THE CCUS HUB

THE CCUS HUB PLAYBOOK

A guide for regulators, industrial emitters and hub developers

UNDERSTANDING CCUS

1. CCUS BASICS

1.1 UNDERSTANDING CCUS

WHAT IS CCUS?

Carbon capture, utilization and storage (CCUS) is a set of methods to stop carbon dioxide reaching the atmosphere.

The combustion of fossil fuels, and some industrial processes such as cement or steel making, emit carbon dioxide that is mixed in with other gases in various concentrations. A range of capture technologies are used to extract it in concentrated form. The carbon dioxide can then either be stored or used.

In carbon capture and storage (CCS), the captured carbon dioxide is transported predominantly by pipeline or ship to an offshore or underground storage site and pumped into a suitable storage reservoir such as a deep saline aquifer or depleted oil or gas field.

In carbon capture and utilization (CCU), the captured carbon dioxide is put to use. The carbon dioxide can be permanently locked up in a product (in construction materials, for example) or go into a process (such as enhanced oil recovery, EOR). It can also be used and then emitted – for example through chemical conversion to make synthetic fuels, displacing fossil-fuel use.

Today, CCUS projects around the world are storing millions of tonnes of carbon dioxide each year. We now need to turn millions into billions. One way to accelerate that scale-up is to focus on CCUS hubs, which take carbon dioxide from several sources and then transport and store it using common infrastructure.

WHY IS CCUS IMPORTANT FOR THE ENERGY TRANSITION?

CCUS can clean up the stubborn emissions that renewables struggle to reach. According to the International Energy Agency, “reaching net zero will be virtually impossible without CCUS”.

Industrial cleaner. Industry accounts for about 30% of global greenhouse gas emissions, mostly in the form of carbon dioxide. Some can be cut out easily using renewable electricity, but much cannot. For example, carbon dioxide is a by-product of some chemical processes, such as making the most common type of cement using limestone. CCUS may be the most realistic way to tackle those emissions. Many industrial processes also need intense heat, which can be difficult or expensive to provide with electricity using today’s technologies, so it usually comes from burning fossil fuels. CCUS could be the most cost-effective way to cut those emissions.

Power supporter. Future electricity generation is likely to be dominated by solar and wind power, with output that depends on the weather rather than tracking demand. On a still, grey day, we will need backup power. In many countries, backup will be provided by natural gas – which could supply low-carbon electricity with the help of CCUS.

Hydrogen launcher. Hydrogen will be an essential part of a net-zero world. It can be used to power heavy industry and long-range transport in a low-carbon way. It can also replace natural gas in providing heat. It is becoming an important part of Europe’s decarbonization plans. Eventually, most hydrogen will be made using surplus renewable power; in the meantime, gas-rich countries can drive the clean hydrogen market by making it from natural gas. This process generates carbon dioxide, so CCUS is needed to clean it up.

Air purifier. Just cutting down on emissions won’t be enough to prevent dangerous climate change. Some carbon dioxide will need to be taken out of the air, both to balance any remaining greenhouse gas emissions and to compensate for emissions in the past. This is known as carbon removal. The storage element of CCUS will be vital in ensuring the removed carbon does not return to the atmosphere.

HOW MUCH CCUS IS NEEDED TO REACH NET ZERO EMISSIONS?

The International Energy Agency (IEA) recently developed a scenario to show what technologies must be deployed to reach net zero emissions from the energy sector. It sees carbon capture reaching 1.6 billion tonnes (gigatonnes) per year by 2030 and 7.6 gigatonnes per year by 2050. To put that into perspective, stand-alone CCUS facilities can capture around 1-2 million tonnes of carbon dioxide per year. CCUS hubs will be able to store 5-10 million tonnes of carbon dioxide per year by 2030, so around two hubs a month would need to be built every year until 2030 to meet the IEA scenario.

In the IPCC Special Report on Global Warming of 1.5°C, nearly all of the 90 scenarios include CCS in some form. Across all scenarios, the average volume of CCUS in 2050 is 10 gigatonnes per year.

LEARN MORE

- CCUS: Barriers, enabling frameworks and prospects for climate change mitigation, The Oxford Institute for Energy Studies (January 2022)

HOW CCUS CAN SUPPORT INDUSTRIAL REGIONS AND JOBS

Renewable electricity and efficiency measures can only go part way to decarbonizing heavy industry. The main barriers are access to enough on-demand renewable power, the need for intense heat, and the carbon dioxide produced in some common chemical processes.

CCUS is currently the most promising and in some cases the only viable way to remove the remaining emissions from making cement, steel, chemicals and fertilizers.

Without CCUS, rising carbon prices in some countries could make their heavy industries uncompetitive, pushing production into countries where emissions are not regulated. Then, as countries introduce carbon border taxes to re-level the playing field, exporters will need to introduce CCUS or other decarbonization solutions to remain competitive. In July 2021, the European Commission announced plans for such a carbon border tax, to be phased in from 2026.

With CCUS to lift the carbon burden, industrial regions can survive and flourish while moving to low-carbon production. As well as preserving traditional industries and all the jobs that go with them, it promises to minimize disruption to society and economy by making use of existing infrastructure. The CCUS industry itself will bring new jobs and income. It can also enable industrial regions to reinvent themselves as low-carbon technology hubs, attracting low-carbon green businesses.

WHAT ARE THE ALTERNATIVES TO CCUS?

Low-carbon hydrogen is likely to be a friendly rival to CCUS in decarbonizing some areas of industry, and for backup power. When made using renewable power to split water, it is known as green hydrogen. This can be burned instead of natural gas in backup powerplants; it can replace the fossil fuels used in steelmaking; and it can provide high temperatures for some other industrial processes.

Green hydrogen is expensive today and is expected to take several years at least to scale up. Until then CCUS could give the hydrogen economy a boost, by enabling a different kind of low-carbon hydrogen – blue hydrogen – made from natural gas with carbon dioxide captured and stored. That would scale up the market for low-carbon hydrogen and pave the way for more green hydrogen in the future.

There are some industries where hydrogen is not a decarbonization solution. For example, it cannot decarbonize cement manufacturing, the source of over 5% of manmade global greenhouse gas emissions, which releases carbon dioxide from limestone used in the process. Alternative building materials are being explored that could eventually do away with the need for cement, but for the foreseeable future CCUS is the only way to cut emissions.

In the IPCC's Fifth Assessment Report, excluding CCS from the portfolio of technologies was found to double the cost of remaining within 2°C, the largest cost increase from the exclusion of any technology. Now that policymakers are exploring how to decarbonize industry in the next few decades, they are starting to see CCUS – as hard as it is – as faster, cheaper and more scalable than available alternatives.

IS CCUS NECESSARY FOR CARBON REMOVAL?

To meet the Paris goal of limiting global warming to 1.5°C, the world will almost certainly have to go carbon negative, taking a lot more carbon dioxide out of the air than is put into it. Nature-based solutions like planting trees and other land-use change can address part of the challenge, but the required quantities are so vast and the need for more durable solutions so crucial that technological solutions will be unavoidable.

Some emerging solutions, such as biochar and enhanced weathering, use technology to support and enhance natural solutions. The IPCC estimates that each of these could remove up to a few gigatonnes of carbon dioxide per year in 2050, but uncertainties are large.

The leading technological carbon removal options involve CCS. Bioenergy with carbon capture and storage (BECCS) bolts CCS onto power plants that burn biomass – so plants suck carbon out of the air, which is then buried via CCS. Direct air capture and storage (DACS) captures carbon dioxide directly from the atmosphere. These technologies are certainly not perfect. DACS is expensive and requires large amounts of energy, while BECCS will require a source of sustainable biomass in vast quantities, without competing for agricultural land. They are, however, crucial options to develop as part of net zero strategies.

By scaling up CCUS now, the world will make a vital start on building the infrastructure needed for this negative carbon effort.

HOW MATURE IS CCUS TECHNOLOGY?

Carbon capture has been in use since the late 1930s, using carbon dioxide as an ingredient for carbonated drinks and other industrial purposes. The storage part began in 1972, when a plant in Texas started injecting captured carbon dioxide into an oilfield, in order to force more oil out of the wells – a process known as enhanced oil recovery (EOR). Pure geological carbon storage, without EOR, goes back to 1996, when Norway started pumping carbon dioxide captured from natural gas production into a saline aquifer under the North Sea at its Sleipner facility.

These two uses – EOR and natural gas processing – still account for most of the 40 million tonnes of carbon dioxide captured globally each year. While these uses will continue and can support CCUS business models, the scale-up of CCUS needs to focus on abating industrial and backup power emissions, as well as negative emissions.

HOW DOES CARBON CAPTURE WORK?

In the exhaust from industrial processes and fossil fuel powerplants, carbon dioxide is mixed in with nitrogen, oxygen and other gases. So CCUS first separates out the carbon dioxid.. The main method currently used to do this is amine scrubbing. Flue gas is piped into the bottom of a vertical reactor vessel, where it rises up through a mist of a carbon dioxide absorbing liquid (usually an amine solution). The scrubbed gas is released at the top, with typically 90% or more of its carbon dioxide removed. The amine then goes to another vessel where high-temperature steam takes out the carbon dioxide. Finally, the near-pure carbon dioxide is compressed ready for transport.

Other approaches are being pursued to reduce costs and improve efficiency. One option is to use solid calcium oxide that reacts with carbon dioxide in flue gas to become calcium carbonate, which is then heated to reverse the reaction and generate concentrated carbon dioxide. Then there are polymer membranes that can separate gases, as well as adsorption onto the surface of porous structures such as metal-organic frameworks.

Instead of catching the carbon dioxide after combustion, fuel can be pre-treated at high temperature to turn it into a mixture of carbon dioxide and hydrogen. One of the capture technologies is to separate out the carbon dioxide, keaving hydrogen that is burnt as low carbon fuel. It is also possible to burn fuel in pure oxygen to generate a stream of concentrated carbon dioxide, doing away with the need for any gas-separation technology. This technology is, however, still in development.

HOW DOES CARBON TRANSPORT WORK?

The main options are pipelines, ships and tanker trucks. For pipeline transport, the carbon dioxide gas is usually compressed. At a pressure of more than 74 atmospheres it enters what's known as densephase: dense like a liquid, but highly compressible and low viscosity like a gas. Pipeline transport is the lowest-cost option for large volumes of carbon dioxide or where pipeline infrastructure already exists. This is the solution being used by Net Zero Teesside in the UK and Port of Rotterdam in the Netherlands, for example.

Where stores or pipelines are not readily available or volumes are smaller, carbon dioxide can be chilled into a liquid state to go on ships and/or tanker trucks for transport to the injection location. The transport cost per tonne is higher, but the solution offers greater flexibility for collecting multiple sources, requires less capital expenditure upfront and is lower risk in built-up areas. Northern Lights in Norway is developing an innovative solution to allow emissions to be collected by truck from emitters from across Europe, brought to ports where it is shipped to Norway and stored in a saline aquifer in the North Sea.

HOW DOES CARBON STORAGE WORK?

The aim of CCUS is to keep carbon dioxide permanently out of the atmosphere. The favoured method is geological carbon storage – injecting carbon dioxide into deeply buried rocks. It is injected at high pressure, in a state that is both dense like a liquid and low viscosity like a gas.

Before injection can take place, the subsurface is studied and tested with seismic analysis to verify that the site is suitable for storage. Suitable rock formations are porous, to accommodate the carbon dioxide, and sealed off by impermeable layers of rock above.

Depleted oil and gas fields fit the bill, as the geology is well known and has demonstrated ability to hold oil and gas and natural carbon dioxide underground for millions of years, trapped in microscopic rock pores and under impermeable cap rocks. Old wells are potential leakage sites, so they need to be plugged with cement and monitored to ensure the storage is secure. The Porthos CCUS hub in Rotterdam plans to use a depleted gas field in its first phase.

Carbon dioxide can also be injected into large saline aquifers, where brine is held within porous rocks. Some carbon dioxide gets trapped in small pores, while the majority flows upwards to be trapped under the impermeable caprock. Over hundreds to thousands of years it dissolves in the brine, eventually combining chemically with the rock. This last process, mineralisation, ensures storage for thousands of years, and also occurs in depleted oil and gas fields. (For more detail on trapping mechanisms see this 2019 review article.)

Saline aquifers have more potential capacity than depleted oil and gas fields, but they are less well studied and therefore require more appraisal work upfront to support carbon dioxide storage on a huge scale. Northern Lights in Norway and the Net Zero Teesside and Humber CCUS hubs in the UK are using saline aquifers for storage.

Close monitoring using seismic data, helps to confirm that the carbon dioxide is migrating within the rock space as expected. If it does not, the operator can change the injection pressure or sites to manage its behaviour.

Another option is mineral storage: chemically reacting carbon dioxide with calcium or magnesium-based minerals to form stable carbonates. This is currently much more expensive than geological storage and uses a lot of energy. Mineralization is being used on a small scale in Iceland to store carbon dioxide from direct air capture. Research is underway in several countries to test its potential for large-scale storage.

HOW MUCH GEOLOGICAL STORAGE SPACE IS AVAILABLE?

The Oil and Gas Climate Initiative has put together a CO_2 storage resource catalogue covering more than 700 potential geological sites in 18 countries. The catalogue estimates potential global carbon dioxide storage capacity at roughly 13,000 gigatonnes – more than enough to meet projected needs for CCUS over the coming century. Around 550 gigatonnes is identified as 'discovered capacity' – sites where at least one well has been drilled to establish the potential for carbon dioxide storage. Further exploration is expected to reveal many more such sites.

HOW MUCH DOES CCUS COST?

CCUS is costly, but both scientists and politicians have calculated that it is the most cost-effective way to decarbonize industry. The IPCC's Fifth Assessment Report found that excluding CCS from the portfolio of technologies doubled the cost of remaining within 2°C, the largest cost increase from the exclusion of any technology.

More recently, politicians in the Netherlands and Norway have determined that CCS is the cheapest way to remove carbon dioxide emissions at scale. In the Netherlands, the government held an auction in 2021 to identify the cheapest price per tonne of industrial carbon dioxide reduction. CCS solutions were the most cost-effective by far, taking 40% of the available subsidy budget to achieve 60% of the government's targeted emission reductions. In Oslo, the City Council identified CCS on waste-to-energy as the most cost-effective option for decarbonizing these hard-to-abate facilities, and cities across Europe are now working on this solution..

The exact cost of CCUS depends to a great extent on the mixture of gases it has to deal with. If there is a high proportion of carbon dioxide, at high pressure and on a large scale, it is relatively easy to capture, making costs lower than for dilute or low-pressure exhaust gases. A 2021 Global CCS Institute report showed that for industries making fertilizers or ethanol, capture cost is well below $50 per tonne; for steel it can be around $100 per tonne, rising up to around $250 per tonne for aluminium. In 2017 the Institute calculated the cost of pipeline transport and storage to be $7 to $12 per tonne for onshore, and $16 to $37 per tonne for offshore.

Overall, CCUS costs are expected to fall rapidly as the industry grows and more cost-effective capture technologies mature. CCUS hubs are expected to accelerate this process through economies of scale on transport and storage, as well as standardization effects as new industries deploy and develop new capture technologies.

HOW SECURE IS CCUS?

It is vital that stored carbon dioxide stays stored, rather than leaking into the atmosphere. Leakage risk is low in a well-managed reservoir, but can occur in small volumes through ill-maintained abandoned wells or rock fractures. The risk of carbon dioxide leaks decreases significantly once the injection stops, wells are sealed and longer-term trapping mechanisms lock in a growing proportion of the carbon dioxide.

A 2012 report for the UK's Department of Energy and Climate Change looked at the risks of carbon leakage from sites in the North Sea. The report acknowledged that there is considerable uncertainty over some of the risks, notably from faulting. But even the upper end of their assessments saw only a very small percentage of carbon dioxide leaking out. The report concludes: "Overall, the risk of experiencing a leak over the anticipated lifetime of a storage site is considered to be very low and the magnitude of any associated carbon dioxide loss is estimated to be low and manageable through existing and proven corrective measures."

WHAT IS THE RISK OF INDUSTRIAL ACCIDENTS?

Transporting large amounts of any gas holds the potential for accidents. A sudden pipeline failure could release a cloud of gas, and because carbon dioxide is denser than air it would stay close to the ground and settle in any depressions, with potential for asphyxiation. But risk assessment and safety measures deployed by the industry are well developed, with CCUS projects running safely for decades. Where there are innovations such as carbon dioxide shipping, engineers have developed tanks with thick walls made of special high-tensile nickel steel alloy to cope with the high pressure and density.

A 2009 IEA study concluded that "the industry has sufficient experience…to conduct CCS operations safely". The UK's Health and Safety Executive comes to a similar conclusion: "where the risks are properly controlled the likelihood of a major hazard incident is expected to be very low, as in other similar processes in the energy, chemical and pipeline industries." As the industry scales up, there stakeholders will conduct further research into safety.