THE CCUS HUB

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A playbook for regulators, industrial emitters and hub developers

2023 EDITION

FOREWORD

CCUS hubs are driving the deployment and development of carbon capture, transport, use and storage, with governments and companies increasingly working in partnership to accelerate scaling up of this set of critical climate mitigation technologies.

A lot has happened since we launched The CCUS Hub platform in early 2022. The number of CCUS hubs in development has grown strongly, with an additional 210 Mt of new dedicated storage capacity announced over the year. Governments, led by the US, the EU and the UK are strengthening policies and regulatory frameworks to drive private sector investment in CCUS. The numbers themselves are compelling, but it is the emergence of real market dynamics that is most exciting.

We are seeing competition between countries to take advantage of the opportunities that CCUS brings. When the US massively improved its 45Q tax credit scheme in early 2022, it unleashed a wave of new supportive policies around the world. National and local governments responded, recognizing not only that CCUS hubs can help strengthen their domestic industrial base while decarbonizing, but also that providing carbon storage can become a significant service export as the world decarbonizes – building both on demand for storing industrial emissions and enabling carbon removal at scale.

Potential carbon transport and storage providers started competing to make sure they had the best access to the best carbon storage resources. But they also started collaborating more to create a value chain that makes CCUS possible at scale. If there is one lesson that is already clear, it is that CCUS will only get close to achieving its potential if we collaborate.

With so much happening on the ground, we're delighted that OGCI has updated the CCUS Hub playbook and provided translations to share the lessons we are learning as CCUS hubs develop more widely. playbook and provided translations to share the lessons we are learning as CCUS hubs develop more widely.

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THE CCUS HUB

THE CCUS HUB PLAYBOOK

A guide for regulators, industrial emitters and hub developers

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 or remove what is already there.

The combustion of fossil fuel and some industrial processes such as making cement or steel emit carbon dioxide that is mixed 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 utilized.

In carbon capture and storage (CCS), the captured carbon dioxide is transported predominantly by pipeline or ship to an onshore or offshore 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) that ensures permanent storage. 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. But millions need to turn into billions to meet the Paris Agreement goals. One way to accelerate CCUS 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 a quarter of global GHG emissions, most in the form of carbon dioxide. Some of those emissions can be eliminated 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, backup power will be needed. In many locations, 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 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 will not 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) has developed a scenario to show what technologies must be deployed to reach net zero emissions from the energy sector. It sees carbon storage capacity reaching 1.2 gigatonnes a 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 are likely to store an average of 10 million tonnes of carbon dioxide per year by 2030, so around four hubs each quarter would need to be built every year from 2024 to 2030 to meet the IEA scenario.

In the latest IPCC AR6 reports, nearly all the 97 scenarios that keep global warming below 1.5°C with no or limited overshoot include CCUS in some form – for industries, power and for carbon removals – with 665 gigatonnes of carbon dioxide cumulatively captured and stored by 2100. That translates to around 10 gigatonnes of CO_2 capture and storage per year by 2070.

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

CCUS, in association with other clean technologies, can help industrial regions survive and flourish while moving to low-carbon production. As well as preserving traditional industries and the jobs and infrastructure that go with them, having access to carbon transport and storage infrastructure and clean hydrogen will help industrial regions attract new green businesses across the supply chain.

The CCUS industry itself will also bring new jobs and income. Developers of two UK hubs, HyNet NorthWest and the East Coast Cluster, predict that potential job gains could be significant: 6,000 regional jobs in the area around HyNet and 25,000 jobs per year to 2050 for the East Coast Cluster.

Imperial College London is developing a new tool for The CCUS Hub using a standardised methodology to show the economic impact of deploying CCUS technologies on a range of industries in four UK regions. The methodology can be applied to other global regions.

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 clean hydrogen – blue hydrogen – made from natural gas with CCS.

That would scale up the market for clean 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 manufacture, the source of around 7% of global carbon dioxide 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 primary way to cut emissions.

IS CCUS NECESSARY FOR CARBON REMOVAL?

To meet the Paris goal of limiting global warming to 1.5°C, negative emissions are "unavoidable", according to the IPCC. Carbon removal is essential to balance residual emissions from aviation, shipping and heavy industry – it is the 'net' in net zero. It can also remove historical or legacy emissions – carbon dioxide still in the atmosphere from past industrial activity.

Nature-based solutions like planting trees and other land-use changes can address part of the challenge, but the required quantities of carbon dioxide to be removed are so vast and the need for more durable solutions so crucial that the large-scale deployment of engineered and hybrid solutions will be vital.

Some solutions, such as biochar and enhanced rock weathering, use technology to support and enhance natural solutions. While still nascent, methodologies are now available and dozens of companies in both areas are currently developing commercial-scale operations.

Two of the leading technological carbon removal solutions – bioenergy with carbon capture and storage (BECCS) and direct air capture and storage (DACS) – require the infrastructure of CCS. BECCS bolts CCS onto power plants that burn biomass – so plants suck carbon out of the air, which is then injected into saline aquifers or depleted oil and gas reservoirs, or mineralised in rock. Direct air capture and storage (DACS) captures carbon dioxide directly from the atmosphere and then permanently stores it in geologic formations.

Both technologies are in the early stages of development and expensive. DACS requires large amounts of energy, while BECCS requires a source of sustainable biomass in vast quantities, without competing for agricultural land. There is a growing consensus, however, that they are crucial options to develop at scale as part of global net zero strategies. As a result, momentum is growing and costs are projected to fall with further deployment.

CCUS infrastructure designed to decarbonize industry is often seen as preparing the infrastructure for carbon removal to be developed at scale in the future. Over the past year, however, carbon removal facilities have been touted as anchor projects for broader industrial CCUS hubs. 1PointFive expects its direct air capture facilities – including one currently under construction in Texas – to be the anchor for other companies that want to use its transport and storage infrastructure. Similarly, in Denmark, Orsted's planned BECCS plants are expected to provide the infrastructure for decarbonizing a refinery and other companies.

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 increase oil production from 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 will focus on abating industrial and backup power emissions, as well as negative emissions. That requires adapting existing technologies for new applications and testing them on a new scale. Until recently, a commercial-scale stand-alone CCUS facility had a storage capacity of around 1-2 million tonnes per year. The average storage capacity for CCUS hubs currently under development is around 10 million tonnes per year, a figure that is likely to grow as technology is standardized and costs fall.

HOW DOES CARBON CAPTURE WORK?

In the exhaust from industrial processes and fossil fuel powerplants, carbon dioxide is mixed with nitrogen, oxygen and other gases. Carbon capture separates out the carbon dioxide to get a level of purity that facilitates compression and makes the gas safe for transport and storage, avoiding risks due to corrosion and chemical reactions.

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. There are also 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 capture technology separates out the carbon dioxide, leaving 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.

LEARN MORE

- Technology Centre Mongstad: Opportunities for streamlining CO_2 capture technology (February 2023)

HOW DOES CARBON TRANSPORT WORK?

The main options are pipelines, ships, tanker trucks, barges and trains. For pipeline transport, the carbon dioxide gas is usually compressed. At a pressure of more than 74 atmospheres it enters what is known as a supercritical phase: dense like a liquid, but highly compressible and low in 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 planned for use by the East Coast Cluster in the UK and Porthos in the Netherlands, for example, and for the bulk of planned US hubs.

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 the first hub to develop a shipping option. It will start operations in mid-2024, collecting carbon dioxide from terminals and taking it by ship to temporary and then permanent storage. It has ordered two medium-pressure 7,500 cubic metre liquid carbon dioxide carriers from China for delivery in 2024 and two more for 2025. That will meet its initial target of 1.5 million tonnes per year. To reach its Phase 2 goal of 5 million tonnes per year, from a range of European ports, it will need many more ships of different sizes, as well as inland waterway barges, able to transport carbon dioxide safely, also at lower temperatures and pressures.

The development of more complex transport options in Europe is also leading to the development of new players in the value chain that take responsibility for elements such as compression, temporary storage, transport to terminals and the building of terminals at ports.

LEARN MORE

- ZEP/CCSA, Guidance for CO_2 transport by ship (March 2022)
- CATF, Europe's cross-border CO_2 networks start to take shape (February 2023)

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 supercritical state that is both dense like a liquid and low in viscosity like a gas.

Before injection can take place, the subsurface is studied and tested with well and geophysical data 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. Wells that have been abandoned or not plugged properly are potential leakage sites, so these conditions need to be reviewed to ensure their ability to contain high pressure carbon dioxide. Carbon dioxide storage into a depleted field was already implemented as part of the Lacq CCS demonstration pilot.

Carbon dioxide can also be injected into large saline aquifers, where brine is held within porous rocks. While some carbon dioxide gets trapped in small pores, 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. (For more detail on trapping mechanisms see this 2019 review article.)

Saline aquifers have more carbon dioxide storage resources than depleted oil and gas fields, but they are less well characterized and therefore require more appraisal work upfront to support carbon dioxide storage on a large scale. Sleipner offshore Norway has been injecting carbon dioxide in a saline aquifer since 1996 in line with initial expectations.

Close monitoring, using multiple approaches including 4-D 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, but is progressing in areas where there is plentiful geothermal energy along with suitable rock. Mineralization is being used in Iceland to store carbon dioxide from direct air capture via a facility that is currently being expanded. Pilot projects and further research are also underway in Oman, UAE, Saudi Arabia, Kenya and other countries to test the 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 that covers 850 potential geological sites in 30 countries. The catalogue compiles carbon dioxide storage resource assessments, summing to 14,000 gigatonnes – more than enough to meet projected needs for CCUS over the coming century. Less than 600 gigatonnes is identified as 'discovered resources' – sites where at least one well has been drilled to establish the potential for carbon dioxide storage. Further appraisal is expected to reveal many more such sites.

The Catalogue is updated annually. The 2023 iteration will cover additional European, Middle Eastern and North African Mediterranean countries.

WHAT IS THE POTENTIAL OF CARBON UTILIZATION?

In an ideal world, carbon utilization would shift CCUS from a fee-based waste-disposal business model into a self-financing recycling one. However, while carbon utilization is starting to pick up, it will account for just a tiny fraction of the gigatonnes of carbon lock-up needed for the foreseeable future.

Several industries today use carbon dioxide as a raw input for a variety of products and processes. According to the IEA, top uses for the carbon dioxide include fertilizer and enhanced oil recovery, while applications in food and beverage, healthcare and materials also claim significant market share. Worldwide demand for carbon dioxide is predicted to grow by more than 7% per year to 2030.

The expanding range of use cases for carbon dioxide could help make the economics of CCUS hubs feasible, but the big question is whether the carbon dioxide is ultimately released back into the atmosphere once sold to a third party. Most current commercial applications of carbon dioxide are not net-positive for the climate; for carbon utilization to play a key role in the development of CCUS hubs as a climate tool, the carbon dioxide must be locked away for good.

Nevertheless, several nascent use-cases could lead to lower- or zero-emitting options to business-as-usual, particularly in hard-to-decarbonize sectors like aviation. The IEA outlines several promising areas:

- **Synthetic fuels:** Captured carbon dioxide, in combination with hydrogen produced from green sources, could be used as feedstock for various types of liquid fuels. Burning these fuels in airplanes, for instance, would provide substantial climate benefits over traditional kerosene. Using synthetic fuel could also reduce greenhouse gas emissions from marine vessels.
- **Chemicals:** Captured carbon dioxide could be used to substitute for fossil-derived inputs to a number of everyday materials, including plastic, fibre and synthetic rubber. Climate benefits would endure as long as the material does not degrade, ensuring that the carbon dioxide remains sequestered in the end product.
- **Building materials:** Captured carbon dioxide could be used to substitute for various inputs at numerous stages of the production of different building materials, thereby sequestering it away indefinitely. One of the most promising applications could see it replace the water used in traditional concrete mixtures.
- **Biofuel:** Some companies are using captured carbon dioxide to supercharge the growth of living organisms like algae, which could then themselves be burned for fuel. Climate benefits could be substantial, especially if the carbon dioxide released while burning the biofuel is, itself, captured.

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 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 specific technology.

More recently, policymakers in the Netherlands and Norway have selected CCS as the most affordable way to mitigate industrial 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 reduction. In Oslo, the City Council identified CCS on waste-to-energy as the most cost-effective option for decarbonizing such hard-to-abate facilities, and cities across Europe are now working on this solution.

For most sectors, capture is by far the most expensive part of the process, with the exact cost depending largely 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. In 2022, the US Department of Energy's NETL report calculated that for industries with high-purity carbon dioxide streams such as those making fertilizers or ethanol, capture cost ranges from $19 to $32 per tonne of carbon dioxide. For cement the capture cost is around $60 per tonne and for steel around $65.

Transport and storage costs depend on the distance to cover and the infrastructure available. In 2017, the Global CCS 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. In Europe, where pipelines are less prevalent, the Clean Air Taskforce (CATF) estimates transport and storage costs to fall from a range of $75-270 per tonne, depending on location, to less than $65 everywhere as new storage sites are identified.

Overall, CCUS costs are expected to fall rapidly as the industry grows and more cost-effective capture technologies mature. The capture costs above are already substantially lower than earlier cost calculations reflecting closer work on actual facilities. 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.

LEARN MORE

- NETL, Cost of Capturing CO_2 from Industrial Sources, (July 2022)
- CATF, Mapping the cost of carbon capture and storage in Europe (February 2023)

HOW SECURE IS CCUS?

It is vital that stored carbon dioxide stays stored, rather than leaking into the atmosphere. Leakage risk is extremely 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. As the IPCC AR6 report concludes: "If the geological storage site is appropriately selected and managed, it is estimated that the CO_2 can be permanently isolated from the atmosphere."

The industry has had almost 20 years' experience, starting with Sleipner in Norway, of observing actual carbon storage projects that closely monitor what happens to the carbon dioxide once it is injected. These projects have provided reams of data and the chance to use learnings to make guidelines for future storage sites.

A new study, published in 2023, uses a new methodology to assess the possibility of basin-wide carbon dioxide leakage where billions of tonnes of carbon dioxide are injected underground in aquifers with caprocks. It finds that even in the worst-case scenario, where rocks present a large number of fractures, the carbon dioxide would be contained deep in the subsurface for millions of years.

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, possibly leading to asphyxiation. But the risk assessment and safety measures deployed by the industry are well developed, with CCUS projects running safely for decades. As part of 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."

1.2 THE ROLE OF CCUS HUBS

WHAT IS A CCUS HUB?

A CCUS hub takes carbon dioxide from several emitting sources, such as heavy industries and power, and then transports and stores it using common infrastructure. A CCUS hub can be more complex to establish than a CCUS value chain on a single point source, managed by one company; but CCUS hubs bring many benefits, including lower unit costs, reduced risk and the ability to standardize and scale up quickly. For emitters, the hub offering opens up CCUS as a decarbonization option without them having to take responsibility for building pipelines and drilling storage wells and without long-term liability for the stored carbon dioxide.

Most CCUS hubs will be based around industrial clusters, where emission sources are close together, as in the East Coast Cluster or China's Junggar Basin. But some will be geographically scattered, collecting emissions sources by pipeline or ship, as in Northern Lights in Norway and a series of planned hubs in the Asia-Pacific region.

WHAT ARE THE PROS AND CONS OF A CCUS HUB OVER A SINGLE PROJECT?

- ✔ **Faster scale up.** CCUS must expand rapidly to play a role in reaching climate goals. At present, the average large-scale CCUS project captures and stores around 1 Mt of carbon dioxide per year. Early CCUS hubs are aiming at around 5-10 Mt a year or more by 2030 and expect exponential growth. Future hubs are likely to be even larger.
- ✔ **Lower costs and investment risks.** Collective transport and storage infrastructure bring economies of scale in construction and operations, specifically in compression, dehydration, pipeline use and storage. At the same time, shared lessons and standardization will bring down the costs of carbon capture and reduce risk. In the early stages of appraising potential new storage sites for hubs, sharing costs and risks make it simpler to get started in areas that have not been developed.
- ✔ **More government support.** A hub can decarbonize an entire industrial region, supporting jobs and attracting new clean industries. Such social and economic benefits buttress a hub's contribution to meeting climate goals, increasing the likelihood that an individual project will gain government support. Efforts to create hubs in the UK, for example, have ensured that the government develops policy incentives for emitters and operators. The Norwegian and Dutch governments worked to change London Protocol regulations on the cross-border export of carbon dioxide, and both Northern Lights and Porthos – along with several associated emitters – have attracted large-scale EU funding. The Northern Lights JV has gained support from standard-setter Verra and emitting industries to take a new look at carbon accounting for CCUS and carbon removal, via the CCS+ Initiative.

- ✖ **Complexity.** This is the main disadvantage – and the reason we have set up this platform. A CCUS hub is a multi-stakeholder undertaking, which magnifies the need for careful communication and alignment between partners. Decisions on commercial relations, risk management and long-term investments must all be agreed between emitters, operators and government – who are all acting with different drivers and timescales. Countries that are pioneering hubs, such as the UK, Norway and the Netherlands, are building on years of frustrating attempts to get large-scale CCUS off the ground. They have learned lessons from these failures that they are now applying to make CCUS hubs a reality. Importantly, newcomers like Denmark and Malaysia have also taken these lessons on board to accelerate the implementation of CCUS hubs.

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WHAT FACTORS DRIVE HUB DEVELOPMENT?

Three conditions came together to enable the development of the earliest CCUS hubs in Norway, the UK and the Netherlands.

1. **Confidence that carbon storage exists and can be used,** due to previous work on CCUS and the involvement of companies with subsurface and transportation experience.

    - Northern Lights/Longship in Norway built on lessons learnt from over 20 years of experience storing carbon dioxide under the North Sea.
    - The East Coast Cluster in the UK built on the White Rose project which selected the Endurance Reservoir now being used by the hub's transport and storage operator, Northern Endurance Partnership.
    - Porthos in the Netherlands is based on the ROAD project in the Port of Rotterdam, and carbon dioxide suppliers Shell and ExxonMobil have engaged their upstream subsurface engineers to build confidence in storage capacity.

2. **National and regional support** to incentivize and build confidence for the large, high risk capital investments initially required.

    - In Northern Lights/Longship, the Norwegian government has committed to national political objectives for CCUS and, in the first phase, is subsidizing 80% of investment costs for emitters and transport and storage infrastructure.
    - In the UK's East Coast Cluster, both regional and national authorities are politically committed to supporting the North's industrial regions through the energy transition.
    - In Porthos, the Port of Rotterdam wants to position itself as a clean industrial hub and national authorities are committed to industrial decarbonization.

3. **Understanding of the CCUS hub value proposition** by a group of stakeholders involved in knowledge building and lobbying – smoothing the pathway and creating a broader ecosystem.

    - Knowledgeable ministers have driven support at the top of the house. In Norway, governments and industry learned how to work together productively from failed attempts to start CCUS facilities in the 1990s.
    - Industry associations have created synergies at lower levels – such as the Energy Technologies Institute and the Carbon Capture and Storage Association in the case of the UK clusters.
    - Cross-national engagement between ministers and policy-makers from Norway, the UK and the Netherlands was crucial. They communicated frequently to exchange information, provide support and explore how a potential network of linked projects can be created to reduce costs and risks.

CCUS's long history has been instrumental in building strong foundations for these early CCUS hubs, but other countries and hubs are building on these lessons – and learnings from introducing other clean technologies – to move far more quickly. This acceleration will be essential for CCUS hubs to fulfil their potential.

Denmark has taken just a few years to do what Norway, the UK and the Netherlands did over decades. CCUS was made legal in Denmark in 2020 as the government recognised its necessity for achieving a legally binding target to reduce greenhouse gas emissions by 70% by 2030 and reach carbon neutrality by 2050. Since then, the government has moved quickly to develop all three factors listed above. Specifically it:

Created confidence that carbon storage resources exist and can be used
- commissioned seismic studies covering the entire Danish storage resource both onshore and offshore
- streamlined storage permitting for four pilot projects
- tendered for carbon storage permits
- launched environmental impact assessments

Built national and regional support
- gained public, parliamentary and municipal support for CCS through the Danish Climate Agreement
- built public-private partnerships to launch hubs
- requested six cities to develop collaborative industrial cluster plans

Demonstrated the CCUS hub value proposition

- allocated €5 billion for CCUS and carbon removal projects
- introduced laws and signed agreements to allow cross-border trade of carbon dioxide
- introduced green taxation for industry

Denmark expects to start its first injections of 400,000 tonnes of carbon dioxide in 2025, with plans in place to reach 3 million tonnes by 2030. Danish storage capacity is estimated at 22 gigatonnes and the country sees itself as a carbon storage hub for Europe.

LEARN MORE

- State of Green (Denmark), Carbon capture, utilisation and storage: picking the high-hanging fruits of CO_2 mitigation (November 2022)

In **North America**, CCUS ecosystems have also developed in areas such as the US Gulf Coast and Alberta, where the Quest CCS facility has operated for over six years. In the US, CCUS evolved initially in relation to enhanced oil recovery projects, which resulted in both storage knowhow and pipeline infrastructure. Now, with significant support from the Department of Energy for projects, hubs and research and development, CCUS is increasingly being seen as a key part of low carbon business transformation for US industry.

- Multi-stakeholder coalitions have been responsible for developing and expanding the 45Q carbon storage tax credit through the US federal government legislative process and building knowledge among policymakers.
- Knowledge sharing by groups of emitters and potential hub developers, including OGCI, has also been crucial to get state-level support and regulations in place and to help industrial emitters understand the options.
- Competition between potential operators, eager to take first-mover advantage now that incentives are available, is now driving the industry.

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Get a concise summary of latest CCUS hub trends in:

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- USA
- Asia-Pacific

WHERE IN THE WORLD ARE CCUS HUBS POSSIBLE?

OGCI is continually analyzing the global potential for CCUS hubs as part of the CCUS Hub Search tool. We have reviewed the potential for CCUS hubs in 52 countries, focusing on how much carbon dioxide can be captured and stored, and at what cost (techno-economic potential), as well as the environment of policy, regulation and commercial readiness.

Most of the 52 countries have potential CCUS hubs with cost levels below $100/tonne for capture, transport and storage, assuming existing technology costs. These span all world regions, and add up to 933 Mt of abatable annual emissions or around 2% of total emissions.

The most promising near-term opportunities are regions where high techno-economic potential meets a supportive environment. The Tool identifies 23 such potential CCUS hubs, representing 319 Mt of annual emissions that could be abated.

CAN CCUS HUBS BE SET UP EVEN WHERE THERE ARE NO GOOD LOCAL STORAGE OPTIONS?

Yes. Where there is no convenient storage site, it is possible to create a geographically distributed CCUS hub, with ships or a pipeline carrying carbon dioxide to a distant storage site. The cost of using ships for transport is more expensive on a large scale than a localized hub based on pipelines, but a shipping solution has two advantages: it supports the gradual development of a CCUS hub, and allows one storage facility to serve several smaller CCUS emission clusters.

The Northern Lights project in the North Sea is the most advanced example of a distributed hub and it is building ships that can safely carry large volumes of carbon dioxide. Several projects in Europe are looking at the potential of using multimodal carbon dioxide transport – road, rail, inland barges and maritime shipping, as well as pipelines – to offer services to new clusters of emission sources. These projects are disaggregating the CCUS value chain, creating nodes for collection, compression and temporary storage, or new transport operations. In 2023, the EU opened funding to cross border carbon transport and storage infrastructure projects as part of its broader energy infrastructure strategy.

Hub projects in Asia are also exploring how to manage the mismatch between the concentration of industrial emissions and the availability of suitable storage sites. A consortium of six South Korean industrial companies, for example, is working with Petronas in Malaysia, to create a full carbon capture, transport and storage value chain between the two countries.

CAN A CCUS HUB SUPPORT CARBON REMOVALS?

Yes. Negative emissions, also known as carbon dioxide removal, require carbon dioxide to be taken out of the atmosphere and then stored. This is possible through various natural, hybrid and engineered approaches, and some of the most promising and scalable approaches involve CCUS technology.

Removals are already being built into hub concepts. At the East Coast Cluster, one power station will burn biomass, in a process known as bioenergy with carbon capture and storage (BECCS). Northern Lights is already collaborating with world leaders in direct air capture and BECCS technology.

In the US, a specific federal programme is providing $3.5 billion in support to set up four regional direct air capture (DAC) hubs, each storing at least a million tonnes of carbon dioxide per year. California, for one, has proposed an ambitious DAC hub in the state's Central Valley.

Even CCUS hubs that don't include carbon removal technologies will help indirectly, doing their bit to drive a massive scale-up of CCUS infrastructure. This will enable the kind of multi-gigatonne negative emissions that will be needed in the next few decades.

1.3 STATE OF PLAY

WHAT IS THE CURRENT STATUS OF CCUS AND CCUS HUBS?

The CCUS project pipeline is more robust than ever. Investment in CCUS almost tripled in 2022 to $6.4 billion, according to BloombergNEF, with a total of almost $12 billion invested over the past three years. The US led development with 45% of global investment, overtaking Europe, but the trend is broad, with large new investments in Australia, Malaysia and China.

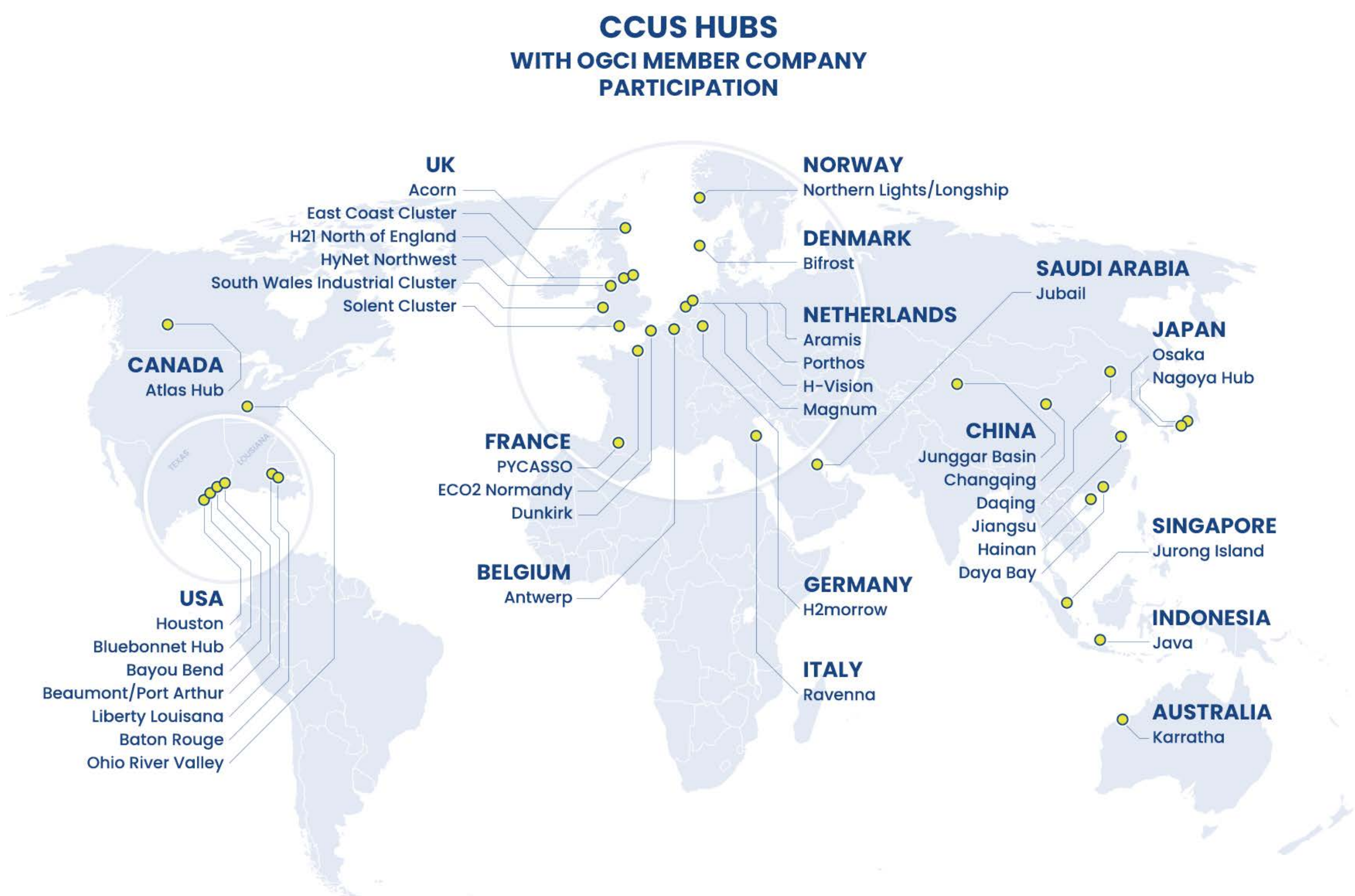
The 2022 status report from the Global CCS Institute identifies 30 commercial CCUS facilities operating around the world, with a total capture capacity of about 43 million tonnes of carbon dioxide per year. While the number of projects in development rose to 196, an increase of 44%, the capacity of planned projects more than doubled and now totals 244 million tonnes per year.

That capacity increase is largely due to CCUS hubs becoming the predominant method of deployment. According to the IEA, there are currently over 140 CCUS hubs proposed or in development around the world, more than three times as many as in 2021. Over 30 of these hubs are being developed with the involvement of OGCI member companies (see map).

Growth is accelerating as governments and companies focus on how to implement net zero targets, interest in low carbon hydrogen grows and CCUS hubs open scalable options for industrial decarbonization.

LEARN MORE

- GCCSI, 2022 Status Report, 2023
- IEA, CCUS Projects Database, 2023



CCUS HUB TRENDS IN THE US

Two major pieces of enabling legislation, designed to drive down costs and kickstart the CCUS industry, have transformed the hub landscape in the US. The Infrastructure Investment and Jobs Act, passed in November 2021, provided over $12 billion in funding for CCUS over five years. The Inflation Reduction Act enhanced the 45Q tax incentives, opening access to a wider group of emitters and extending validity (projects must start before 2033 to qualify and have 12 years of subsidies).

These changes have created confidence among potential hub operators that there will be funding now and until 2050. That has kickstarted a competitive race to snap up pore space and develop multiple connected hubs that would lower risk for operators.

Trends in 2023:

- There will be dozens of new announcements for hub projects as potential transport & storage operators sign leases to rent pore space.
- Competition is growing among hub operators to be first movers and get access to pore space that has the fewest old wells requiring expensive remediation.
- A few states will lead the way, including Texas, Louisiana and Wyoming – but interest is growing across the country as land-owners see a new revenue source.
- Pressure is growing from industrial emitters to get access to storage, with some looking to take equity in stores with the aim of gaining privileged access.
- Direct air capture facilities, which attract higher tax incentives and have an additional revenue stream from carbon credits, will play a significant role in many hubs as an anchor and risk-reduction mechanism for operators.
- The biggest roadblock for CCUS hubs will be Class VI well permitting, a process that despite federal and individual state efforts is moving significantly more slowly than incentives.
- With carbon dioxide pipeline infrastructure already widespread, pipeline operators are starting to become key players connecting multiple storage sites. Long-distance pipelines are unlikely to get permits.
- There will be a push to add new sources of value such as low carbon premiums and standards.

CCUS HUB TRENDS IN EUROPE

CCUS hubs are becoming part of mainstream industrial decarbonization strategies in many European countries, driven by projects in Norway, the UK, the Netherlands and Iceland. These were built on a fledgling set of funding incentives and regulations, but in response to US incentives, both the EU (Net Zero Industry Act) and national governments are currently developing new policy mechanisms and targets to support CCUS.

These developments look set to lead to a more comprehensive network of carbon management infrastructure that will connect hubs and generate increasing demand for carbon dioxide storage options from industrial emitters. The EU's CCUS Forum forecasts demand for storage services will rise from a very low base to 80 million tonnes in 2030, reaching 300 million tonnes by 2040.

Trends in 2023:

- Multi-modal, cross-border carbon transport infrastructure is developing across Europe to feed into carbon stores, especially around the North Sea.
- Several countries with storage capacity (particularly Norway, Denmark and Iceland) are focused on developing CCUS hubs as a lucrative service for European industry and governments.
- The European Commission will release a strategic vision for carbon capture in spring 2023, focusing on future funding models, infrastructure (including pipelines) and easier permitting.
- Bans on commercial-scale underground storage of carbon dioxide are being repealed, notably in Germany where the government is currently legalising geological storage and participating in cross-border infrastructure projects in order to sustain industrial competitiveness.

- The next generation of transport and storage hub projects is starting to emerge, relying on demand from and fees paid by emitters, rather than on capital grants or regulated assets.
- Onshore storage is no longer taboo in Europe, with Denmark conducting a survey of capacity and a pilot project.

CCUS HUB TRENDS IN ASIA-PACIFIC

There is huge potential for CCUS hubs in the Asia-Pacific region. A few hub projects are already underway in China (see Junggar Basin) and Australia; India recently announced it wanted to focus more on CCUS and Japan is exploring how to use depleted gas fields for CCUS.

What is really driving new CCUS hub developments, however, is demand from industrial countries with high industrial emissions but inadequate storage capacity – such as Japan, South Korea and Singapore – to gain access to significant underground storage resources in other parts of Asia (in particular, Malaysia, Australia, Indonesia, China and possibly the Gulf states.)

A number of innovative cross-border hub concepts are emerging to bring these sources and sinks together. Some of these are based on a shipping model (for example, one project aims to bring emissions from South Korean companies to Malaysia for storage). Others are based on importing already abated energy sources (LNG, ammonia, hydrogen), supporting CCUS as needed in the country of origin or closer to the point of use.

These complex projects can build on a long history in Asia with the type of public-private ecosystems needed to develop CCUS hubs. Overall regulations and incentives, however, are still insufficient. Indonesia passed Southeast Asia's first detailed regulations to enable the development of commercial scale CCUS projects in March 2023.

WHY IS CCUS TAKING OFF NOW?

Governments and businesses are increasingly realizing that climate action is urgent, spurred in part by recent IPCC reports. Over 130 countries and over 800 of the world's 2,000 largest companies have net zero targets. As they implement them, they require solutions for decarbonizing hard-to-abate sectors such as steel, cement and chemicals. They also need solutions for negative emissions. CCUS is a ready solution.

In the past, CCUS tended to be viewed primarily as a way to decarbonize power. As a result, its cost was seen in relation to renewables. Now, both governments and businesses understand that its main value is in relation to industrial decarbonization strategies. In that light, CCUS can be the cheapest and quickest way to achieve rapid decarbonization while sustaining an industrial base and jobs. The infrastructure it creates can also be used to deploy carbon removal technologies.

Higher carbon prices, particularly in Europe, are driving emitters to look for new low-carbon strategies. The emergence of CCUS hubs provides emitters with an affordable service to abate their emissions.

Policy incentives and regulations for CCUS are maturing, particularly in Europe and North America, but increasingly in Asia-Pacific too. And there is now a huge quantity of finance seeking ethical investments, with ESG (environmental, social and governance) assets projected to reach $34 trillion by 2026.

This new momentum is now visible, with the number of new CCUS projects accelerating and investment tripling in 2022.

2. POLICIES & BUSINESS MODELS

2.1 POLICIES & REGULATIONS

WHY SHOULD GOVERNMENTS SUPPORT CCUS HUBS?

Governments have committed over $6 billion to accelerate the deployment of CCUS since 2021, led by the US, EU, Australia and the UK. They are driven by the recognition that accelerating the pace of industrial decarbonization will depend on the build-out of carbon management infrastructure.

There will be new technologies and approaches that transform heavy industrial sectors, but CCUS is currently one of the few viable ways to remove emissions from products such as cement, chemicals, fertilizers and waste incineration – those that require intense heat and even involve chemical processes that themselves produce carbon dioxide. Building out carbon transport and storage infrastructure will facilitate that hard-to-abate decarbonization, but it will also enable the production of abated power and clean hydrogen, and help scale up high-durability carbon removals. That makes it a no-regrets net zero strategy, rather than a transitional measure.

Supporting CCUS hubs, rather than one-off projects, is now seen as one of the most cost-effective ways to enable industrial decarbonization. Hubs leverage economies of scale, while reducing costs by allocating risk management along the entire value chain. That helps governments to meet interim and long-term national climate targets.

> *Explore the CATF's interactive cost calculator for capture and storage in Europe*

CCUS helps to enable a just transition, allowing existing industries to remain competitive, keep and create jobs and continue contributing to local economies while transitioning to a net-zero future. A CCUS hub can help industrial regions to keep existing industrial jobs. It also helps to attract new businesses close to storage areas, creating jobs and growth in industrial regions. The UK government expects CCUS to support up to 50,000 jobs and create a significant export opportunity.

CCUS hubs accelerate the commercial scale up of CCUS technologies and can help to create a new carbon management industry. Policy support can enable faster decarbonization in the short and medium term, tailormade to the specifics of one or more CCUS hubs, and phase out that support over time as a commercial industry evolves. For countries with significant geological storage resources, that can open up a significant new cross-border industry as a carbon manager for larger regions.

> *Watch Brad Crabtree of the Department of Energy talk about how the US is incentivizing commercialization of CCUS (04.58 – 9.00)*

Flexible power generation capacity that complements renewables can be an integral part of a CCUS hub – providing reliable low-carbon power for businesses in the hub area.

> *Read about the UK government's business model for dispatchable power with CCUS and standard contract terms*

Hydrogen is set to play a big role in decarbonizing industry, heating and transport, and the cheapest way to make low-carbon hydrogen today is using natural gas with CCUS. Integrating low-carbon hydrogen production into a hub provides energy for multiple applications in the industrial region.

> *Read about hydrogen at H2H Saltend in the East Coast Cluster*

CCUS hubs can also provide opportunities to remove carbon dioxide from the atmosphere at scale, through direct air capture with storage (DACS) and bioenergy with CCS (BECCS).

> *Read about Stockholm Exergi's BECCS project, with storage planned in Northern Lights*

WHY DO CCUS HUBS NEED GOVERNMENT SUPPORT?

Today's market models make it more favourable for industrial companies to emit carbon dioxide (even where carbon has a cost) than to invest in carbon capture and have the carbon dioxide stored. As carbon prices rise, incentives develop and mandates kick in, CCUS will become cheaper than emitting.

The most advanced CCUS hubs today are supported by government-backed incentives and subsidies that tackle two main challenges:

- Incentivising emitters to invest in capturing their carbon dioxide emissions – so they can maintain competitiveness despite today's market models
- Incentivising potential carbon transport and storage operators to invest in infrastructure – providing a business case despite the lack of a sufficiently high and stable carbon price to ensure demand

In addition, the incentives also need to address challenges throughout the CCUS value chain like performance risk and counterparty risk.

Policy support is likely to match the dynamics of low-carbon energies such as offshore wind. Early-stage demonstration focuses on proving that a novel technology works in practice. Scale-up develops a few projects near or at full-scale, proving viability and deliverability. In these initial phases, governments are likely to offer some form of development funding, followed by upfront co-funding of capital costs, as well as revenue support.

At roll-out, the objectives are to establish a sustainable industry and to build capacity via a funnel of projects, multiple developers, and a mature understanding of risks and contracting structures. As risks and costs fall, and the cost of private finance comes down, CCUS hub development could be driven by industry and supported by market-based mechanisms, based on giving a value to carbon. Government co-funding of the costs could then be phased out as commerciality is reached.

Once established, a mature and stable industry can attract commercial finance on acceptable terms. CCUS hubs will be sustained by an explicit or implicit carbon price, supported by further reductions in the cost of technology applied, and by growing demand for decarbonised industrial products. In this phase, government action would be limited to addressing any remaining market failures and removal of regulatory barriers.

WHAT KIND OF POLICY ENABLERS CAN SUPPORT CCUS HUBS?

Governments are using a range of different policy frameworks to help a CCUS industry get off the ground and scale rapidly. Government support is expected to decrease over time as the industry matures and sufficiently high carbon prices, mandates and/or market demand for low carbon products create business models.

These are the most common tools governments are using in different combinations to support the large-scale deployment of CCUS, especially through CCUS hubs. In most cases, mechanisms are stackable for the user to create a viable business model.

Grants/loans

Capital grants support investment in developing and deploying large-scale capture, transport and storage facilities. Particularly relevant in the early phases of CCUS hub development, these grant schemes can also include support for the operations phase, including minimum performance requirements.

Loans can offer preferential interest rates to support investment in CCUS.

Feasibility study grants are designed to help emitting companies in industries with tight profit margins to do due diligence on integrating CCUS into their processes. This is particularly important for companies that are pioneering the use of CCUS in their industry, such as waste-to-energy, glass and paper.

Carbon price

Carbon taxes on emissions, fossil fuel production, import or supply, often with revenues earmarked to subsidise clean technology projects through grants, as in Norway, Sweden and Denmark.

Emissions Trading Schemes set a carbon price that supports low-carbon technologies by reducing the cost of compliance. These can be cap and trade schemes as in the EU and UK, or benchmark and trade schemes such as the Australian Carbon Credit Units.

Carbon Border Adjustment Mechanisms, as in the EU, extend carbon pricing regimes to trade partners that are importing carbon-intensive products.

Tax incentives

Tax credits incentivize deployment according to tonne of carbon dioxide stored, as in the US 45Q credit, or via investment in CCUS equipment and infrastructure (as in Canada).

Public procurement

Contracts for Difference use the public procurement system to set a minimum price on stored carbon dioxide, paying the difference between the current market price and this floor, as in the UK (Industrial Carbon Contract) and Netherlands (SDE++). These are similar to Dispatchable Power Agreements, for power plants with CCUS that provide back-up power as needed to the grid.

Emissions performance standards for industry, power or products, such as California's Low Carbon Fuel Standards, now used by several states and provinces in North America.

Regulations

Carbon Storage Obligations are a polluter-pays model obliging fossil fuel companies to store geologically the carbon dioxide equivalent of any fuel extracted or imported. Not yet introduced anywhere, but under discussion.

Regulated Asset Base, as in the UK, sees transport and storage operators receive a licence from the regulator, granting them the right to charge an independently regulated price to users in exchange for delivering and operating the transport and storage network.

LEARN MORE

- Clean Energy Ministerial, Global Overview of CCUS Policies and Programmes (September 2022)

Policy support mechanisms for CCUS hubs

■ Grants/low-cost loans ■ Carbon price ■ Tax incentives ■ Public procurement ■ Regulations

Australia	Emissions Reduction Fund – CCS Method The Clean Energy Regulator issues (by auction or directly) Australian Carbon Credit Units (ACCUs), over a 25-year period, to new registered capture projects with permanent storage, including new capture points in CCUS hubs. ACCUs can be sold to the Government or on the secondary market.
	Carbon Innovation Grants Program (West Australia) • Feasibility studies (up to 50% of project costs, to a maximum of A$500,000) • Pilot projects and capital works (up to 25% of project costs, to a maximum of A$1.5 million)
Canada	Investment tax credits for CCUS • Valid 2022-2030; (credits decline after 2030 and expire in 2040) • 60% for investment in direct air capture equipment • 50% for investment in other carbon capture equipment • 37.5% for investment in transportation, storage and use Covers geological storage in Alberta, British Columbia and Saskatchewan (plus mineralization in concrete).
	Alberta Government incentives The Technology, Innovation and Emissions Reduction fund has created grants for specific CCUS projects and spawned an emissions reduction credit system, with offsets for capture and storage, sequestration credits and capture recognition tonnes.
China	Low-cost loans for emitters The People's Bank of China provides financial institutions with low-cost funds (interest rate of 1.7%) through a carbon emissions reduction facility, including carbon capture projects.
Denmark	Subsidies for CCS deployment 20-year contracts to be awarded through competitive tendering to industrial companies capturing and permanently storing at least 400,000 tonnes of carbon dioxide per year from 2026 (max. €55 million per year). Aid covers the difference between estimated total costs and expected returns. Total spend €2.4 billion, funded by green carbon tax. See sample contract.

Policy support mechanisms for CCUS hubs

■ Grants/low-cost loans ■ Carbon price ■ Tax incentives ■ Public procurement ■ Regulations

EU	Grants/low-cost loans	European Innovation Fund Risk-sharing support of up to 60% of additional capital and operation costs for large and small-scale flagship decarbonization projects, including a focus on construction of CCS infrastructure, carbon capture, and carbon utilization. Funds derived from ETS; disbursed between 2020-2030
	Grants/low-cost loans	Projects of Common Interest Accelerated permitting and Connecting Europe funding for key cross-border infrastructure projects, such as CCUS transport and storage infrastructure, connecting energy systems and aligned with the Paris Agreement.
	Regulations	Net Zero Industry Act A March 2023 proposal to include CCUS as one of eight strategic climate technologies, with a target of 50 million tonnes per year of storage capacity by 2030, support and possible mandate for developing storage capacity.
	Carbon price	Carbon Border Adjustment Mechanism The EU carbon border mechanism, designed to prevent carbon leakage (the shift of production to less-regulated jurisdictions) will be phased in transitionally from October 2023, with the system in full force from 2026. It sets a carbon price on carbon-intensive goods entering the EU to create a level playing field for EU producers as free ETS allowances are phased out. It could incentivise CCUS outside the EU.
Netherlands	Public procurement	SDE++ Operating subsidies based on a contract for difference on the ETS carbon price for carbon reduction projects, including CCUS. Reverse auction bidding based on application for a subsidy intensity limit (€ per tonne of CO_2). Funding is awarded over 12-15 years and continues through 2035
Norway	Grants/low-cost loans	Longship support scheme To kickstart the commercialization of the world's first CCUS hub, the Norwegian government is spending over €2 billion to cover around two-thirds of the cost of setting up the Northern Lights infrastructure and for two Norwegian capture projects. After that, funding for operators will come from commercial fees and for emitters from EU funding (for which Norway and Iceland are eligible).

Policy support mechanisms for CCUS hubs

■ Grants/low-cost loans ■ Carbon price ■ Tax incentives ■ Public procurement ■ Regulations

US	Tax incentives	45Q investment tax credit Amended with the Inflation Reduction Act in 2022 to raise levels, improve access, extend remit and lengthen duration. • $85/tonne for permanent storage • $60/tonne for EOR or other industrial uses, if emissions reductions can be clearly demonstrated • $180/tonne for direct air capture with permanent storage; $130/tonne for direct air capture with utilization • Projects have until 2033 to begin construction and the subsidies last 12 years.
	Grants/low-cost loans	Infrastructure Investment and Jobs Act $12.1 billion in total, divided between demonstration projects, pilot projects, front-end engineering and design (FEED) studies, shared transport infrastructure, storage site development, permitting, grants to states and direct air capture.
	Grants/low-cost loans	Grants for demonstration projects The Carbon Capture Demonstration Program and the DAC Hub program provide federal cost sharing for projects that advance the development, deployment and commercialisation of CCUS and DAC technologies.
UK	Grants/low-cost loans	Carbon Capture and Storage Infrastructure Fund £1bn to fund four clusters that can capture at least 10 million tonnes per year by 2030, including two already announced. Includes detailed government-supported business models for transport and storage, industrial carbon capture, power, hydrogen, waste. The Scottish government will independently award up to £80 million for one CCUS cluster.
	Regulations	Industrial Carbon Contract Mechanism to incentivize industrial users to deploy carbon capture technology to achieve deep decarbonization. Provides capital co-funding and ongoing revenue support, based on a payment for difference between a strike price and a reference price, for projects selected as part of the cluster sequencing process.
	Grants/low-cost loans	Direct support to large-scale CCUS hubs Announced in March 2023, the UK government has promised £30 billion over the next 20 years to support projects that aim to store 20-30 million tonnes of carbon dioxide annually.

DESIGNING EFFECTIVE POLICIES FOR CCUS HUBS

Identify the potential and value of CCUS

- Map sources of carbon dioxide from industry and power plants with their concentration and purity
- Map storage reservoirs, their type and capacities – saline aquifers, depleted oil and gas reservoirs
- Identify carbon transport options – pipelines, ships, barges, rail, trucks
- Quantify the socio-economic value of CCUS, including its potential for retaining and creating jobs

Set up national CCUS strategy and targets

- Articulate the role CCUS can play versus other levers to accelerate decarbonization in the national context
- Integrate CCUS into industrial, commercial and environmental policy
- Give relevant ministries the resources they need for implementation
- Develop a roadmap laying out targets for captured carbon dioxide
- Ensure a funnel of storage resource options are appraised in a timely manner to match the expected demand from captured carbon dioxide
- Design incentives to ensure industries meet those targets
- Provide support for storage maturation
- Review frameworks regularly to ensure they are keeping up with developments

Provide clarity with regulations

- Clarify issues around carbon transport, verification of capture and storage, the integrity of storage sites, monitoring, and long-term stewardship
- Design permitting process to be streamlined across the numerous regulatory actors

Assign roles and responsibilities

- Assign roles and responsibilities to the appropriate authorities for developing policies, incentives, and regulatory frameworks
- Doing so transparently and predictably in the context of a roadmap reduces uncertainties and de-risks capital investments
- In many cases it will be beneficial to assign one party to take the lead role for a CCUS hub development

Work on community acceptance

- Collaborate with local government, environmental organizations, trade unions, and other industries in the region

LEARN MORE

- Global Hub Search
- CO_2 Storage Resource Catalogue

DEVELOPING EFFECTIVE REGULATIONS FOR CCUS HUBS

Regulations relating to CCUS vary considerably by country. In order for CCUS hubs to scale, consistent regulations across geographies are necessary. Suggested guidelines for developing such regulations are as follows:

- Permit the adaptation of existing pipelines for carbon dioxide transport
- Enable new transport infrastructure such as pipelines, trucks, rail, ships and barges
- Streamline the process of awarding permits for capture, transport and storage
- Introduce standards for construction, operation and carbon dioxide injection
- Clarify storage liability: who is responsible at each stage of injection, monitoring and long-term stewardship; how is risk shared and eventually transferred to government.
- Introduce monitoring, reporting and verification protocols and processes for injected carbon dioxide to ensure safe, reliable, and permanent storage
- Establish provisions for carbon dioxide leakage
- Provide legal certainty on pore-space ownership and how it relates to mineral rights
- Develop rules for joint development of carbon dioxide stores that span land under licence by different companies
- Enable trans-boundary (state and national) movement and storage of carbon dioxide, including the delineation of associated risks and liabilities
- Ensure that emitters have access to carbon transport and storage infrastructure at reasonable rates
- Establish processes for stakeholder consultation

READ MORE

- What questions should policymakers ask themselves when developing policies and regulations for CCUS hubs?
- What are the policy lessons learned from the first generation of CCUS hubs?

2.2 BUSINESS MODELS

HOW DOES THE CCUS HUB VALUE CHAIN WORK?

The CCUS hub value chain is made up of three elements: capture, transport and storage. In the earliest hubs, the players typically consisted of a hub developer, who initiates and manages the value chain, several emitters who guarantee to capture and supply carbon dioxide, and a single transportation and storage company (that could serve several hubs).

As the industry evolves, however, the value chain has started to become more complex. In northern Europe, for example, industrial hubs are consolidating (as in East Coast Cluster) and coalitions are springing up to organize specific parts of the transport infrastructure (see Aramis, Antwerp@C). Specialized players are emerging to manage different aspects of the business: managing pipelines, retrofitting existing assets, shipping carbon and providing capture solutions.

At this stage of development, CCUS hubs will depend on government support to provide some form of upfront co-funding of capital costs and revenue to attract emitters and operators. That support is motivated by the need to decarbonize heavy industry, maintain and create jobs, and secure growth and global competitiveness.

As risks and costs fall, carbon price rises and demand for decarbonized industrial products grows, hubs will be driven by industry, supported by market-based mechanisms and commercial financing.

Hub developers can be:

- Companies building a business around providing transport and storage services to industrial emitters (Northern Lights)
- Companies looking to use CCUS initially for their own facilities but with the perspective of opening the transport and storage infrastructure to other emitters (Junggar Basin and Ravenna)
- A public-private partnership aiming to develop strategic infrastructure to support industry and jobs in a region (Porthos)
- A consortium of industrial companies aiming to tackle a decarbonization obstacle in their region through CCUS (Antwerp@C)
- A specialized infrastructure company, such as a pipeline company, looking to develop new markets

Emitters are responsible for developing facilities in their plant to capture carbon dioxide from their operations, purifying it to meet specifications and getting it to a pick-up point. If specific transport services are not available, they may need to take responsibility for compressing the carbon dioxide, transporting it to loading terminals, developing loading infrastructure and even providing temporary storage in tanks.

Transport and storage operators are responsible for transporting the carbon dioxide from a designated pick-up terminal to the storage site, where they inject it into the subsurface geology. As the industry evolves, dedicated carbon transport operators are emerging to provide a smoother link between individual emitters and storage operators. In northern Europe, for example, companies and joint initiatives are emerging in key industrial areas to compress the carbon dioxide, provide temporary storage facilities and transport carbon dioxide to North Sea ports for storage operators to collect.

LEARN MORE

- Carbon capture and sequestration – the business, pages 11-16, The Oxford Institute for Energy Studies (January 2022)

THE BUSINESS MODEL FOR EMITTERS

The business model for emitters depends on them securing revenue streams to cover both their investment in capture, purification and, potentially, compression facilities (capex) and the transport and storage fees they pay to the operator and any additional service providers (opex).

Revenue streams can come from a variety of sources, depending on the regulatory environment and the demand for carbon dioxide and related products from end-use customers. Depending on their location, emitters may be able to secure income from multiple revenue streams.

In the current phase of CCUS hub developments, some governments are looking to provide one-off capital grants to emitters for first-of-a-kind (FOAK) capture projects, for example through the CCS Infrastructure Fund in the UK, the European Innovation Fund, and state aid for the Longship projects in Norway.

POTENTIAL EMITTER REVENUE STREAMS

Compliance markets
Direct carbon taxes and carbon prices created by Emissions Trading Schemes (for example in the EU or UK) support CCUS for emitters by reducing the cost of compliance. For each tonne of carbon dioxide captured and stored, the emitter avoids having to pay carbon tax and/or buy an emissions allowance.

As the carbon price in most compliance markets is currently lower than the overall cost of carbon capture and storage, governments will generally still need to top up investment incentives. One way to do this is with a contract for difference mechanism, used for example in the UK and Netherlands. The emitter is paid the difference between an agreed strike price and the prevailing market price for carbon dioxide in the trading scheme.

LEARN MORE
- Emissions Trading and Carbon Capture and Storage, International Carbon Action Partnership (February 2023)

Tax credits
Some governments offer performance-based tax credits designed to incentivize carbon capture and storage or utilization.

An example of this is the 45Q tax credit for in the US. Qualifying emitters such as power and industrial facilities can generate a federal tax liability offset per captured tonne of carbon dioxide stored securely or used in a way that prevents it from ever being released into the atmosphere. This offset can be used directly by the emitter or traded with other organizations in any US state.

Voluntary carbon markets
In the absence of a compliance market, emitters can potentially sell carbon credits in the voluntary carbon markets based on certified emissions avoided or reduced through their involvement in a CCUS hub.

Voluntary carbon markets are expanding, stimulated by growing corporate net zero commitments. The methodologies for claiming CCUS reduction or carbon removal credits are still evolving, however. Initiatives such as CCS+ and ACCU are developing transparent ways to create carbon credits and also make use of Article 6.4 of the Paris Agreement that regulates voluntary international trading of carbon credits. Until regulations come into place, voluntary markets could play an important supporting role in funding CCUS.

Carbon dioxide as a commodity
Carbon dioxide is used in a number of agricultural, food production and industrial processes where it has a market value. It can be locked permanently into some products, for example in the production of certain types of cement and building aggregates or plastics. It can also be used in the production of zero carbon synthetic fuels. The utilization market is currently marginal but is expected to grow rapidly.

READ MORE
- Carbon utilization

Low carbon products
Emitters may be able to attract a premium for lower carbon products enabled by CCUS. Some of these are regulated markets. For example, Low Carbon Fuel Standard regulations introduced by California, Oregon and British Columbia (Canada), and under consideration in many other states and provinces, attracts a significant premium for fuels that meet lower carbon intensity standards.

Low carbon procurement is also starting to create a potential revenue stream for CCUS-enabled industrial products. Consumer goods industries such as the automotive sector are looking at procuring low carbon industrial inputs such as steel to meet demand for greener products. Cities and regional governments are looking at low carbon procurement for commodities such as steel and cement, for use in infrastructure projects.

LEARN MORE

- Watch Magnus Ankarstrand, President of Yara Clean Ammonia discuss his business model for participating in Northern Lights (40.00) – February 2023
- Watch Philip Aldridge, CEO of NEPIC, representing chemical companies in the northeast of England, on the value of the East Coast Cluster (08.00) -

THE BUSINESS MODEL FOR TRANSPORT AND STORAGE OPERATORS

The business model for transport and storage operators is relatively simple: they are paid a fee to transport and store the carbon dioxide emissions captured by their industrial customers. The tariff is structured to cover the operator's investment and operating costs and provide a return on capital employed.

The fee structure will cover the following elements:

- Connection – which relates to the costs incurred by the operator in connecting the emitter to the transportation infrastructure.
- Capacity – which relates to the right the emitter has to flow carbon dioxide onto the transport and storage system.
- Commodity – which relates to the actual volume of carbon dioxide transported and stored on behalf of the emitter by the operator.

As dedicated transport operators emerge, these might also change for additional services such as compressing the carbon dioxide, storing it temporarily and transporting it by truck, barge, rail or pipeline to the hub operator's pick-up point.

Because carbon prices are low and demand for low carbon products is nascent, the current business model for carbon transport and storage is likely to require government support. There are three broad types of business model, reflecting different market conditions and levels of government involvement.

Contractor to the state: This model is suitable when market and policy incentives are weak.

Investments and operating costs are predominantly financed (or guaranteed) by the government, which contracts planning, development and operations to state owned or private entities. The contractor holds some 'skin in the game'.

> *Phase 1 of Longship/Northern Lights is an example of the contractor to the state model. The Norwegian government is funding 80% of the investment costs and up to 95% of the operational costs for the initial transport and storage infrastructure. The Northern Lights JV is responsible for developing the market further on a commercial basis.*

Enabled market: This is a hybrid model comprising state intervention in some parts of the market and managed competition in other parts. A regulated entity is responsible for developing the transport and storage infrastructure and is required to take all the carbon dioxide captured by the emitters. This can be a private company although it will be strongly regulated.

The regulated asset base approach being developed by the UK government for carbon transport and storage infrastructure, including that for the East Coast Cluster, is an example of the enabled market model. Here, an operator – the Northern Endurance Partnership – receives a licence from the government regulator, which grants it the right to charge a regulated price, or fee, to users in exchange for delivering and operating the transport and storage network. The charge is set by the regulator which considers allowable expenses, over a set period of time, to ensure costs are necessary and reasonable.

Porthos is another enabled market approach, with some capital funding from the EU and fees to emitters structured in a way that covers costs.

Liberalized market: This model is suitable where market and policy incentives are strong and private companies develop and manage pipelines and storage sites without specific state direction. Individual participants are free to decide how their business will be structured – whether to pre-invest in over-sized transport and storage capacity, and how to allocate risk and return.

This is how CCUS infrastructure is currently being developed in the US, for example in the Liberty Louisiana hub, where the initial storage sites are likely to be onshore and lower cost. Transport and storage infrastructure development in the US may follow the oil and gas industry where hubs emerge on the back of infrastructure developed by the private sector for CCUS point-to-point projects.

In Europe, too, a second generation of commercial hub projects is starting to emerge. In Norway, for example, Horisont Energi, Neptune Energy and E.On are working together to set up a commercial hub, initially storing emissions from E.On facilities in Europe.

> *For more information on transport and storage business models see these resources from the UK government on CCUS business models.*

LEARN MORE

- Watch Borre Jacobsen, Managing Director of Northern Lights discuss the key risks in his business model and how he approaches risk sharing with customers (25.45)
- Watch Andy Lane, Head of the East Coast Cluster and Northern Endurance Partnership, talks about the evolution of his business model and government support (14.40)

MOBILIZING FINANCE FOR CCUS HUBS

Mobilizing private finance for CCUS hub projects faces two fundamental challenges, according to a report by the Energy Futures Initiative. The first is that the application of CCUS as a decarbonization tool for many new industries is continually raising new first-of-a-kind challenges that need to be mastered to bring down costs and build commercial confidence. The second is that the value chain is complex – covering capture, transport, storage and monitoring – and each of these areas is evolving into an industry of its own that also need to collaborate closely. The result is that potential developers face multiple risks and uncertainties.

Governments have started to address some of these specific risks with targeted incentives, but to make CCUS hub projects bankable, two broad groups of investment risks need to be addressed in detail:

Project risks around technology, construction, price and operations, which are common to any infrastructure investment. For hubs, the specific risks are around volume, leakage and multi-stakeholder project development. These will be mitigated over time through learning by doing: as more CCUS hubs are built, technologies and supply chains mature and prices are driven down through competition; and hub developers and transport and storage operators gain more project experience.

Hard-to-reduce risks include revenue risk, relating to an insufficiently high carbon price, cross-chain risks arising from the interdependency of the CCUS value chain, and long-term storage liability risk. These require government support to manage at present. Regulators also need to factor in subsurface risks that impact capital, operational and performance risks.

LEARN MORE

- The Energy Futures Initiative, Turning CCS projects in heavy industry & power into blue chip financial investments (February 2023)

RISKS IN THE CCUS HUB VALUE CHAIN AND HOW THEY CAN BE MITIGATED

PROJECT RISKS

Volume risk
For transport and storage operators: the promised carbon dioxide does not arrive, reducing fee revenues potentially, but also jeopardising injection strategies designed to maximize storage capacity.

For emitters: the delivered carbon dioxide cannot be stored and must be vented, jeopardising the achievement of reduction targets and potentially costing significant amounts in carbon tax.

This has several elements:

- *'Daily' volume risk* – the risk that volumes delivered by the emitter to the transport and storage operator are lower than expected
- *During-life volume risk* – the risk that at a certain point in time the emitter decides to reduce its production capacity and therefore its associated emissions
- *Storage capacity risk* – the risk that volumes delivered by the emitter cannot be stored due to maintenance downtime or other issues. (Leaks and subsurface risks are covered below)

Possible contractual solutions to volume risk include:

- *A send-or-pay contract* – this de-risks the transport and storage operator by guaranteeing their revenues, but pushes the risk towards the emitter. It is possible to address this through banking or make-up rights, as feature in natural gas contracts
- *A take-or-pay contract* – this de-risks the emitter by guaranteeing that costs are covered, but adds risk to the transport and storage operator
- A *pay-as-you-go contract* – this is favourable for the emitter, but will incur higher tariffs since the transport and storage operator will address volume risk by charging higher tariffs. One solution is to stipulate a minimum volume to keep the scheme operational

Other risk mitigation options for the hub operator:

- Create networks with other carbon dioxide stores to allow for alternatives
- Build flexible options for carbon dioxide supply into the business model, such as direct air capture facilities at the point of storage.

Leakage risk
Leakage of carbon dioxide is a small risk during operations, taking place along the injection well bore or during maintenance, for example. That could result in carbon price exposure, depending on the regulatory regime.

The contract should address who bears the liability and at what point in the operation: the emitter or the transport and storage operator, or is it shared? This is more complex if the operation spans state or international boundaries.

Impurities risk
This relates to the consequence of impurities in the capture stream, like mercury, which can cause pipelines to erode.

The contract should address who bears the liability: the transport and storage operator, because they should have anticipated this, or the customer – or shared.

Project development risk
This relates to the timing risk on Final Investment Decision (FID) since multiple parties need to take their FIDs at the same time for the CCUS hub development to proceed.

On the transport and storage operator side, the risk can be managed by having a portfolio of emitter companies.

For emitters, this risk is more challenging as they are generally working with only one transport and storage operator. Possible solutions include creating a take or pay contractual structure or taking a direct ownership share in the transport and storage company.

HARD-TO-REDUCE RISKS

Insufficient value on carbon dioxide
A robust policy mechanism that places a sufficient value on carbon dioxide is needed to support investments in capture facilities that can then pass

on a share of the benefit to transport and storage providers. This may take the form of a carbon tax, tax credit, emissions trading scheme, CCS obligation, emissions performance standard, or government procurement standards.

In markets where carbon prices exist, these prices may not be sufficiently high enough to incentivize investment in CCS projects and governments may need to introduce additional levels of support, through instruments such as a Contract for Difference.

Interdependency of the CCUS value chain
CCUS projects require the coordination of multiple investment decisions in different parts of the CCUS value chain, each with long lead times. This creates risks associated with relative timing and capacity management.

This interdependency continues during the operational phase where failure of one element of the CCUS value chain may affect the costs and revenues of other participants and prevent the value chain from performing as a whole.

Government ownership of the transport and storage infrastructure or capital support can help mitigate the timing risk. As more emitters connect to the network, the interdependency risk will be reduced. Governments may then choose to sell the infrastructure to the private sector for a profit.

Hubs are also cooperating with each other to provide storage back-up if needed, for example in the North Sea region.

Long term storage liability
Legal and regulatory frameworks may place limits on private investors' exposure to any long-term storage liabilities. This can be managed by transferring these liabilities to the state after a specified period post-closure, subject to transparent monitoring and acceptable performance of the storage facility. Jurisdictions may specify a minimum number of years for which operators will have to continue post-closure monitoring of a site.

Another way long-term storage liability can be managed is through a risk capping mechanism. This would allow the private sector operator to take responsibility for risks incurred below a cap, while the government would take responsibility for all additional risks above that cap. The value of the cap could be a function of the balance of public and private equity in the storage operation, with higher private equity translating to a higher cap.

3. GETTING STARTED

3.1 POLITICAL DECISION-MAKERS

As net zero targets become mainstream, government officials at national, regional and local levels need solutions for decarbonizing existing heavy industry, as well as infrastructure for new clean industries to thrive. CCUS hubs can help industrial regions keep existing jobs and attract new ones, accelerate the adoption of low carbon hydrogen across many sectors, create the infrastructure for carbon removal technologies alongside a new carbon management service industry.

WHAT YOU NEED TO KNOW ABOUT CCUS HUBS BEFORE YOU START

With momentum picking up in countries around the North Sea, in North America and Asia, what was once seen as an expensive, unproven technology is becoming a cost-effective decarbonization option for industries that have few alternatives currently available to them. Indeed, governments are starting to compete with each other to take first-mover advantage of the opportunity CCUS hubs provide.

Developing the market and the business models are the biggest challenges facing CCUS hubs. All the technologies required in the CCUS hub value chain are functional and in use, so the main technical challenges lie in deploying these technologies at scale, in new industries and at a lower cost. This process is well underway around the world.

On the business model side, government support is currently required to tackle five main issues:

- Develop the legal and regulatory framework to enable and manage hubs properly.
- Incentivize emitters to invest in capturing their carbon dioxide emissions – so they can maintain competitiveness until a direct or indirect carbon price is high enough to create a level playing field.
- Incentivize potential carbon transport and storage operators to invest in infrastructure – providing a business case despite the lack of a sufficiently high and stable carbon price.
- Address challenges throughout the CCUS value chain like performance risk and counterparty risk.
- Establish the permission space for a CCUS hub.

In the absence of sufficiently high carbon prices or mandates, governments are using a range of tools in different combinations to support CCUS hubs. These include subsidies, carbon price mechanisms, tax incentives, public procurement mechanisms and regulations.

READ MORE
- Why should governments support CCUS hubs?
- Why do CCUS hubs need government support?
- What kind of policy enablers can support CCUS hubs?
- CCUS incentives by country

WHAT ARE THE POLICY LESSONS LEARNED SO FAR?

Understand and align objectives
- Be clear why are you doing the project
- Make sure that the goals of government, emitters and hub developers are all moving in the same direction.
- Establish priority objectives, and build your policy framework around them
- Establish clear no-goes/boundaries; be flexible on things that are less important

Define roles
- Be clear on the different roles in the project – for example, the state as enabler sharing costs and risks, letting companies do what they are good at, such as selecting technologies

Build trust
- Create a forum to bring together government, emitters and storage service providers
- Co-develop national CCUS strategies

- Build confidence with a step-by-step process, showing good faith in feasibility studies, negotiations and other project stages, and articulating progress made

Design incentives

- Don’t force industry to get on board, encourage them with incentives
- Understand companies’ businesses in order to incentivize them effectively
- Develop commercial models with industry upfront so that the major risks are allocated before negotiations start
- Make sure incentives enable a long-term business rather than bring purely subsidy dependent
- Get the incentives right, then let industry make their own decisions – they are making huge investments and things can change, so they need flexibility
- Look forward – ensure that policies incentivize scaling
- Align incentives with industrial strategy

Take care of regulations

- Work to harmonize international regulations (such as the London Protocol on transporting carbon dioxide) so they are appropriate for CCUS
- Be aware of changing protocols, standards and emerging regulations
- Be prepared to work with regulators to help them understand CCUS
- Make sure regulations on transport and storage can deal with multiple emitters and negative emissions – existing regulations were developed for point-to-point CCUS
- Develop regulations to deal with cross-border transport of carbon dioxide, including carbon accounting systems – for example, how to account for emissions captured in one country but stored in another

Public and political support

- The right narratives are critical for gaining political and broad societal support. Emphasise that CCUS hubs are addressing climate change in a constructive way. They are needed to deal with heavy industry, not a fig leaf for polluting forms of energy
- Don’t present CCUS as an alternative to other approaches – all tools are needed and some work better in specific contexts
- Consistent political support is vital, spanning a sequence of governments
- Prove the value of CCUS hubs

Keep communicating

- Maintain good communication between government and industry, especially explaining the different processes involved in business and the state. Forums such as the CCUS Advisory Group in the UK can help play this role
- Give decision makers the relevant information – not too much information
- Maintain a positive mindset
- As policy direction is often evolving in parallel with hub projects, industry needs to be consulted on policy development
- To help state and industry understand each other, it can be useful to have an agency in the middle, such as Gassnova in Norway, or secondees
- A specialist CCS agency, such as the CCSA in the UK, can also advise both industry and government on the technical sides of capture and storage

READ MORE

- Designing effective policies for CCUS hubs
- Developing effective regulations for CCUS hubs

WHAT QUESTIONS SHOULD POLICYMAKERS ASK THEMSELVES WHEN DEVELOPING POLICIES AND REGULATIONS FOR CCUS HUBS?

Objectives

- What are our objectives? For example:
  - reduce national emissions, to meet or beat NDCs
  - preserve industrial activity and jobs
  - stimulate a domestic CCUS industry, including equipment manufacturers and service companies
  - catalyse global CCUS investment at scale
- How do our CCUS-specific objectives align with our climate targets and industrial strategy?
- What policies can reflect our objectives?
- Who can we learn from other jurisdictions, other CCUS projects, other industries?

Working together

- What are the objectives of other project stakeholders: industry, local and national government, politicians, local communities, trade unions and NGOs?
- What are industry's risks, and why do they want to get involved in CCUS?
- How can we build and retain trust between state and industry during the process of setting up a hub?
- How do we make hubs sustainable so that the transport and storage service provider can expand as demand grows?
- What formal project-development processes are used in industry, and how can they work alongside the different processes of the state?
- How do we allocate risk and reward when expectations regarding return on investment vary?
- How do we understand the risk profile of different emitters?
- Which issues need compromises?
- How do we retain political and public support?

Policy design

- What market failures do we need to address?
- What are the key risks that government has to take on?
- How can we incentivize cost reductions?
- How can we incentivize scaling, for example obliging companies to share project lessons?
- Where we are providing subsidies, what return can we allow commercial participants and how do we match it to risk and requirements for additional investment?
- Are commercial models clear for both the emitter and transport and storage side?
- How long should support last? What are the conditions to scale down and stop funding?
- What types of support are needed at different stages, such as concept definition, FEED, execution, operation?
- How do we create a robust policy mechanism, insulated from changes in government?
- Are we looking to work with other countries/states, and what are the policy implications?
- Have we addressed global industrial competitiveness, for example through carbon border mechanisms?

Legal framework and regulations

- Do we have an appropriate legal and regulatory framework for CCUS?
- Can CCUS be regulated under or adapted from current regulations for oil and gas? What differences are required?
- What permits are needed and from whom? What is needed to smooth this process?
- Which other government departments should we be working with?
- How do our CCS policies and regulations work together?
- What is the reporting landscape for a CCUS project?
- Are there any international or regional legal obligations we need to consider?

3.2 INDUSTRIAL EMITTERS

USING CCUS TO DECARBONIZE HARD-TO-ABATE INDUSTRIES

Hard-to-abate industrial companies in sectors like cement, steel, chemicals, fertilizers and waste-to-energy are increasingly looking at CCUS as part of their pathway to net zero. BloombergNEF's net zero scenario suggests that CCUS could make up 29% of industrial emission abatement by 2050, alongside clean hydrogen, electrification, bioenergy and recycling.

Finding the right business model to finance carbon capture is still tough, but that is changing in a growing number of countries as carbon prices rise, new low carbon product standards are introduced, and funding is directed to companies in hard-to-abate sectors to speed up decarbonization.

Depending on their location, emitters may be able to secure income from multiple revenue streams, including compliance (carbon) markets such as the EU ETS, tax credits, voluntary carbon markets, carbon dioxide as a commodity and low carbon product markets.

The emergence of CCUS hubs is making it easier to embrace CCUS, without having to take responsibility for building pipelines and drilling storage wells – and without long-term liability for the stored carbon dioxide. First movers in each sector face the challenges of managing first-of-a-kind capture projects, but they have the advantage of locking in future storage space to implement their net zero transition plans.

HOW DIFFERENT SECTORS ARE USING CCUS TO DECARBONIZE

Chemicals
Direct carbon dioxide emissions from chemicals production totalled nearly 1 Gt in 2021 and the IEA singles out CCUS as the most important lever for the sector's decarbonization, with electrification of refinery furnaces unlikely to be possible until after 2040.

In order to reach a net-zero pathway consistent with the Paris Agreement, the chemicals sector must triple the volume of carbon dioxide captured annually across the industry, reaching nearly 0.5 Gt per year by 2060 – with most of that stored away permanently.

Some of the world's largest chemicals companies are aggressively pursuing CCUS as part of their net-zero strategies:

- BASF is spearheading Kairos@C, part of a cross-border CCUS value chain designed to take carbon dioxide from chemical plants in Antwerp for injection into one of the North Sea stores.
- Dow has called CCUS "critical" to industrial decarbonization targets and includes CCUS investments in its net-zero roadmap. In North America it is looking to use CCUS on an ethylene cracker and derivatives site in Alberta, Canada. In Europe, it is testing making hydrogen from off-gas in its Dutch complex, with a plan to store the carbon dioxide and utilize it in future as a feedstock for production.
- SABIC is leaning on CCUS in its net-zero pathway and operates the world's largest capture and utilization plant.

Fertilizers
As of 2019, the fertilizer sector was the single largest industrial user of carbon dioxide, consuming nearly half of the 220 Mt in commercial circulation each year. This carbon dioxide, in combination with ammonia, is used to create urea, the basis for synthetic fertilizer. Ammonia production itself generates huge quantities of carbon dioxide, largely due to the energy and processes needed to isolate its components – hydrogen and nitrogen – from various sources and then combine them to create ammonia. Experts estimate this accounts for roughly 1.4% of all global carbon dioxide emissions, with nearly twice the emissions intensity of steel and four times that of cement.

The carbon dioxide released when isolating hydrogen from coal or natural gas can be captured and itself used as feedstock further downstream in fertilizer production. The sector's pre-existing use of capture technology makes CCUS an attractive pathway for it to achieve net zero; the IEA says 100 million tonnes of storage by 2050 will be needed.

Major fertilizer makers are undertaking and proposing several CCUS projects, predominantly as part of the ammonia production cycle:

- Yara has signed an agreement to start using the Northern Lights CCUS hub to store 800,000 tonnes of carbon dioxide annually from its Dutch operations starting in 2025.
- CF Industries intends to store up to 2.5 Mt of carbon dioxide per year from blue ammonia production. Its Teesside site is one of the East Coast Cluster's capture projects.
- Nutrien, the largest fertilizer company by market capitalization, touts its two permanent carbon storage facilities and is considering plans to build what it calls the world's largest clean ammonia production plant in Louisiana, with expected annual storage of 1.8 Mt.
- WesCEF calls CCUS a major pillar of its long-term decarbonization plan. The Australian company is looking at producing "blue" ammonia – ammonia with CCUS – in partnership with two Japanese companies.

Cement

Concrete comprises 7% of global greenhouse gas emissions, most of which emerge when limestone is converted into cement, concrete's main ingredient. Although many players are looking for lower-emitting substitutes to limestone and other inputs, the IEA still sees a major role for CCUS in the sector's decarbonization, contributing 18% of the total between 2017 and 2060.

The Global Cement and Concrete Association lists 34 CCUS projects around the world involving its member companies, and aims to have 10 cement plants around the world outfitted with CCUS by 2030.

CCUS is also growing as a decarbonization lever among other top cement makers:

- Heidelberg, the world's fourth-largest cement maker, has eight CCUS initiatives worldwide. Its Brevik facility in Norway will become the world's first large-scale carbon capture facility in a cement plant in 2024, storing captured carbon dioxide in the Northern Lights hub. Heidelberg has other projects in Europe and Canada and recently announced a new CCUS initiative at a subsidiary in Indiana.
- Holcim, the world's largest cement company, sees CCUS as a major component of its net-zero-by-2050 strategy and is working on over 30 CCUS pilot projects, many involving utilization of carbon dioxide, in Europe and North America.
- Cemex says that carbon capture "offers the most encouraging prospects" at helping the company meet its 2050 net zero target. The Mexican company is working on several CCUS projects to this end, including some announced at the end of 2022.

Steel

Processing iron and making steel are highly emissions-intensive, accounting for 11% of global carbon dioxide emissions, according to one estimate. The industry typically uses coal both to generate the high temperatures needed to turn iron into steel and as a feedstock for the process itself. CCUS could abate emissions at various points in the steel value chain; the IEA estimates it will account for 15% of the reductions needed for the industry to meet net-zero targets, reaching 10 Gt in total by 2060.

Major steelmakers are recognizing the potential of CCS:

- Baowu Group, the world's largest producer, announced at the end of 2022 that it will explore the possibility of sequestering "tens of millions" of tonnes annually in partnership with Shell, Sinopec and BASF. The Chinese company has previously discussed CCUS as a part of its broader decarbonization strategy.
- ArcelorMittal also sees a significant role for CCUS in its net zero roadmap and is participating in an innovative capture pilot project in France run by TotalEnergies.
- Nippon Steel, Japan's top steelmaker, is also studying CCS as a decarbonization lever, including via technological research through Japan's steel industry consortium.

Waste incineration

Waste from households, businesses and other sources is typically collected and sent to landfill, where it breaks down and releases methane, a potent greenhouse gas – as much as 11% of the worldwide total, according to estimates. Burning waste to generate electricity instead is not a new idea – by 2027, the global capacity of such waste-to-energy plants could total 530 Mt, avoiding as much as 6.27 Gt of greenhouse gas emissions by

2050. Yet this process releases carbon dioxide – between 0.7 and 1.7 tonnes per tonne of waste as a result of the gas burned to fire the plants.

Several facilities are capturing and using the carbon dioxide emitted in this process. One plant in Japan has been capturing carbon dioxide released from waste incineration to grow algae to make skin lotion since 2016. A plant in the Netherlands will utilize captured carbon dioxide to help crops grow when it becomes operational at the end of 2023.

But many cities are looking to capture and sequester carbon dioxide from their waste-to-energy plants, taking advantage of the negative emissions that come from the organic waste, which typically makes up 50% of municipal waste (see bioenergy below).

Oslo opted to use CCUS for its Hafslund Oslo Celsio plant. It will capture 400,000 tonnes of carbon dioxide per year and store it in Northern Lights once operational. It aims to be the first full-scale facility to divert carbon dioxide from waste-to-energy into permanent storage. Waste incinerators in Zurich and London (Cory) are also working on CCUS projects.

Bioenergy

Burning organic material – from crops, food waste, algae and other sources –currently comprises 55% of all renewable energy as defined by the IEA. Attitudes differ as to the climate benefits of bioenergy production, since the carbon dioxide released in biomass combustion could be reabsorbed by plants, theoretically constituting a "climate-neutral" pathway. In practice, however, the additionality of this approach is difficult to prove and some assert that biomass generates more emissions than fossil fuels.

Bioenergy with CCS (BECCS), on the other hand, is an unmitigated climate win. The IEA's net-zero scenario sees BECCS projects removing net 250 Mt of carbon dioxide from the atmosphere annually by 2050. Rapid scale-up will be necessary from the current annual amount of only 2 Mt.

Several players are entering this space. Britain's Drax is sketching out blueprints to build the world's largest carbon capture facility at a bioenergy plant, which could remove 8 Mt carbon dioxide per year once operational, storing the carbon dioxide in the East Coast Cluster hub. It has plans to build BECCS plants in the US to store a further 4 Mt. In the US, a network of ethanol plants in the Midwest could form what its developer says is the largest carbon capture and storage project in the world, with capacity to store 12 Mt every year.

Japan plans to open what it bills as the world's first negative emission biomass power plant as an extension of a pre-existing CCU pilot at a waste incineration plant (see waste incineration), which will capture more than 182,000 tonnes annually.

IS CARBON CAPTURE A COMMERCIALLY VIABLE WAY TO DECARBONIZE?

The exact cost of carbon capture depends to a great extent on the mixture of gases captured. 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 much lower than for dilute or low-pressure exhaust gases.

Emitters need certainty on the specifications (around purity and pressure) of carbon dioxide to be delivered to the transport and storage operator. The tighter the specifications, the higher the costs for the emitter. Impurities such as water, nitrogen, SOx, NOx, carbon monoxide, hydrocarbons and mercury can have major implications, such as corrosion, for carbon dioxide transportation and storage infrastructure and on how the carbon dioxide behaves once it is injected into the target reservoir deep underground.

Compression costs will vary depending on the capture and associated industrial process but can be high to meet pressure specifications.

Depending on their location, emitters may be able to secure income from multiple revenue streams, including compliance (carbon) markets such as the EU ETS, tax credits, voluntary carbon markets, carbon dioxide as a commodity and low carbon product markets.

Government support to emitters typically takes the form of capital grants and operational cost funding, through a contract for difference on a carbon price, as in the UK and Netherlands, or a storage tax credit combined with a low carbon fuel standard, as in the US.

Emitters are likely to recover their capex on investments in carbon capture over a longer period of time than is normal for other investments. Returns will effectively be regulated as opposed to market driven.

READ MORE
› The business model for emitters

WHAT ARE THE PROS AND CONS OF A CCUS HUB FOR AN EMITTER?

A CCUS hub takes carbon dioxide from several emitting sources, such as heavy industries and power, and then transports and stores it using common infrastructure. Emitters can sit on one physical location, close to the main storage infrastructure or feed into the infrastructure through a broader transport network that links to it. For emitters, the hub offering opens up CCUS as a decarbonization option without them having to take responsibility for building pipelines, drilling storage wells and monitoring carbon dioxide storage.

The downside is that developing a CCUS hub is complex. The value chain typically consists of a hub developer who initiates and manages the value chain; multiple emitters who guarantee to capture and supply carbon dioxide; a single transportation and storage company (that could serve several hubs) and a growing number of service providers.

Many industrial emitters with different industrial processes and specific regulatory constraints need to be pulled together in a big infrastructure project. It is therefore important to communicate clearly to the hub developer and/or transport and storage operator what it will take to optimize your production operations – while capturing carbon dioxide.

Multiple parties need to take their Final Investment Decision at the same time for the CCUS hub development to proceed, representing a major project development risk. Possible solutions to the timing risk faced by emitters include creating a contractual structure where the transport and storage operator guarantees to take carbon dioxide or taking a direct ownership share in the transport and storage company.

Lining up the value chain, allocating risks and liabilities along it and negotiating fees and terms are difficult – but first-mover emitters are locking in scarce storage space to implement their decarbonization plans.

READ MORE
› Why do a CCUS hub?

HOW DOES CARBON CAPTURE AND STORAGE WORK?

CCUS involves three phases: capture, transport and storage. In a CCUS hub, emitters are responsible for capturing a near-pure stream of carbon dioxide, compressing it and getting it to a pick-up point. In some regions, service providers are emerging to take care of compression and temporary storage.

In this early phase, most emitters are adapting capture technology to their specific processes. This testing phase would require additional expenditure in the feasibility (pre-FEED) phase.

Before committing to expensive FEED studies, the emitter needs to get a clear understanding from the transport and storage operator that the proposed reservoir has sufficient permanent storage capacity and that the injection wells will work.

READ MORE
› Understanding CCUS

WHAT SORT OF RISKS DO EMITTERS FACE?

A key part of the commercial negotiations between the emitter and transport and storage operator focuses on the allocation of risks. Emitters face project risks around technology, construction, price and operations, which are common to any infrastructure investment. For hubs, the specific project risks are around volume, leakage and multi-stakeholder project development.

Emitters' hard-to-reduce risks include revenue risk, relating to an insufficiently high carbon price, cross-chain risks arising from the interdependency of the CCUS value chain, and long-term storage liability risk.

READ MORE

- Risks in the CCUS hub value chain and how they can be mitigated

WHAT QUESTIONS SHOULD EMITTERS ASK THEMSELVES?

- Are companies in our sector already using CCUS and what is their experience?
- Will we need to test the capture technology on our processes?
- How certain are we that carbon dioxide storage is available and ready to be used?
- Are the necessary regulations in place for my capture project?
- What forms of government support are in place for emitters to capture carbon dioxide?
- Will the proposed incentives provide appropriate support for our industry?
- What revenue streams are available to our project?
- How much will capture and compression cost?
- What are the carbon dioxide specifications required by the transport and storage operator?
- Does the transport and storage operator impose specific volume restrictions?
- Is there more than one storage operator and, if not, how do we manage risks?
- What are the transport, temporary storage and loading costs?
- How high is the tariff for storage?
- How are we dealing with project and operational risks?

3.3 TRANSPORT AND STORAGE OPERATORS

The essence of a CCUS hub is collective transport and storage infrastructure, supporting a range of different emitters and possibly even several hubs. Transport and storage operators are responsible for transporting the captured carbon dioxide from a designated loading point by pipeline, ship or other means to the storage site, where they inject it into the subsurface geology. They assume most of the liability for the captured carbon dioxide once it is handed over, and they are responsible for permanent storage and monitoring, at least until the well is safely closed.

WHAT KINDS OF COMPANIES ARE TRANSPORT AND STORAGE OPERATORS?

To date, transport and storage operators have tended to be large companies or joint ventures, with infrastructure and sub-surface knowledge, as well as experience in running major projects. They are often also involved in hub development, playing the role of integrator as well as operator. As the industry matures, companies focusing only on transport or only on storage are starting to emerge and these service providers will more frequently be brought in by emitters or other companies wanting to set up a hub.

WHAT IS THE BUSINESS MODEL FOR TRANSPORT AND STORAGE OPERATORS?

The business model for transport and storage operators is relatively simple – they are paid a fee for transporting and storing the carbon dioxide emissions captured by their industrial customers. The tariff is structured to cover the operator’s investment and operating costs and provide a return on capital employed.

Since carbon prices are low and demand for low carbon products is nascent, the current business model for carbon transport and storage is likely to involve government support and regulation, depending on market conditions.

Where transport and storage operations have the form of a natural monopoly – multiple emitters using a single piece of carbon dioxide transportation and storage infrastructure – returns are likely to be regulated and comparable to those achieved by utilities and large-scale infrastructure companies. As competition in transport and storage services develops, the need for regulation will decrease.

READ MORE
- Understanding The business model for transport and storage operators
- What kind of policy enablers can support CCUS hubs?

WHAT SPECIFIC RISKS DO TRANSPORT AND STORAGE OPERATORS FACE?

Storage liabilities are a key risk for transport and storage operators. Government CCUS regulation should be clear on carbon dioxide storage liability: who is responsible at each stage of injection, monitoring and long-term stewardship; and how risk is shared and eventually transferred to government.

The transport and storage operator will need to spend money upfront to quantify the storage capacity and de-risk it for potential customers. For example, geological de-risking may require shooting seismic and drilling wells. Upfront investment in de-risking storage will make it much easier to scale CCUS hubs, but few policymakers have focused on this to date.

The operator will also need to identify the specifications (around purity and pressure) of the carbon dioxide to be delivered to the transport and storage operator. Looser specifications make post-capture compression and purification cheaper for emitters, but impurities in the carbon dioxide – such as water, nitrogen, SOx, NOx, carbon monoxide, hydrocarbons and mercury – can have major implications, such as corrosion, for carbon dioxide transportation and storage infrastructure.

READ MORE
- Risks in the CCUS hub value chain and how they can be mitigated

WHAT REGULATIONS ARE NEEDED FOR CARBON TRANSPORT AND STORAGE?

CCUS hubs require regulations relating to permitting, standards for construction and operation of transport and storage infrastructure and storage facilities, storage liabilities, monitoring, reporting and verification (MRV) protocols and rules for third party access.

Governments typically have the tools and experience to incentivize and regulate the carbon dioxide transportation business, but they can struggle with understanding geology and the associated storage risks.

READ MORE
- Developing effective regulations for CCUS hubs

3.4 POTENTIAL HUB DEVELOPERS

A CCUS hub requires a hub developer who initiates and drives stakeholder engagement, especially on the local level, and manages the value chain. Hub developers are often oil and gas or infrastructure companies looking to offer carbon transport and storage services. But they can also be state-owned entities aiming to develop strategic infrastructure to support industry and jobs in a region, or an emitter or group of emitters looking for a cost-effective solution to decarbonization.

WHAT YOU NEED TO KNOW ABOUT HUBS BEFORE YOU START

A CCUS hub is a highly complex collaboration
All the technologies required in the CCUS hub value chain are proven. Adapting these to scale, and developing the market and business models are the main challenges in these early hub developments. There are also uncertainties to be addressed in relation to government support mechanisms, regulations, geological storage verification and risk, commercial agreements and getting broader societal buy-in.

Navigating these requires a convergence of interests, as well as shared knowledge and a shared narrative from companies with subsurface and CCUS experience, national and local politicians and community groups, and multiple emitters. When this ecosystem is in place, it creates the conditions and momentum to build a business model around concrete hub opportunities.

Creating that ecosystem is a massive alignment and co-ordination challenge – among hub partners to coordinate different interests and investment processes; with government over support mechanisms and risk allocation; and more broadly in relation to the value the project delivers both at a local level and as a credible part of a country's overall energy transition.

Government support is essential
It is needed to tackle five main challenges:

- Develop the legal and regulatory framework to enable and manage hubs properly.
- Incentivize emitters to invest in capturing their carbon dioxide emissions – so they can maintain competitiveness until a direct or indirect carbon price is high enough to create a level playing field.
- Incentivize potential carbon transport and storage operators to invest in infrastructure – providing a business case despite the lack of a sufficiently high and stable carbon price.
- Address challenges throughout the CCUS value chain like performance risk and counterparty risk.
- Build public support to establish the permission space for a CCUS hub

CCUS hubs require local backing
National-level support is critical to getting hubs off the ground, but it is not sufficient. CCUS hubs enable regional industrial decarbonization and a transition of existing industrial hubs to low carbon ones. Strong local on-the-ground support – from mayors and local authorities, local businesses and industrial associations, labour unions and community organizations – is needed to navigate the complexity involved in achieving that transformation process. It is not enough to agree a single national approach to hub development.

READ MORE
› What are the pros and cons of a CCUS hub over a single project?

HOW DO YOU IDENTIFY A POTENTIAL HUB?

> *Global CCUS Hub search*

The identification of potential CCUS hub opportunities starts with two basic questions:

- where are the big industrial emission clusters?
- where are the potential geological storage sites?

High-level geospatial screening will suggest many possible hub locations. These then need to be analyzed along a number of dimensions to determine project viability:

Existing infrastructure and CCUS activity

- Are there any existing CCUS projects in the potential host country including demonstrations and pilots?
- Is there existing oil and gas knowhow and infrastructure – subsurface data, depleted wells, pipelines, platforms – that can be re-used for CCUS?
- What is the potential for cross-border shipping?
- What are the estimated costs associated with carbon capture, transportation and storage?

Climate and CCUS targets, policies and regulations

- Does the government have clear and effective climate targets, for example, NDC commitments, and associated CCUS targets?
- What is the status of policy support for CCUS hubs?
- Is there any form of carbon pricing such as an emissions trading scheme or carbon tax?
- Are there any CCUS mandates planned?
- Are regulations for CCUS projects in place?

LEARN MORE

> IEA, Legal and Regulatory Frameworks for CCUS (2022)

HOW TO GET SUPPORT FROM STAKEHOLDERS?

Multiple stakeholders are involved in and affected by CCUS hub projects. In addition to hub partners, these include national and regional governments, local authorities, industry regulators, trade unions, industry associations, local communities and NGOs. Establishing the permission space for CCUS in general and for the specific hub project is vital. How can this be done?

Stakeholder engagement should start with a listening process – aiming to understand the needs and goals of different stakeholders, their questions about CCUS and specific concerns about the hub project. This can be done through a combination of structured one-on-one interviews with key stakeholders, public meetings and even workshops to explore how to align their needs with the overall hub project. Early and frequent communication with stakeholder groups as the project progresses is essential.

At a broader societal level, the focus of the engagement is likely to be on the role of CCUS hubs in meeting climate targets and decarbonizing heavy industry. At a local level, topics such as the safeguarding of existing jobs and creation of new opportunities enabled by the hub project will be key.

The Climate Accord Process in the Netherlands provides one example of engagement leading to broader acceptance of CCUS as a necessary climate technology in a country where scepticism was particularly high.

The government held a joint fact-finding process on the potential role of CCUS in the Dutch energy transition, led by independent, academic facilitators and involving NGOs, industry and industry associations. Eight roundtables were convened, structured around a list of questions. All stakeholders were invited to provide answers to these questions which gave the basis for a common view. While some NGOs pulled out of the process, there was alignment around the conclusion that CCUS would be necessary to get quick reductions in industrial emissions without stopping the economy.

This provided an important source of legitimacy for CCUS and gave the government confidence to let emitters compete for SDE++ CCUS funding, alongside other decarbonization projects, based on the cost of emissions reductions.

WHAT FOUNDATIONS ARE NEEDED WHEN LAUNCHING A HUB PROJECT?

Frontload on collaboration: Hubs bring together different industries which may, or may not, have pre-existing commercial relationships and different stakeholder groups, all of whom can have distinct and different goals and objectives. One lesson that emerges from the most advanced CCUS hubs is not to skimp on building solid collaboration at the beginning of the project. Ensuring that partners are aligned takes time but is critical.

How to get collaboration right:

- **Establish strong foundations:** Start by agreeing why you are undertaking the project and why you need each other. Spend the necessary time to understand each other's business, key drivers, risks and company cultures.
- **Develop deep alignment:** Create a simple shared narrative built around a common vision shared across the whole value chain and write it down to keep on track later. At this early stage of hub development, the focus should be on the why, rather than what or how.
- **Build confidence and trust:** Build trust by sharing power and creating cross-partner teams to work together on progressing different elements of the hub development project. Create confidence and deepen trust by demonstrating and celebrating tangible progress at each stage in the hub development process.

Other lessons emphasised by hub developers include:

- **Get the right people on board:** Involve the right people and start the project with positive attitudes and mindsets. Invest in personal relationships.
- **Be agile:** Expect that the rules of the game will change in relation to government support, financing and customer needs. Think win-win and use agile working methods.
- **Understand your customers:** Hub projects involve multiple emitters operating different industrial processes each subject to different regulations and different internal processes. These are the customers for the hub and it's vital to understand their specific needs. They are typically low-margin businesses, and they are focused on optimizing their production operations – not on the amount of carbon dioxide they produce. They might know very little about CCUS, their risks and how they can manage them. Even in the early stages, it's important to go beyond just one or two emitter customers. Design for what success would look like.
- **Do not play hide and seek:** Once you have built trust, show your weaknesses and organize for them. Hub partners should start by focusing on the risk areas and identifying their positions on these risks to each other before embarking on the heavy load with technical detail otherwise big issues might be discovered at the last moment.
- **Learn how to work with government:** At this early stage of CCUS hub development, policy definition and hub developments are often proceeding in parallel. Resist the temptation to ramp the project up quickly if policy is not mature.

    - *Build confidence and trust.* Take a step-by-step approach when working with government. Build confidence and trust by demonstrating tangible progress at each stage. Take photographs of that progress so politicians have something to show.
    - *Keep communicating.* During this early phase of hub development, there is so much uncertainty - policy development requires trust and continual dialogue between hub developers, transportation and storage developers, emitters, policy makers and politicians. Understand the political process.
    - *Help governments understand the risks.* It is vital for the hub partners to provide input into the risks that government is taking. Governments typically have the tools and experience to incentivize and regulate carbon dioxide transport but they can struggle with understanding geology and the associated storage risks.
    - *Understand government processes and timelines.* Government timelines for deciding policy support are driven by political processes whereas CCUS hub development timelines are driven by industrial project maturity processes. These two timelines do not always coincide and sometimes hub partners need to make commercial decisions before detailed technical work (FEED) is completed. Continued dialogue between government and hub partners is necessary.