely need to grow significantly to make the CCUS industry viable.

Subsidies and regulatory interventions

Tax credits, direct subsidies, and price support mechanisms are already beginning to encourage investment in CCUS. For example, the 45Q tax credit in the United States provides a fixed payment per ton of captured carbon dioxide sequestered or used.^[9] The IRA has provided a significant boost to 45Q by increasing the amount of the credit from \$50 to \$85 a ton for sequestered industrial or power emissions, and from \$50 to \$180 a ton for emissions captured from the atmosphere and sequestered. The IRA also makes the credit easier to claim by lowering capture volume requirements, implementing direct pay for a period of five years, and enabling the credit to be transferred to other parties.^[10] However, tax credits such

as 45Q largely benefit established revenue-generating companies with significant tax burdens to reduce, but pre-revenue start-ups and innovators with limited tax burdens benefit less. Although the previous 45Q credit spurred development of projects with a low cost to capture such as in ethanol, the enhanced 45Q is expected to support development in higher-cost sectors, such as cement and steel. The IRA has often been compared to the solar incentive from ten years ago, but the capital expenditure requirements and build time are an order of magnitude larger for CCUS, limiting speed and economies of scale that solar manufacturing, for example, could rely on to bring down costs.

In the European Union, the EU Emissions Trading System (ETS) is the world's largest greenhouse-gas (GHG) emissions trading scheme, covering emissions from around 10,000 manufacturing facilities and installations in the power sector. Overall, the EU ETS covers approximately 40 percent of the European Union's GHG emissions.^[11] Low-carbon fuel standards (LCFS) such as those in California create a market-priced incentive for approved pathways that lower the carbon intensity of fuels. In many developed countries, including Canada, the European Union, the United Kingdom, and the United States, direct grants are being awarded to support carbon prices between emitters and transportation and storage, a move that should enable at-scale deployment of CCUS by the end of the decade.

But these direct-pricing, price-support, and market-making strategies are not the only ways regulators can stimulate the industry. Equally important are tools such as product standards—for example,

mandating certain volumes of green commodities, including steel or cement, in public or private construction projects or structuring markets to protect more expensive, CCUS-enabled products. On this point, the European Union's carbon border tax will also go into effect in 2026, effectively charging importers and non-EU manufacturers for the carbon emissions that stem from their goods or materials sold in the European Union.^[12] This is designed to level the playing field between decarbonized products produced in the European Union and higher-carbon (and potentially lower-cost) imports.

Regulatory backstops are also important tools in stimulating the CCUS industry. For example, the decision in the United Kingdom to phase out unabated gas power by 2035 effectively forces gas providers to switch to hydrogen or install CCUS to continue to deploy flexible power to balance renewables. Canada has also committed to a cap on emissions from the oil and gas sector, without capping production.

Importantly, these regulatory measures can have effects far beyond the internal markets they are set to cover. For example, steel offtakers for plants outside the European Union will have incentives to invest in CCUS and other decarbonization technologies if it results in better market access or lower tariff barriers, meaning plants could invest in the technology without local regulatory regimes. This is likely to be observed in products such as steel and hydrogen (particularly lower-carbon "blue" hydrogen from the Middle East).

Willingness to pay for lower-carbon-intensity products

Many companies believe businesses and consumers are willing to pay premium prices for green products, whether a car that has a net-zero bill of materials, a cleaning product packaged in net-zero plastic, or houses or apartments constructed with zero-carbon cement. In fact, a recent survey shows UK consumers could be willing to pay up to 100 percent more for zero-carbon plastic bottles.^[13] This willingness to cover extra costs is translating into real prices. Today, recycled polyethylene terephthalate (rPET) trades at a 10 to 20 percent price premium, and similar stories hold true for other sectors. For example, several automakers have signed deals with steelmakers to procure green steel.^[14]

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Green premiums are likely to be highest for zero- or near-zero-carbon products, making CCUS-enabled premiums particularly promising in sectors such as cement, where CCUS is the leading option for deep decarbonization. The key user of cement, the construction industry, is under significant pressure to go green in response to new policies, such as France’s RE2020.^[15] In addition,

market studies show substantial willingness to pay for various types of green homes, including energy efficient, low-carbon energy, and zero energy. One recent study found that LEED-certified Class A urban office sales generated a 25.3 percent price premium over noncertified buildings. Some of this premium can be attributed to energy efficiency, but it can likely cover the additional cost of green cement in the overall construction costs, which is typically around 3 percent.^[16]

However, this consumer willingness to pay will not be universal across industries or geographies. To create maximum value from green premiums, commodity producers should understand customer preferences, identify market segments with higher willingness to pay, and identify segments undersupplied by green products. Initial demand centers could include downstream businesses with ambitious decarbonization targets or niche or intermediary refined-product value chains. Luxury consumer segments could also be a good entry point because materials make up a smaller percentage of costs in luxury goods, so substantial green premiums on materials will have modest impacts on the final prices of products.^[17] However, this high-end market segmentation also limits the decarbonization potential from lower-carbon-intensity premiums. This will require a much deeper understanding of end markets by commodity producers to create the “golden thread” of consumer green premiums back into the supply chain.

Valuation of CO₂ as a feedstock

Most CCUS business cases assume that captured CO₂ will be transported to a local site and sequestered, meaning the CCUS industry is effectively a waste-disposal business. This is an expensive process that involves complex infrastructure and ongoing measuring, monitoring, and management. The utilization of CO₂ and its sale as a product offer a revenue source to offset the cost of capture. Although sequestration will be part of the equation when and if CCUS scales, incumbent players and entrepreneurial start-ups alike are increasingly seeking productive uses of CO₂.

One of the primary uses of CO₂ today is enhanced oil recovery, for which the CO₂ is employed as a working fluid to extract additional oil from reservoirs while storing some CO₂ underground. Other uses are also gaining momentum. For example, there are several commercial offerings of CO₂-based polymers, particularly polyurethane foams and polycarbonates, although the overall volume of polymers produced is small compared with the required volumes of CO₂. Cement and aggregates could potentially permanently store a high volume of CO₂ by forming a reaction between the CO₂ and minerals in the mix of cement and aggregates, and many start-ups have demonstrations in the works to gain the confidence of a conservative construction industry.^[18] In addition, CO₂ can be combined with hydrogen to create synthetic gasoline, jet fuel, and diesel (see sidebar, “Making green products with captured CO₂”).

Voluntary carbon market

Voluntary carbon market payments could come in two forms as they relate to CCUS. First, some CCUS pathways, such as BECCS, DAC, and hydrogen or cement based on biofuels, have the potential to deliver negative emissions. In turn, negative-emissions credits can be monetized in voluntary carbon markets and will likely make up significant future value pools as the demand for high-quality negative-emissions offsets grows in the coming years.

This means CCUS projects capable of delivering negative emissions could have a significant additional revenue source—for example, DAC can currently be priced at more than \$500 per ton, though this will come down as technology costs go down and supply increases. Negative-emissions credits also provide demand for CCUS transportation and storage infrastructure, meaning that connection costs for local players in clusters could be brought online for much lower costs, overcoming infrastructure barriers.

Second, funding could become available for decarbonizing existing assets in voluntary markets. However, many buyers currently prefer nature-based solutions or solutions that provide significant cobenefits, such as distributing cookstoves in developing countries at values significantly below those required to decarbonize an industrial asset using CCUS. Thus, it is unlikely this will be a material source of funding for many projects in the future, though it will doubtless play a role in some.

How to scale CCUS

The speed and scale of the technological adoption needed to achieve the goals laid out in the latest round of NDCs are significant and will require collaboration and systems thinking to turn into reality. The following actions can help industry players, regulators, and investors determine the next steps.

Industry players

Companies need to take four steps toward scaling and capitalizing on CCUs:

- *CCUS business cases need to rely on more than just subsidies.*
Companies should aim to deliver positive business cases based on the four revenue sources highlighted above: subsidies and regulatory interventions, a willingness to pay for lower-carbon-intensity products, the valuation of CO₂ as a feedstock, and a voluntary carbon market. This will require collaboration in new ways with new partners as well as finding new ways to connect end-to-end supply chains.
- *Collaboration and coordination.* These can help industry players get serious about the shared infrastructure that will enable CCUS. Current clusters have been slow to mobilize, and lessons will need to be quickly transmitted to the next generation of projects so they can get going faster. This will require mechanisms to make hard choices, which should be led from the top of organizations. In addition, some regions will need to build large new pipeline

networks to gather and dispose of CO₂, which could be time intensive.

- *Reduce capture costs.* There are a lot of promising technologies, but many tech players are hamstrung by cautious customers. Pilot units to prove the technology—and make the subsequent units more affordable—can create large benefits from comparatively small amounts of spending.
- *Advocate for carbon taxes, higher ETS levels, or other tariff barriers.* This will likely favor low-carbon products delivered using CCUS (and other technologies) and can level the playing field to create a secure environment for investing. These costs would help consumers move away from products with a high-carbon footprint toward those with a lower-carbon footprint.

Regulators

Regulators, meanwhile, must decide how CCUS will factor into policy, create frameworks to build up the industry, and recognize the reality that early CCUS projects will need support.

- *Decide whether CCUS can be a major feature of industrial policy.* Making such decisions will likely rely on a determination of whether existing high-intensity assets need to be retired or replaced, which requires difficult trade-offs among industry, financiers, citizens, nongovernmental organizations, and other stakeholders. Once the decision has been made, either get behind CCUS or begin creating

the next generation of industry.

- *Create the regulatory, tax, and reporting frameworks that will allow the industry to scale.* If CCUS is determined to be a part of the future industrial strategy, frameworks will be required. These can include nonfiscal measures, such as regulatory backstops, which involve the private sector when delivering solutions involving innovation and risk.
- *Accept that early projects will need subsidies and direct support.* This doesn't need to be seen as "picking winners" but rather as priming the pump of the future industry and derisking to help companies more quickly decarbonize their assets.

Investors

Investors can use their clout in the industry to encourage environmental, social, and governance (ESG) policies, and investments can ultimately improve the value of CCUS technologies.

- *Insist on bold ESG commitments from the companies they invest in.* These commitments should be backed by clear, standardized reporting and credible plans that boards can scrutinize. Currently, it is too easy to make promises and too difficult to track whether and how companies are keeping them.
- *Understand how investing in CCUS can create value.* Investors must actively work to define the structures, vehicles, and value

chains that can make the technology investable and how investing can create value. Players that invest in emitters, storage, and midstream assets can create the pressure needed for equitable risk and value sharing and act as honest brokers in infrastructure decisions.

The importance of deploying CCUS at scale to deliver the net-zero ambitions of the world is no longer in question. The technology will need to play a material role in enabling lower-carbon hydrogen, decarbonizing low-purity point sources, and serving as a future component of the BECCS and DAC industries. But this has been clear for many years, and every scale-up target thus far has been missed. Papers dating back 20 years or more refer to a CCUS industry that is just around the corner. This time needs to be different. Through close collaboration between the public and private sectors; leveraging green premiums, voluntary carbon markets, and CO₂ as a feedstock; and continued investor and societal pressure, the industry can begin to mobilize. Whether or not the true ambition of all parties matches the scale of the task at hand remains to be seen.

1. For more, see “All about the NDCs,” United Nations, accessed September 21, 2022.
2. For more, see Inflation Reduction Act of 2022, H.R. 5376, 117th Cong. (2022).
3. A total of 139 countries (covering 91 percent of global emissions) have committed to net-zero emissions.
4. Metric tons: 1 metric ton = 2,205 pounds.
5. [Global Energy Perspective 2022](#), April 26, 2022.
6. [Global Energy Perspective 2022](#), April 26, 2022. “Achieved Commitments” scenario.

7. Keigo Akimoto, Gregory F. Nemet, and Nan Wang, “What went wrong? Learning from three decades of carbon capture, utilization and sequestration (CCUS) pilot and demonstration projects,” *Energy Policy*, November 2021, Volume 158.
8. For more, see *COP26: The Glasgow climate pact*, UN Climate Change Conference UK 2021, 2021.
9. For more on 45Q, see “The tax credit for carbon sequestration (Section 45Q),” Congressional Research Service, June 8, 2021.
10. Inflation Reduction Act of 2022, H.R. 5376, 117th Cong. (2022).
11. For more on the EU Emissions Trading System, see “EU Emissions Trading System (EU ETS),” European Commission, accessed September 21, 2022.
12. For more on carbon border taxes, see “What is a carbon border tax and what does it mean for trade?,” World Economic Forum, October 26, 2021.
13. Victor Ajayi and David Reiner, *Are consumers willing to pay for industrial decarbonisation? Evidence from a discrete choice experiment on green plastics*, University of Cambridge working paper, CWPE20110, November 24, 2020.
14. For examples, see “SSAB to deliver fossil-free steel to Mercedes-Benz,” SSAB, September 1, 2021, and “Volkswagen Group and Salzgitter AG sign Memorandum of understanding on supply of low-CO₂ steel from the end of 2025,” Volkswagen Group News, March 21, 2022.
15. For more, see “Réglementation environnementale RE2020,” French Ministry of Ecological Transition, August 12, 2022.
16. *Mission possible: Reaching net-zero carbon emissions from harder-to-abate sectors by mid-century: Sectoral focus: Cement*, Energy Transitions Commission, 2019.
17. This strategy is already implemented in the automotive sector. Tesla led with its Model S, following with its more affordable mass-market offering (the Model 3) five years later.
18. For more on green growth in cement, see Thomas Hundertmark, Sebastian Reiter, and Patrick Schulze, “[Green growth avenues in the cement ecosystem](#),” December 16, 2021.

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