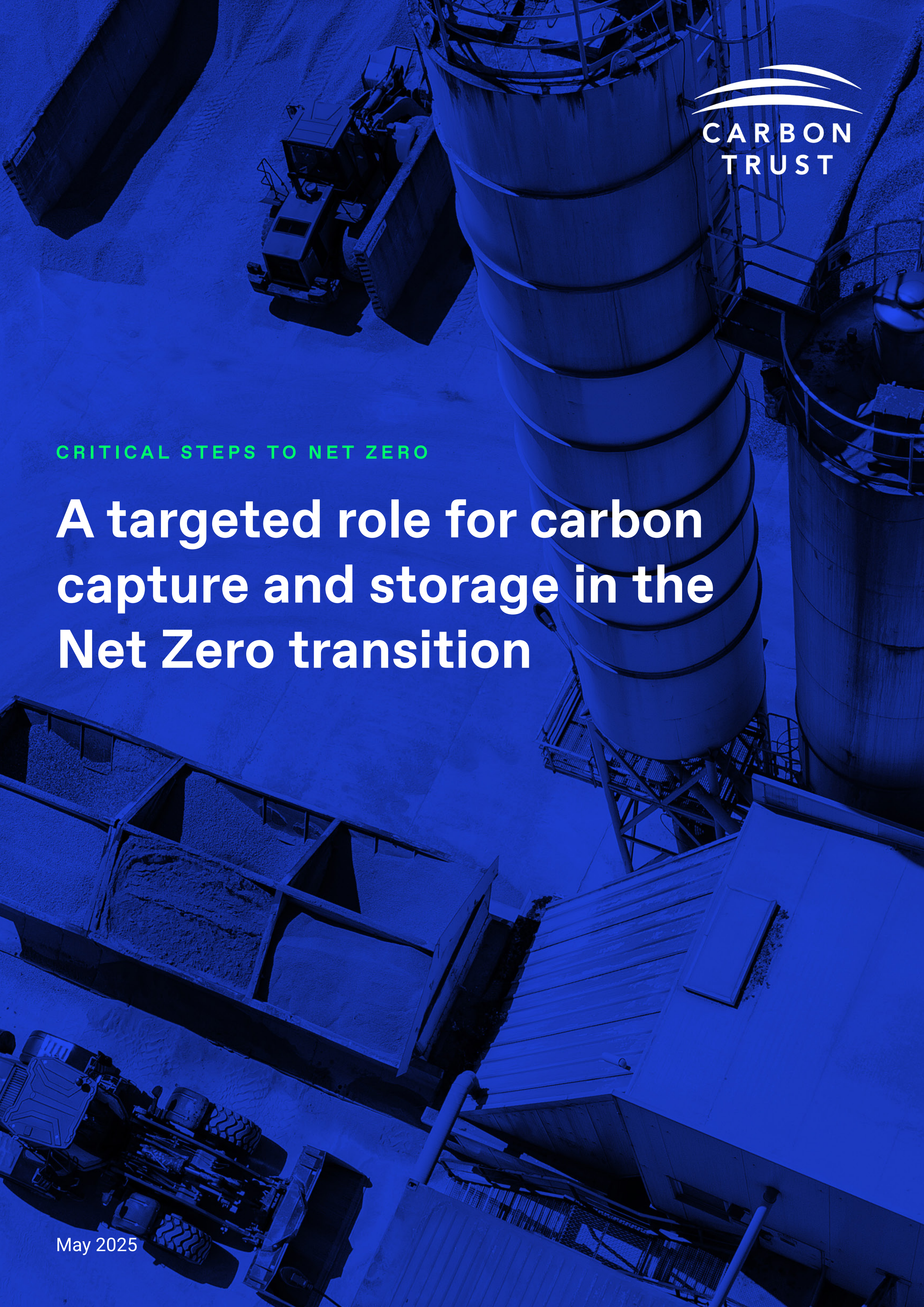

CARBON TRUST

CRITICAL STEPS TO NET ZERO

A targeted role for carbon capture and storage in the Net Zero transition

May 2025

The role of carbon capture and storage (CCS) in reaching Net Zero is complex and contentious, but a targeted role could help to accelerate the transition. In this briefing, experts from the Carbon Trust assess the realities, risks and benefits of CCS, and set out the role these technologies could play in the Net Zero transition.

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Summary

Climate science is clear on the need for urgent and deep emissions reductions to put the world on track for meeting the goal of the Paris Agreement to limit global warming to 1.5C above pre-industrial temperatures, however, views differ on the balance of different technologies needed to deliver emissions reductions.

Carbon capture and storage (CCS) technologies have emerged as a central part of this debate. Oil and gas companies are investors or partners in over 70% of existing and planned CCS projects globally,[1] and yet the International Energy Agency's Executive Director has called the industry's reliance on large-scale CCS for decarbonisation an 'illusion'.[2] It is therefore vital to ask: to what extent can CCS help or hinder the speed of the global Net Zero transition?

In this briefing, we provide some clarity by setting out our view on the role of point-source carbon capture and storage technologies in reaching Net Zero emissions.

We conclude that CCS has an important, but restricted and targeted role in reaching Net Zero.

CCS will be vital for reducing emissions from industrial processes, alongside other decarbonisation levers such as energy efficiency and electrification. A portfolio of options will be needed to support the provision of dispatchable power in a system with a high penetration of renewables, and CCS-enabled power plants may be required as one of those options. However, CCS should not be solely relied upon as a route to urgent and widespread reduction of emissions from electricity generation and should not be presented or pursued as a primary decarbonisation solution for the oil and gas sector.

The role of CCS should be focussed on a limited number of applications where there is a real opportunity to accelerate the Net Zero transition. These include:

1. **The decarbonisation of some hard-to-abate industrial processes, including cement and chemicals production.**
2. **Production of blue hydrogen in markets where a transition is required to scale-up green hydrogen.**
3. **Transitional decarbonisation of a very limited number of existing fossil fuel assets to facilitate dispatchable power generation and support a fair and equitable energy transition.**

[1] IEA (2023), The Oil and Gas Industry in Net Zero Transitions, IEA, Paris https://www.iea.org/reports/the-oil-and-gas-industry-in-net-zero-transitions Licence: CC BY 4.0

[2] Oil and gas industry faces moment of truth – and opportunity to adapt – as clean energy transitions advance - News - IEA

What is carbon capture and storage?

Carbon capture and storage (CCS) refers to the processes used to directly capture CO_2 at the point of being emitted, usually from a heavy industry facility or fossil fuel plant, and then compress, transport and store the captured CO_2 deep in the earth's geosphere, usually through injection into porous rock, where it will be stored for at least 10,000 years.

CCS can be used to reduce emissions from the extraction and production of fossil fuels, for instance emissions released during gas processing, and during the use of fossil fuels to make electricity, industrial products, or hydrogen.

Current and future levels of CCS needed for Net Zero

Today, there are 50 CCS facilities in operation globally. The majority of these facilities capture emissions released during the extraction and production of fossil fuels and then use this captured CO_2 for enhanced oil recovery.[3] This involves injecting CO_2 into oil reservoirs to increase pressure and maximise the ability of oil to flow towards production wells.

The scale of CCS required to achieve Net Zero depends on a number of choices made during the transition. Most IPCC pathways for limiting global warming to 1.5C above pre-industrial temperatures rely on some use of CCS, however some see no role for CCS as long as there can be an extraordinarily rapid decarbonisation of energy supply. The International Energy Agency (IEA) models a limited role for CCS in the future energy mix, with 8 exajoules (EJ) provided by coal and gas with CCS in 2030, compared to 166 EJ provided by renewables. The IEA notes that while this still requires a significant uptick in the scale of CCS compared to current levels,' 'the rising use of fossil fuels combined with CCUS is far smaller than the decline of unabated fossil fuels.'[4]

[3] Global CCS Institute, Global Status of CCS Report, 2024, Global Status Report 2024 - Global CCS Institute

[4] Net Zero Roadmap: A Global Pathway to Keep the 1.5 °C Goal in Reach - 2023 Update (iea.blob.core.windows.net)

What's the difference between CCS and carbon dioxide removal (CDR)?

CCS is sometimes conflated with carbon dioxide removal (CDR), but there are important differences between point-source CCS and CDR, both from a technological perspective and their role in achieving Net Zero.

Point-source CCS refers to techniques used to prevent CO_2 from entering the atmosphere in the first place, whereas CDR refers to techniques used to capture CO_2 that has already been emitted.

Specifically, carbon dioxide removal (CDR, also sometimes known as greenhouse gas removals, GGRs, or negative emissions technologies) refers to the various techniques used to extract CO_2 from the ambient atmosphere and then sequester that carbon on a very long-term, or permanent, basis. For example, direct air carbon capture and storage (DACCS) facilities can be used to remove CO_2 from the atmosphere using fans and filters, before compressing and storing it deep in the Earth's geosphere. Carbon can also be removed from the atmosphere and stored in the Earth's biosphere using natural CDR, such as afforestation or peatland restoration, though these offer less reliable and permanent storage than geological solutions.

All pathways from the Intergovernmental Panel on Climate Change aligned to limiting warming to 1.5C above pre-industrial temperatures rely on some amount of CDR being used to draw down residual atmospheric emissions. Some pathways also rely on CDR to return temperatures to 1.5C following an overshoot.

The term CCS is sometimes used as an umbrella term for the full range of carbon capture technologies, including carbon dioxide removals. For the purposes of clarity, this article will use the abbreviation CCS to refer only to point-source CCS.

Sectors for which CCS will not be the primary solution

Oil and gas

A credible role for CCS in the Net Zero transition involves prioritising its deployment in applications where it will support the most efficient, cost-effective route to a fair and equitable Net Zero transition.

Although CCS is heavily sponsored by oil and gas companies at present, presenting or pursuing CCS as the primary decarbonisation solution for the oil and gas sector obscures the reality of emissions reductions CCS can offer.

CCS cannot 'abate' all the emissions associated with fossil fuels

Although CCS can reduce some of the emissions associated with the *production* of oil and gas, these Scope 1 and 2 emissions[5] represent a very small fraction of the total lifecycle emissions associated with fossil fuels, with the majority (60-90%) coming from eventual usage and combustion (Scope 3). [6] Oil and gas companies have been reticent to take responsibility for these Scope 3 emissions. Notably, the Oil and Gas Decarbonisation Charter launched at COP28 in Dubai, to which over 50 national and private oil companies are signatories, focusses on reducing Scope 1 and 2 emissions with no mention of Scope 3 emissions.

All credible modelled pathways to Net Zero by 2050 require a significant reduction in the production *and combustion* of fossil fuels to deliver the substantial emissions reductions needed to limit global warming to 1.5C above pre-industrial temperatures. This will require fossil fuel companies to ask difficult questions about the compatibility of their business models with the science of what the world needs to limit global warming.

Other interventions would make a more significant contribution to reducing emissions from oil and gas production

Reducing the emissions associated with oil and gas production is important for Net Zero, as a limited amount of fossil fuels will continue to be needed during the transition. The extraction, processing, refining and transport of oil is energy and emissions intensive, currently amounting to 15% of global annual CO_2 emissions.[7] CCS will have a role to play in reducing these emissions, but it is important not to overstate its significance compared with other interventions the oil and gas sector can make.

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[5] Scope 1 covers direct emissions from owned or controlled sources. Scope 2 covers indirect emissions from the purchase and use of electricity, steam, heating and cooling.

[6] Scope 3 emissions are indirect emissions from sources outside an organisation's direct control. The Greenhouse Gas Protocol's Scope 3 Standard categorises emissions across 15 different categories covering business activities common to many organisations, such as purchased goods and services, business travel and waste in operations. It also encompasses activities like leased assets, transport and distribution, the use and disposal of sold products and the impact of any investments.

[7] Ibid.

IEA analysis shows that upstream methane emissions account for nearly half of all greenhouse gas emissions from oil and gas operations.[8] Reducing methane leaks is therefore the most important decarbonisation measure for the sector, along with electrifying production processes and eliminating non-emergency flaring.

CCS can play a small role in reducing operational emissions; however, it is not a silver bullet and cannot abate upstream emissions. CCS will deliver less than a tenth of the total reduction in emissions intensity the oil and gas sector will need to make by 2030 and will play less and less of a role through to 2050.[9]

Electricity production

CCS has not been proven at the cost, scale or effectiveness required to fulfil a major role in abating emissions from electricity production

As the world transitions to Net Zero, a range of clean technologies will be needed to meet the growing demand for electricity. Scaling up wind and solar power, combined with improved storage and grid interconnectivity, remains the most effective route to guarantee a least-cost, zero-emissions electricity system fit for growing demand. Applying CCS to a limited number of existing fossil-based power plants, including gas and coal-fired power plants, could play an important role in supporting a flexible grid during the transition to Net Zero, however CCS is not a primary solution for electricity production emissions, due to challenges with its cost, scale and effectiveness.

Producing electricity using fossil fuels with CCS has a weak economic case. A 2023 study from the Oxford Smith School found that a high-CCS pathway to Net Zero would cost at least $30 trillion more than a low-CCS pathway with greater dependence on alternative low carbon solutions, such as wind and solar energy.[10] Renewables are the cheapest source of electricity available, and variability in supply can be effectively managed through enhanced storage and grid connection infrastructure, demand-side measures and the introduction of dispatchable low carbon energy sources such as nuclear and biomass.

While the *technical* feasibility of both capture and geological storage of CO_2 has been proven, neither process is currently practiced at the scale or effectiveness required to fulfil a major role in urgently abating emissions from electricity production.

Although high rates of carbon capture have been proven at a demonstrator plant level, capture rates across the CCS industry have not been as high as technically possible. One study assessing 20 CCS facilities found that the real-world capture rate averaged 72.5%, far short of the 90%+ capture rate typically targeted by CCS facilities.[11]

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[8] Ibid.

[9] Ibid.

[10] Assessing-the-relative-costs-of-high-CCS-and-low-CCS-pathways-to-1-5-degrees.pdf (ox.ac.uk)

[11] An Estimate of the Amount of Geological CO2 Storage over the Period of 1996–2020 | Environmental Science & Technology Letters (acs.org)

Durable storage of captured CO_2 is also essential for CCS to fulfil a major role in electricity decarbonisation. However, very few CCS projects today permanently store captured carbon in the earth's geosphere. Of the 50 CCS facilities operational globally, just 15 permanently store captured carbon with the rest using it for enhanced oil recovery, which supports more fossil fuel extraction and does not necessitate a focus on durable storage.[12]

The continued lack of policy frameworks to support large-scale CCS projects is also a major barrier to unlocking the effectiveness of CCS technologies. Until policies such as carbon pricing, contracts for difference to support capture, and state-led guarantees to support transportation and storage are in place, CCS will remain a nascent technology unable to fulfil a major role in decarbonisation of the electricity system.

[12] Global CCS Institute, Global Status of CCS Report, 2023, Global CCS Institute

Sectors for which carbon capture and storage has an important role to play

The use of CCS should be focussed on a limited number of applications where there is a real opportunity to accelerate the Net Zero transition

A phase out of fossil fuels is required to put the world on track for 1.5C, however, CCS can play a restricted and targeted role where it provides the most efficient, cost-effective route to a fair and equitable Net Zero transition.

There are three main applications of CCS that meet these criteria:

1. Decarbonisation of some hard-to-abate industrial processes, such as cement and steel production

For several industrial sectors, including cement and steel, CO_2 emissions are an inevitable by-product of the production process. While emissions can be reduced through efficiency improvements, CCS is essential to capturing these residual process emissions.[13] In the case of cement, CCS has the potential to significantly reduce the emissions associated with process and heat emissions in cement kilns.[14]

Cement and steel are also vital materials for supporting the Net Zero transition, as they are needed to build renewable energy infrastructure. Using CCS to reduce the emissions from these growing sectors is therefore essential.

However, significant innovation support is required to make CCS commercially scalable for industrial use. There is currently no operational CCS infrastructure for use in cement, and only one operational CCS plant for steel production.[15] Collaborative programmes to drive demonstration and prove commercial models are needed to develop the use of CCS in industrial sectors.[16]

2. Enabling production of low carbon ('blue') hydrogen, in the limited number of markets where blue hydrogen is needed to stimulate a transition from grey to green hydrogen

Hydrogen is an essential feedstock for many industrial processes, including oil refining and chemical production. In a Net Zero economy, hydrogen will also be used to support flexible power systems and

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[13] Making-Net-Zero-Concrete-and-Cement-Possible-Executive-Summary.pdf (missionpossiblepartnership.org)

[14] CCS is virtually the only known solution for cutting emissions from the cement sector. About CCUS – Analysis - IEA

[15] A closer look at CCS: Problems and potential - Zero Carbon Analytics (zerocarbon-analytics.org)

[16] Energy Innovation Needs Assessment: carbon capture, usage and storage (publishing.service.gov.uk)

enable the creation of e-fuels for aviation and shipping. However, the vast majority of the hydrogen used today is 'grey hydrogen', which is produced using steam methane reforming combined with the water gas shift, a highly emissions intensive process.

Novel methods would lower or eliminate greenhouse gas emissions from hydrogen production processes**.** Green hydrogen is the cleanest form of hydrogen production, as it made by using electrolysis powered by renewable energy to split hydrogen out from water molecules. Blue hydrogen is made in the same way as grey hydrogen, except 90-95% of CO_2 emissions are captured using CCS.

The Carbon Trust's view is that in most markets, especially those that have huge potential to scale up renewable energy supplies, green hydrogen production will be the more cost-effective solution and should therefore be the focus of policy and investment.[18]

However, there are some circumstances in which blue hydrogen may be needed to enable and accelerate the decarbonisation of high-emitting sectors and the electricity system. For instance, in markets where renewable energy supply pathways have had limitations placed on them through policy decisions, blue hydrogen can help to stimulate economy-wide demand for hydrogen by lowering costs through economies of production and scale. For example, in the UK, blue hydrogen is essential to deliver the early emissions reductions required for Net Zero and while creating the market for green hydrogen usage.[19]

Any use of blue hydrogen must be supported by strict regulation and enforcement to ensure at least 95% of CO_2 emissions are captured and stored. This use of blue hydrogen supports overall decarbonisation of the economy by ensuring that where renewable energy supplies are limited, they are directed towards the sectors where they can deliver the most impact.

3. Transitional decarbonisation of a limited number of existing fossil fuel assets to facilitate, low carbon dispatchable power generation and support a fair and equitable energy transition

The transition to Net Zero will require the majority of existing fossil fuel-based power infrastructure to be retired and replaced. As the per MWh cost of wind and solar PV power continues to decline, grids with a high penetration of renewables will provide an economically sound and resilient energy system.

However, many national power systems are dependent on a small number of very large fossil fuel plants to provide baseload power. Transitioning these power systems away from fossil fuels while ensuring

[17] Currently, most global hydrogen production is provided by **'**grey' hydrogen**,** or by 'black' hydrogen. This carbon-intensive hydrogen is produced by splitting methane (CH_4) into carbon dioxide (CO_2) and hydrogen (H_2), or by partially burning coal to isolate hydrogen. CO_2 emissions are therefore a key by-product of current hydrogen production: for every kilogram of grey hydrogen produced, approximately 10 kilograms of CO_2 are emitted into the atmosphere.

[18] Worth the hype? The role of clean hydrogen in achieving Net Zero | The Carbon Trust

[19] The UK's Climate Change Committee advises that blue hydrogen will needed to transition to green hydrogen due to policy limitations being placed on them due to policy decisions. Hydrogen in a low-carbon economy - Climate Change Committee (theccc.org.uk) See also IRENA:'Blue hydrogen, produced from natural gas with CCS, can serve as an interim solution while green hydrogen production from renewable electricity scales up (provided that CCS technology continues to advance)' in World Energy Transitions Outlook 2023: 1.5°C Pathway (azureedge.net)

energy security will require both time and investment in new technologies that can support grid stability, including synchronous condensers, static synchronous compensators and batteries. A portfolio of options will be required to support the provision of dispatchable power, including hydrogen-powered gas turbines, though this technology is not yet proven. In some cases, a limited number of existing power plants might need to be retained to provide dispatchable power to ameliorate variability in renewable energy generation. For these power plants, the use of CCS is important to ensure a significant reduction in emissions during the transition to high-renewables power system.

In a very limited number of cases, CCS-enabled gas power plants may be a good option for providing dispatchable power. For instance, in areas with industrial clusters, where CCS infrastructure is already used to support the production of blue hydrogen, CCS-enabled gas power plants may be an efficient and effective way of supporting grid flexibility.[20] Due to the economics of operating CCS, it is unlikely to be viable to operate CCS-enabled gas power plants only when electricity demand peaks, so a flexible grid may require CCS-enabled gas to play a 'mid-merit' role in the production of electricity.

Another very limited use-case for CCS is to support transitional decarbonisation of a limited number of existing, young, coal-fired power plants to facilitate immediate reductions in emissions and support a just transition to Net Zero.[21] In the past ten years, approximately 680 GW of coal-fired power capacity have been constructed globally.[22] These relatively young plants are more complicated to retire early, due to the financial commitments of owners, system operators and governments. Retrofitting CCS infrastructure onto a limited number of existing coal-fired power plants that are less suited to retirement could help to reduce emissions and smooth the transition by limiting the effects of coal retirement on asset owners, investors, communities, and energy systems.

The use of CCS to support transitional decarbonisation of a limited number of existing fossil fuel power plants should never be the default option. The majority of coal plants, including young ones, will still need to be retired early, however CCS could be a viable consideration for a limited number. The use of CCS for transitional decarbonisation must be economically assessed against alternative options and be accompanied by a steep decline in the use of fossil fuels for power generation.

Scaling up CCS will be essential to the Net Zero transition, not only to support the above use-cases, but also to develop the infrastructure required to support the scale-up of carbon dioxide removal (CDR) technologies. The transport and sequestration infrastructure used for CCS can be redeployed to support engineered CDR and bioenergy with carbon capture and storage, particularly in industrial clusters near coastal areas with good sequestration locations, such as depleted oil and gas fields. The innovation in technologies and supply chains for CCS infrastructure will also help to drive down costs of CDR, which is likely to be a relatively expensive mitigation measure.

[20] In the UK, the government's independent advisory body on climate change, the Climate Change Committee, has recommended a portfolio approach to decarbonising the grid covering the full range of low carbon flexibility options, including demand flexibility, storage, hydrogen, CCS-enabled gas and interconnection capacity. Progress in reducing UK emissions - 2023 Report to Parliament (theccc.org.uk)

[21] Coal-to-clean energy: Assessing progress for a rapid and just transition | The Carbon Trust

[22] Dashboard - Global Energy Monitor

Five focus areas to drive the most effective CCS deployment

To unlock a strategic role for CCS in the Net Zero transition, governments and industry should be focussed on scaling the highly effective, cheap solutions we already have for drastically reducing emissions from electricity generation while supporting targeted development of CCS infrastructure where it will drive the most decarbonisation value.

To achieve this, five key steps are needed from government and industry:

1. Drive deployment of renewables, storage and grid connection to deliver a secure energy system

Low carbon, variable generation (solar and wind) are cost competitive with unsubsidised fossil fuel generation across much of the world.

Renewable energy penetration must be complemented by improvements to grid infrastructure and transmission system upgrades, as well as electricity storage capacity to ensure a reliable supply. This is also true of heat networks, which are critical sources of energy in colder climes.

Supported by strong grids and storage capacity, substantial investment in low carbon variable generation is the first step toward deep decarbonisation.

2. Set stringent targets for the reduction of upstream emissions within the oil and gas sector

CCS cannot capture upstream emissions from fossil fuels, for instance leakage of methane and other greenhouse gasses during extraction and transportation. It is vital that these upstream emissions are substantially reduced, through the introduction of leak detection technologies and minimisation of methane flaring.

Governments should set stringent targets for the reduction of upstream emissions within the oil and gas sector, which will steer the sector towards the most effective decarbonisation measures for its Scope 1 and 2 emissions. Oil and gas companies can, and should, set voluntary targets to reduce these emissions.

3. Introduce a carbon price to support the business case for CCS in key sectors and drive private investment

Setting a carbon price aligned with climate targets can be a key tool to shift private investment decisions towards a Net Zero future. To accelerate investment in CCS, governments could consider a carbon price for the heavy industry sector accompanied by other policies and/or incentives to fully support energy intensive decarbonisation including CCS deployment. Furthermore, governments should focus on permanence of storage and define robust measures to address this issue (i.e., MRV provisions for preventing and quantifying leaks, defining legal liability).

4. Set strategic targets for CCS deployment, including near and long-term targets for the amount of emissions captured and stored

To guide the research and development of CCS towards the most effective applications, governments should set strategic targets for CCS deployment in industry and blue hydrogen production. These should include near and long-term targets for the amount of emissions captured and stored across sectors such as cement, steel and chemicals, as well as targets for the scale-up of blue hydrogen in markets that will require it during the transition to green hydrogen.

5. Fund and incentivise the most effective applications of CCS, for instance by allocating capital support for demonstrator projects in the form of grants, tax credits or concessional finance

Given the high costs and commercial immaturity of CCS and its site-specific challenges (e.g., access to cost effective and permanent geological storage, pipeline infrastructure and supply chain), a number of demonstrator projects are needed to sufficiently derisk the technology to attract private investment. Innovation support in the form of collaborative programmes, funding for research and development and concessional finance would support the development of CCS technologies, supply chains and business models.

Innovation support is also essential to drive high capture rates. CCS has high upfront costs as well as high operating costs. Support schemes and regulation will need to encourage increasingly efficient and low carbon operation to keep residual emissions from CCS as low as reasonably possible, maximising the return on the investment in CCS research and construction while remaining aligned to a Net Zero target.

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Published in the UK: 2025