Energy & Transport

Zero Carbon Analytics

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A closer look at CCS: Problems and potential

Key points:

- Although carbon capture and storage (CCS) has potential to reduce emissions from sectors that are difficult to decarbonise, almost all of the world's 41 operational CCS projects are connected to the production or use of oil and gas.
- 82.5% of existing CCS capacity uses captured CO_2 in enhanced oil recovery (EOR), a process to extract less accessible oil from mature wells.
- The International Energy Agency (IEA) notes in its latest Net Zero roadmap that CCS has a history of slow deployment and "unmet expectations", and that "removing carbon from the atmosphere is costly and uncertain".
- A number of sectors beyond oil and gas are making some limited progress towards applying CCS technologies, led by power generation and chemicals production.

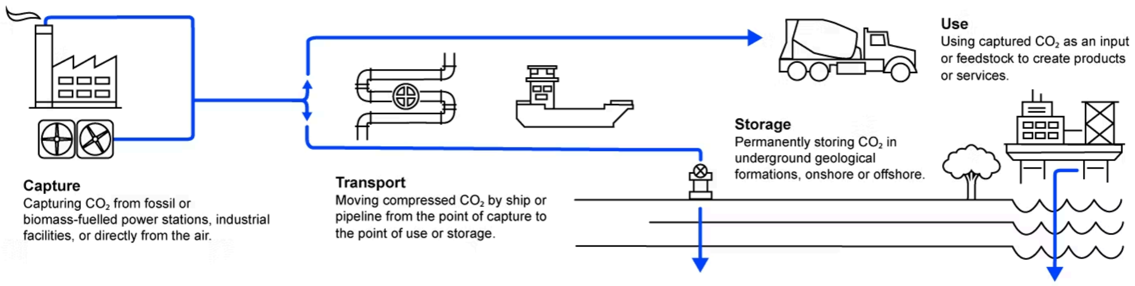
What is CCS?

Carbon capture refers to technologies that remove CO_2 from the air and then transport it to be stored or used in other industrial processes.

Carbon capture is best viewed as an integrated infrastructure, which broadly consists of four components:

- **Capture**: Technologies that remove CO_2 from the atmosphere, either before or after burning.
- **Transportation**: Moving captured CO_2 by pipeline or ship to a new location for storage or use.
- **Use**: CO_2 can then be employed within a new industrial process, or
- **Storage**: CO_2 can be stored more permanently, typically underground in geological storage sites, such as deep saline formations – essentially underground rock formations – or in depleted oil and gas wells.

Fig. 1: Components of CCS infrastructure



Source: IEA 2023; The CCUS chain, Licence: CC BY 4.0

Different configurations of these components, with different applications, are referred to by specific acronyms:

- **Carbon capture and storage (CCS):** A system where the CO_2 is removed from the atmosphere and put permanently underground.
- **Carbon capture and utilisation (CCU):** Captured CO_2 is used, either as CO_2 or as its component parts, to produce chemicals or building materials.
- **Carbon capture, usage and storage (CCUS):** A system in which the use of captured CO_2 also results in its storage. The main application of CCUS to date has been to maximise oil production.

For simplicity, this briefing will use CCS to refer to all three of these approaches, which collectively refer to the capture of emissions at source, rather than its application for carbon dioxide removal (CDR).[1]

History of CCS in the oil & gas sector

CCS technology was developed by the oil and gas industry in the 1970s to extend the life of oil fields. Carbon dioxide is the key component of enhanced oil recovery (EOR), a process used to access the hard-to-reach oil in older wells. When CO_2 is injected into the reservoir, it mixes with any oil remaining in the subsurface rock. This displaces residual droplets of crude oil, which are then pushed towards the oil well and pumped to the surface.

Some sections of the oil and gas industry depend on a constant flow of CO_2 for use in EOR activities. However, EOR can be an expensive process to establish and maintain. It is capital-intensive to build CO_2 transportation infrastructure, drill into a well that is already in operation, and ensure all injected CO_2 is completely used up. According to the United States Department of Energy, the cost of CO_2 is often the "single largest project cost" in EOR, meaning that "operators strive to optimize and reduce the cost of its purchase and injection wherever possible".

Box 1: US subsidies for CCS prioritise increased oil & gas production

High set up and running costs mean proposed CCS projects have historically often relied on government support to strengthen the business case for moving forward.[2] Between 1972 and 2014, almost every CCS project in the world was located in the United States and directed at EOR. Since then, more CCS projects have become operational in Canada, Asia and the Middle East. State incentives were a key factor underpinning these projects. Starting in 1979, and codified in the 1986 US Federal EOR Tax Incentive, a 15% tax credit was applied to costs associated with CO_2 capture and injection, effectively subsidising hydrocarbons exploitation.

In more recent years, these subsidies have been re-labelled as 'climate action', despite being a continuation of subsidies designed to maximise oil extraction. In 2008, Congress added Section 45Q to the Internal Revenue Code, which provided tax credits if captured carbon was injected as part of oil and gas extraction. The Inflation Reduction Act, approved in 2022, updated Section 45Q – the Credit for Carbon Oxide Sequestration – to provide a base credit of USD 12 for every metric ton of carbon dioxide that is injected for

[1] There are also technologies that directly extract CO_2 from the atmosphere, known as carbon dioxide removal (CDR). These include direct air capture (DAC) and Bioenergy with CCS (BECCS).
[2] This study was funded by Chevron.

EOR. This can reach up to USD 60 if the CO_2 is captured from an industrial facility and USD 130 if the CO_2 is from DAC.

The motivations to initiate these subsidies in the 1970s and continue them in the 2020s are broadly the same: to increase domestic oil production to reduce reliance on imports, seeking to stabilise gasoline prices. Backing EOR has been presented as a way to reduce emissions and increase energy security by retrieving significant amounts of oil left in conventional reservoirs in mature oil fields.

Current state: Capturing carbon for EOR

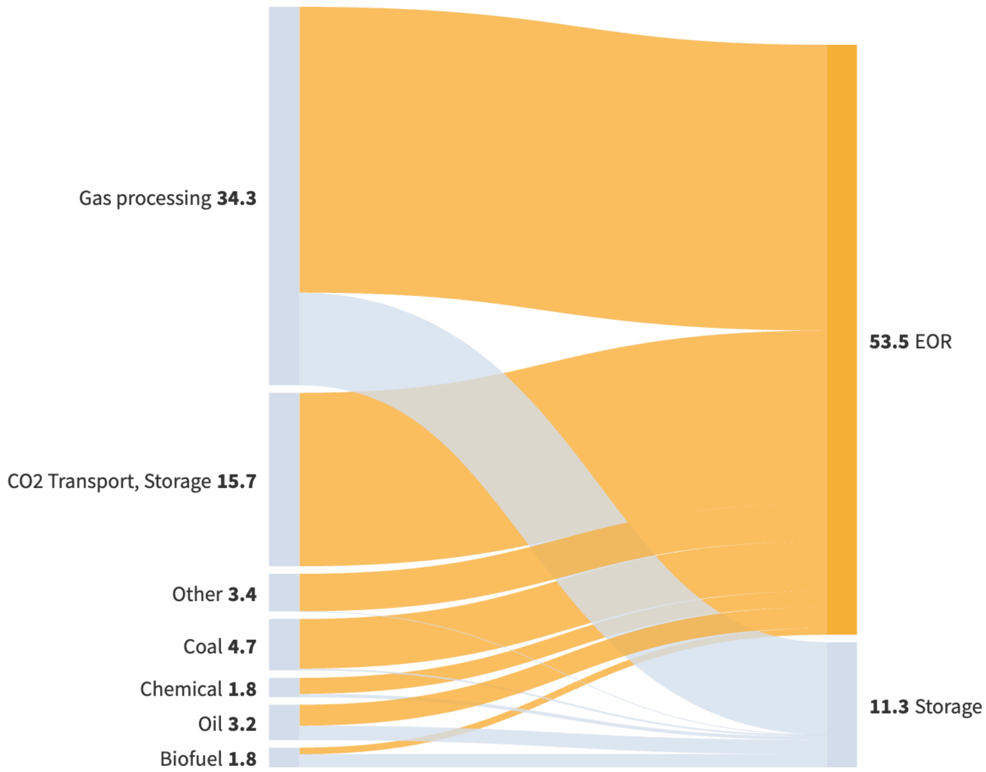
Currently, the majority of operational CCS projects are related to producing oil or gas.[3] Industry body Global CCS Institute, which is closely linked to the hydrocarbons industry, reports 41 active CCS projects worldwide (Figure 2).[4] Within these projects:

- 53% of overall capacity is used in natural gas processing, removing high CO_2 content which would render the gas unsaleable for distribution through pipelines and unusable as liquified natural gas (LNG).
- 82.5% of captured carbon is used to produce oil through EOR.

Although these processes both involve carbon capture technology, the gas or oil being produced will release CO_2 emissions when it is used further down the line. These indirect emissions are known as Scope 3 emissions and make up 85% of the fossil fuel industry's carbon footprint. This limits the overall value of CCS in terms of preventing emissions and marks a difference between how CCS is currently being used and its potential future uses focused on reducing emissions in other hard-to-abate sectors.

[3] One of the only projects in operation that does not appear to have direct links to fossil fuels is the Orca DAC project in Iceland, with capacity to capture just 0.004 million tonnes of carbon per year. For perspective, the Yanchang Demonstration project in China, has a capacity to capture 0.05 million tonnes per year, which is then used in EOR.
[4] See full list of current CCS projects based on information provided by the Global CCS Institute.

Figure 2: Operational CO_2 capture & use capacity by activity (Mtpa)



Source: Zero Carbon Analytics analysis, Global CCS Institute • 'Coal' refers to coal power plants and refining; 'oil' to oil production and refining, and 'other' to fertilisers, ammonia, iron and steel, and DAC.

Reframing CCS: Storing carbon to maintain oil & gas extraction

As awareness of climate change has increased, CCS has been increasingly presented as a way to store CO_2 so that it is not released into the atmosphere, thereby 'abating', or reducing, emissions. CCS is now at the centre of the oil and gas industry's pledges to decarbonise. Some in the oil industry have gone so far as to claim that capturing CO_2 can result in "carbon neutral" oil. However, capturing emissions from fossil fuels continues to be a hugely controversial area in debates on how to tackle climate change. In deploying carbon storage to defend or enhance the profitability of natural gas processing and oil refining, the technology ensures the continuation of oil and gas extraction (see Box 2).

Box 2: Fossil fuel operations storing carbon so that extraction can continue

Sleipner, Norway

Equinor (previously Statoil) began the Sleipner CCS project in the North Sea to reduce the amount of tax it paid: "The reason for the decision was the carbon dioxide emission fee introduced by Norwegian authorities in 1993, which made it more profitable to capture and store the carbon dioxide than to pay the emission fee."

The CCS project has saved the company millions of dollars in taxes, contributing to making extraction from the Sleipner West field financially viable. Since operations in the block began in 1996, almost all of the recoverable gas and reserves have been extracted (remaining gas reserves are just 8 million cubic metres oil equivalent, compared to the original amount of 154.1 million cubic metres).

Quest, Canada

Shell's Quest CCS project began capturing CO_2 from hydrogen manufacturing at the Scotford Upgrader processing facility in Alberta, Canada in 2015. The hydrogen is used to refine bitumen (thick, sticky black oil) from the tar sands to make synthetic crude oil.

Company statements reflect the financial incentive of CCS: "In North America, the adoption of CCS is stimulated by tax credits and the prospect of carbon taxes increasing significantly in decades to come."

Shell refers to Quest as a key component of its abatement strategy to meet legal requirements to reduce its emissions intensity. As well as reducing company expenditure on the purchase of carbon offsets or energy-efficiency measures, the project generates increasing revenues through government funding and the sale of carbon credits.

This has contributed to the profitability and continuation of operations at the Scotford Upgrader which, in the past few years, increased its production capacity from 300,000 to 320,000 barrels per day of oil equivalent. Shell is considering building a second CCS project at the site.

Gorgon, Australia

The Gorgon gas field in Western Australia was discovered in 1980 and began exporting liquified natural gas (LNG) to Asia in 2016. The government licence for the project required the operators - Chevron and its partners, including ExxonMobil and Shell - to install a CCS project at the site and formed part of the final investment decision in 2009.

The Australian government provided AUD 60 million and agreed to take on liability for the stored CO_2. The project has not captured sufficient CO_2 since it began in 2019, leading operators to purchase 5.23 million carbon credits to offset non-captured emissions. Despite this poor track record of CO_2 capture, net production of natural gas at the Gorgon processing facility has increased from 1,000 million cubic feet per day in 2020 to 1,336 million cubic feet in 2022.

Looking forward: Limits to CCS's usefulness in oil & gas

The oil and gas industry continues to be a key developer of CCS technologies. Shell plans to build a second CCS project at Quest in Canada (see Box 2), and the Abu Dhabi National Oil Company (ADNOC) has announced a new large-scale CCS project for EOR at one of its gas-processing plants.

The known current and future plans for applying CCS in the oil and gas industry are primarily to support continued oil and gas extraction. However, if fossil fuels are increasingly replaced with renewable energies, there will be less need to capture emissions from the burning of oil, gas and coal at source.

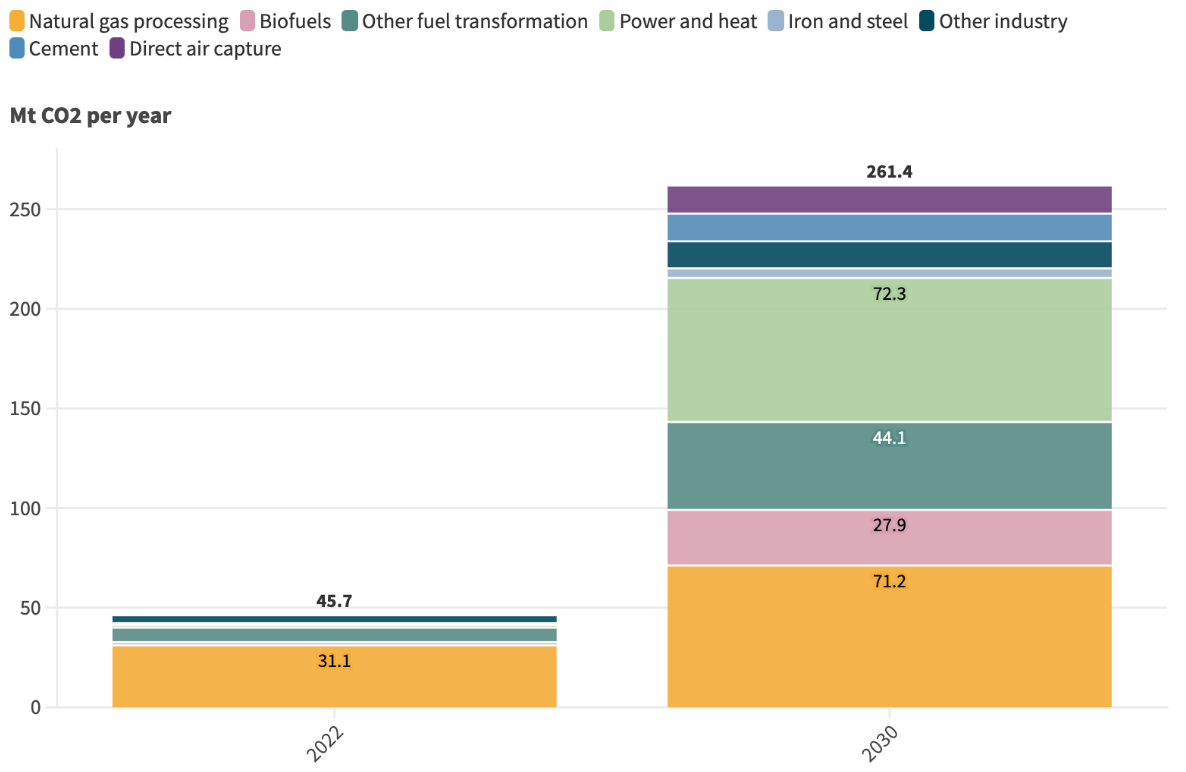
In its latest Net Zero scenario from 2023, the IEA forecasts a reduced contribution of fossil fuels with CCUS citing the "slow pace of current progress on the development of CCUS" as one reason for the decline. The agency further notes that "reduced CCUS deployment is compensated by more renewables and electrification".

Potential for applying CCS in other sectors

In recent years, CCS has shifted from being primarily a technology developed and used by the oil and gas industries to become part of the mainstream climate debate. One of the areas in which CCS could potentially have some impact is heavy industry. Sectors such as steel, cement and chemicals are often seen as difficult to decarbonise because they are energy-intensive, and there can be process emissions that are the result of chemical or physical reactions.

According to the IEA's CCUS projects database, the areas expected to see the largest growth in CCS initiatives are ammonia production, power and heat, and biofuels.[5] A number of CCS projects are planned or being built across a range of sectors beyond oil and gas (Figure 3, and discussed sector-by-sector below). Several of these projects aim to capture CO_2 for use in EOR.

Figure 3: Operational & planned carbon capture by sector, 2022 & 2030



Source: IEA • In 2022, operational capacity below 2 Mt of CO2 exists for biofuels, power and heat, and iron and steel.

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Challenges: Efficacy and cost-effectiveness

In 2022, the IPCC considered the use of CCS across a range of sectors as part of its sixth assessment cycle, citing its abatement potential. However, the IPCC notes that "in contrast to the oil and gas sector, CCS is less mature in the power sector, as well as in cement and chemicals production, where it is a critical mitigation option"

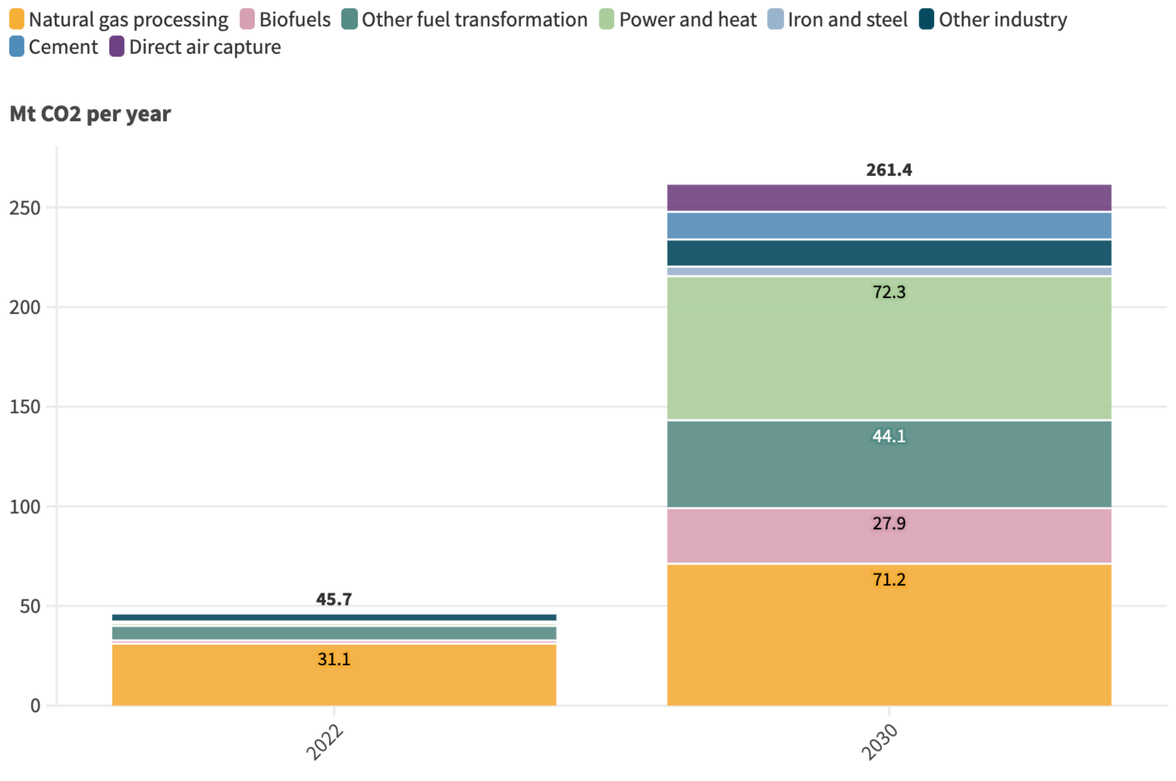
[5] Production of ammonia, which is an input for fertilisers, uses hydrogen; CO_2 can be captured when the hydrogen is produced.

It is unclear to what extent CCS will be a viable and effective technology for use in these sectors. Existing CCS projects have an uneven track record of CO_2 capture rates. For example:

- **Boundary Dam**, a coal power plant in Washington state, USA, has an estimated 65% capture rate (used for EOR).
- **Gorgon** gas processing facility on Barrow Island, Australia, has an estimated 45% capture rate.
- **Quest** oil refinery, in Alberta, Canada, has an estimated capture rate of 48%.
- **Century Gas Processing Plant** in Texas, USA, has an estimated capture rate of under 10% (used for EOR).

The IPCC also finds that in terms of the measures that will do the most to reduce industrial emissions – and do so cheaply – CCS is less effective than actions such as fuel switching (electrification), improving energy efficiency, material efficiency and enhanced recycling (Figure 4).[6] The IPCC analysis reflects net lifetime costs of avoided greenhouse gas emissions for each action or technology, broken down by cost categories, across the mitigation potential, and net greenhouse gas emission reductions that can be achieved by each option.

Figure 4: Technologies' potential contribution to net emissions reduction in the industrial sector and projected costs in 2030



Source: IEA • In 2022, operational capacity below 2 Mt of CO2 exists for biofuels, power and heat, and iron and steel.

[6] Although electrification is currently a more viable option in light industry (for example, using electrothermal heating and heat pumps), the IPCC finds that "both light and heavy industry are potentially large and flexible users of electricity" (box TS.9, page 92)

The inefficiency of CCS relative to its decarbonisation impact, in comparison to other options, is due to the high cost of project implementation. This reality led the IEA to observe in its latest net zero roadmap that "removing carbon from the atmosphere is costly and uncertain". The report goes on to say that "so far, the history of CCUS has largely been one of unmet expectations. Progress has been slow and deployment relatively flat for years. This lack of progress has led to progressive downward revisions in the role of CCUS in climate mitigation scenarios," including the IEA's own Net Zero Emissions by 2050 Scenario, published in 2023.

Alongside low and inconsistent capture rates, CO_2 storage presents another issue. The IPCC notes that "the regional availability of geological storage could be a limiting factor" to the use of CCS. This is a reality in many areas, including Europe. In its proposal for a Net Zero Industry Act of 2023, the European Commission identified that the "emergence of a CCS value chain in the EU is currently being hampered by a lack of CO_2 storage sites".

CCS uptake and potential by sector

Steel

- **Current use of CCS**: One project in operation in the UAE
- **Future use of CCS**: Unclear

Steel production is currently largely reliant on coal, both as a component of the production process and as a fuel to provide high-temperature heat. According to the IEA, the sector is responsible for around 7% of energy-related CO_2 emissions. The IPCC finds that emissions from steel can be reduced through material efficiency, high-quality recycling and partial fuel switching, followed by using hydrogen or CCS to capture residual emissions.

The Al Reyadah CCS project in the UAE captures CO_2 from Emirates Steel Arkan's steel mill for use in local oil fields, where it is used for EOR. The project, commissioned in 2016, was reported to cost USD 122 million to set up, and aims to capture 0.8 million tonnes of CO_2 (Mt CO_2) per year, according to company statements. However, little is known about its effectiveness.

Cement

- **Current use of CCS**: No projects in operation
- **Future use of CCS**: One project under construction in Norway

CCS could be one way to decarbonise the cement sector, which is a major emitter, contributing between 7% and 8% of global emissions. These emissions come both from the fossil fuels used to generate the heat needed to make cement, but also from the chemical composition of the raw materials used.[7]

The IPCC finds cement production can be decarbonised through material efficiency (for example, using right-sized prefabricated components to reduce material waste) and introducing substitutes such as ground limestone. It concludes that, "CCS will be essential for eliminating the limestone calcination process emissions for making clinker, which currently represent 60% of GHG emissions in best-available technology plants".

The Brevik CCS project in Norway, which is due to come on-line in 2024, aims to capture 400,000 tonnes of CO_2 a year, transport this by ship, and store it in the sea bed.

[7] Cement is made through a calcination process, during which CO_2 is burned off limestone and released into the atmosphere, if it is not captured.

Chemicals

- **Current use of CCS**: Six projects in operation in China
- **Future use of CCS**: One project under construction in the Netherlands and two in the United States

The chemicals industry is responsible for about 5% of global CO_2 emissions. Some segments already capture CO_2 from production processes, particularly those that release a relatively pure stream of CO_2, such as ammonia, an input for fertilisers. According to the IPCC, chemical emissions can be reduced through increasing plastic recycling, fuel and feedstock switching, and "depending on availability" by using CCS technologies, including utilisation and removal.

Current CCS projects in the chemical industry are concentrated in China where collectively they have the capacity to capture 1.75 million tonnes of CO_2 a year. These projects became operational between 2012 and 2022 and almost all of them capture CO_2 which is then used in EOR. For example, Sinopec uses CO_2 captured at Qilu Petrochemical for EOR at Shengli Oilfield, "thus turning waste into something valuable", according to the company website.

Two CCS projects are under construction in the United States to capture CO_2 from hydrogen produced from natural gas to make ammonia.

Power generation

- **Current use of CCS**: Two coal power plants capturing CO_2 for use in EOR, in Canada and the United States
- **Future use of CCS**: Five projects are under construction in Australia, China, the Netherlands and Norway

The power sector is the biggest source of CO_2 emissions globally. When a power station burns fossil fuels, CCS can be used to lessen the quantity of emissions released. However, CCS requires additional energy above and beyond the needs of the power plant. This is known as the energy penalty, and makes a CCS-equipped facility more expensive to operate.

CCS projects in the power sector to date have been associated with EOR activities at nearby oil fields, a practice which has served to offset the costs of CCS with the profits from EOR. This is the case with the Boundary Dam project in Saskatchewan, Canada, which has been operating since 2014, and the Petra Nova project in Houston, USA, operational since 2017.

However, this arrangement is contingent on oil prices being high enough to cover the costs of operating the CCS infrastructure. In 2020, the Petra Nova project was temporarily halted when oil prices crashed during the COVID-19 pandemic. A rise in oil prices in autumn 2023 has made the project financially viable once more and work has restarted.

Though CO_2 capture rates at Petra Nova fell short of expectations, at 3.8 million tonnes in its first three years of operations against a targeted 4.6 million tonnes, the company running the project estimates the captured CO_2 contributed to increasing oil production at the West Ranch oil field from 300 barrels per day to over 4,000.

This price differential of CCS-equipped coal plants is likely to be further exacerbated by the cost decline in renewables. In 2022, IPCC found that costs of solar and wind energy, and batteries have fallen by around 85% since 2010. With renewables expected to increase their share of electricity generation, it is unclear to what extent CCS would be needed in coal and gas power plants in the future.

Hydrogen production

- **Current use of CCS**: One project in Canada, capturing CO_2 from hydrogen for use in EOR
- **Future use of CCS**: One project under construction in Canada

CO_2 is produced as a by-product when hydrogen is made using natural gas or coal, known as 'blue hydrogen'. This hydrogen can then be used as a replacement for natural gas in some applications. However, blue hydrogen can have a greater impact on the climate than burning natural gas outright due to methane leaks in the supply chain. Blue hydrogen is also likely to face increasing competition from 'green hydrogen', which is made with renewable electricity, given the volatility of gas prices and residual emissions across its lifecycle production.

In Canada, the Quest CCS project captures CO_2 from the hydrogen produced to refine Canada's tar sands at the Scotford Upgrader in Alberta. Another hydrogen CCS facility in Alberta is under development and has received around USD 350 million in support from the Canadian government.