Buyers must ensure that the subcontractors meet the quality and performance criteria, in accordance with the costs and timeframe defined in the contracts.

This can include security procedures, customer safety rules, environmental rules, including waste management, qualifications of personnel, deployment of IT solutions, inventory management, delivery times, requirements to use specific equipment, requirements to comply with obligations from equipment manufacturers.

A ‘smart contract’ can establish a framework agreement between two entities, defining the entire scope of activities such as scope of work, costs, quality and obligations of the parties. This can include methods for measuring all these elements (KPIs) and periodic evaluation of performance (milestones).

The contract can include sensor (IOT) data, such as for definition of response times related to condition-based maintenance methods..

Depending on equipment category, the management of offshore and dedicated onshore stocks can be inserted. For example, power generators, mud pumps, mixing equipment and processing activities can be subcontracted and could fall under an all-inclusive service agreement including equipment rental and stocks services.

Improving budgeting analysis

If you need to improve your budgeting or reduce spending, one challenge is the quality of financial data collected.

It can be difficult to link an invoice to a project or to an expense for an equipment when the order reference is non-existent, or the name of the equipment is missing. Purchase requests might be made verbally, rather than through a written purchase order connected to a budget.

It is realistic to say that certain expenses can be randomly allocated, leading to incorrect financial information at the project level or by type of equipment.

The purchase order process ensures that any subsequent invoice is also connected to this budget.

A further problem is if you use ships, which are managed by ship management companies operating global fleets with their own systems. The cost information they provide may be broken down to the needs of the customer, geographical places or to the time schedule for the work, but not to the specific customer project they are working on.

Why exploration skills can be most useful in CO$_2$ storage

To understand the behaviour of a CO$_2$ plume in storage, the skills of an exploration geologist may be more relevant than the skills of a reservoir engineer,” said Halliburton’s Geovani Christopher Kaeng

Geovani Christopher Kaeng, an exploration geologist, basin modeller and petroleum system analyst with Halliburton, says he has had many conversations with people from oil and gas companies looking to move into CO$_2$ operations over the past few years.

“most of the time” the people he has been talking to have been reservoir engineers and production geologists, as they were given the responsibility of managing CO$_2$ injection. He was speaking at Finding Petroleum’s forum on May 18, CO$_2$ Storage and Opportunities for Geoscientists.

It may seem to make practical sense for CO$_2$ injection to be managed by reservoir engineers, if they have the best understanding about depleted reservoirs. But they may not be the people with the best understanding of the most critical issue with CO$_2$ storage – where the CO$_2$ is going to go, and if it is going to stay there.

Geovani Christopher Kaeng, an exploration geologist, basin modeller and petroleum system analyst with Halliburton

“I argue it requires exploration geoscience skills to be able to understand the nature of the storage as well as the behaviour of the plume,” he said.

The information we now have about the shape of CO$_2$ storage in Norway’s Sleipner field shows that fluid modelling methods used in geoscience exploration would have made a much better prediction of where the CO$_2$ would go, than the traditional reservoir simulation models which were actually used, he explained. This field started injection in 1996.

Exploration geoscientists may be more willing to consider different options for storage, such as saline aquifers, while reservoir engineers may prefer to start with the reservoirs they know, the depleted hydrocarbon fields. Saline aquifers need to be approached with an ‘exploration mindset’, because you start with limited to no data . Saline aquifers provide greater capacity than depleted fields and they are arguably safer, he said.

Geoscientists may be more comfortable with working with geological heterogeneity (diversity) and seal assessment than reservoir engineers, he said. “The production teams take the seal for granted. Any fine-grained lithologies are just treated as ‘not part of the reservoir.’”

Reservoir engineers express concerns about data scarcity when they talk about building models for CO$_2$ injection. But exploration geologists are much more comfortable working with data scarcity. “We know how to deal with limited data. We can predict reservoir properties, we can predict seal properties, we have basin modelling methods. We do uncertainty modelling.”

So, the management of CO$_2$ storage should move from a ‘production-oriented’ mindset to “more of an ‘exploration geoscientist-oriented’ mindset.”

“CO$_2$ storage injection is more analogous to oil and gas expulsion, migration, and entrapment, than to hydrocarbon production. That’s why exploration geologists [need to] get into this area.”

Sleipner

CO$_2$ has been injected into Norway’s Sleipner field since 1996, with 3D seismic surveys taking place every few years since then. These data show how the CO$_2$ plume developed, spreading out in the subsurface until it reached the seal. It makes for an “amazing flow experiment,” he said.

Before injection started, the reservoir had been modelled as though it was homogenous. But the seismic data showed layers within the storage site. This is an indication of what could be called ‘small scale heterogeneity’ — seals actually within the formation that were just 30cm to 1m thick. The geological heterogeneity controls how the CO$_2$ moves.

A paper published by Equinor and partners, operators of the storage site, showed that the actual CO_2 plume bears very little resemblance to what was expected in the reservoir simulation.

Looking at the development of the CO_2 plume at Sleipner, as it actually happened, there are 3 reservoir sections – a lower section, with vertical stacking, and a strong structure; a middle section, with some lateral movement, first to the north, then back to the middle of the structure, then up and to the south; and an upper section, where the flow is controlled by the seal, so CO_2 can only move sideways.

The variations in the plume shapes have been caused by heterogeneity in the reservoir – the low section is less shaly than the upper section, he said.

A report on saturation analysis from seismic data mentioned that in 2010 most of the CO_2 injected was stored within the intra-formational bodies of the storage

Flow models

Reservoir engineers and exploration geoscientists typically use different methods for working out how fluids flow through the subsurface and building flow models, he said. But Sleipner shows that the exploration geoscientist method is more relevant to how a CO_2 plume develops in a CO_2 storage site.

Reservoir engineers typically model how fluids flow through a reservoir to a well. It is not so important to them which part of the reservoir the hydrocarbons are sourced from.

Exploration geoscientists typically model how hydrocarbons are expelled from their source, migrate through the subsurface and get trapped. Their understanding of the flow is more about understanding flow through narrow capillary spaces in the rock.

CO_2 storage was traditionally simulated using Darcy flow physics, which not only suffers from low resolution and extremely long simulation times, but also fails to model the CO_2 structural trapping after the injection has stopped, making sequestration impossible.

When people drew simplified images of how they thought CO_2 would behave in a storage site, they often drew a simple inverted cone, with CO_2 exiting the well then moving outwards and upwards. As the actual CO_2 plume shape for Sleipner shows us that the movement of CO_2 in the subsurface is controlled by what geoscientists call ‘heterogeneity’. Some of the flow was actually horizontal. If we were producing hydrocarbons we might indeed get an inverted cone shape. But CO_2 is injection, not production.

To understand fully how CO_2 would behave in storage, you need a detailed model of the subsurface, with CO_2 flowing into different layers, showing how much each layer stores, and when it leaks into the one above. If the model’s scale is reduced, as is often done before running in a reservoir simulator, this detail is lost, Mr Christopher said. You thus lose data about the heights of the various storage spaces, and so cannot calculate the overall capacity of the storage.

Pressure in the subsurface

Another area where the perspective of reservoir engineers and geoscientists may differ is in their understanding of pressure in the subsurface. Reservoir engineers may typically think of the ‘reservoir’ as a closed system, which will increase in storage pressure after you inject, Mr Christopher said. “We know, as exploration geologists, that pressure always dissipates within the basin and finds balance as quickly as possible.”

Liquids and gases move through the subsurface through tiny ‘capillary’ gaps, not mainly through faults, as some people believe, he said. Whether a gas passes through a capillary depends on the pressure of the gas and the size of the capillary.

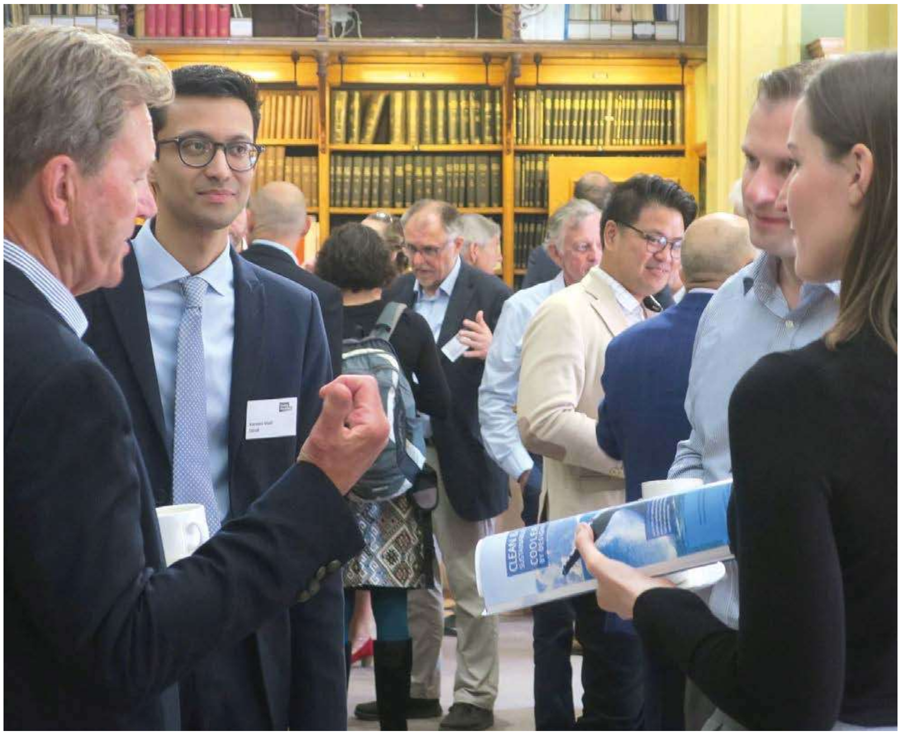
This sounds complicated but looks simple when demonstrated on a YouTube video by Philip Ringrose, Adjunct Professor in CO_2 Storage at the Norwegian University of Science and Technology (NTNU) and Specialist in Geoscience at the Equinor Research Centre in Trondheim, Norway. It is online here https://youtu.be/8-dXwakvmsI

The video shows air being injected under an inverted sieve in a fish tank. Air will be trapped under the sieve, due to capillary trapping. But if the injection rate is increased, the air pressure increases, and eventually the capitally force is overcome by the buoyancy force of the trapped air.

This has long been understood by exploration geologists, who use Young Laplace principles of fluid flow. This models the interaction between fluid buoyancy and capillary pressure. This has been used for decades in exploration, but not yet popular in CO_2 storage.

If you have high velocity, pressurised flow, then it is in the domain of Darcy flow (flow of a fluid through a porous medium), while a relatively slow movement of fluid is in the realm of Young Laplace physics (pressure difference between the inside and the outside of a curved surface). Darcy flow models may be appropriate for CO_2 close to the well bore, but it changes to capillary type migrations just tens of metres away, he said.

Doing a simulation model using Young Laplace physics needs high resolution information, including of the heterogeneity of the subsurface. Equinor did a test to see if it was possible to simulate Sleipner using capillary flow models, which is also called an “Invasion Percolation Model”. It found the output was well matched to what happened in reality, as seen in the seismic data, Mr Christopher said.



You can watch Geovani Christopher’s talk on video with slides at

https://www.findingpetroleum.com/event/e00f5.aspx

A plan for monitoring CO2 storage integrity

How should companies monitor CO2 storage complexes to ensure CO2 is being stored safely? CCUS consultant Robert Hines shared some advice

The important issues in CO2 storage could be distilled to 3Cs – containment, conformance and confidence, said CCUS consultant Robert Hines, speaking at the Finding Petroleum forum on May 18, "CO2 Storage and Opportunities for Geoscientists".

"Containment" is making sure the sealing mechanisms have got integrity; "conformance" is making sure the CO2 plume is behaving as expected; "confidence" comes from both of these – if someone is paying $50 a tonne to store CO2, having the confidence that is the amount being stored.

The basic elements of a monitoring plan are fairly easy to understand – modelling the storage site, monitoring the plume of CO2 and checking it stays within the storage, looking for routes it could reach the surface, and working out overall risks.

The problems can arise more with effects which cross multiple risks, or which need multiple areas of expertise. For example, a marine biologist could work out the effect of CO2 entering seawater, but is unlikely to know much about seismic "except it upsets dolphins". Similarly exploration geologists are likely not know much about marine biology or ocean chemistry, he said.

Seabed monitoring

There has been some research into methods of seabed monitoring, to see if it is possible to detect bubbles of CO2 coming from the subsurface into the sea, or moving through the sediment on the seabed.

There have been 3 big research programs in the UK so far, which have involved releasing CO2 into and the marine environment and measuring how it affects seawater, using remotely operated vehicles and autonomous underwater vehicles.

All the programmes have released similar amounts of CO2. For example the STEMM-CCS project on the Goldeneye site in the North Sea, where CO2 was injected 3m below the seafloor, with 4.2 tonnes CO2 injected over 37 days.

Over the 3 experiments, the research showed that CO2 bubbles were easy to detect with sonar. Chemical detectors, which aim to detect the CO2 from analysing water samples, did not prove to be so useful. If you can drive a sensor right up to the leak point, it can be detected, but that is not a very practical monitoring method, Mr Hines said.

CO2 dissolves quickly in water, and although this changes the acidity of water, the effects are quickly dissipated in a large volume of water.

In one experiment, with CO2 injected 11m deep into sediment, only 15 per cent of CO2 actually escaped, the rest was trapped by sediment. Although this would probably be different with industrial sized CO2 volumes.

There is a significant question of whether CO2 leaking from deep storage will even be in a gaseous phase, since it is injected in a supercritical state (high pressure) and go through complex phase changes as it bubbles up. When it reaches water, or even saturated sediment, it will quickly dissolve.

There is also a question about how useful shallow monitoring could be, since even if it did detect CO2 leaking, it may be too late to do anything to stop it, because the subsurface seal would already have been long breached.

Seabed monitoring could be useful for detecting any old well bores – there have been concerns that wells drilled in the past, not plugged as well as they should have been, or even forgotten about, could provide a leakage path.

Gases bubbling through old well bores could also be methane from shallow gas reservoirs, he said. Ideally this would be detected in an initial baseline survey, conducted before the CO2 storage begins.

"If you've got old and abandoned infrastructure, you treat that as a known leakage path, you might want to monitor it constantly with a suitable detection system until you've established the confidence that nothing has happened, it is performing as expected," he said.

'Deep' monitoring

It may be more useful to use 'deep' or subsurface monitoring techniques, such as seismic, for CO2 storage. It can be relatively cheap when combined with other activities, with arrays towed from ships. Where there is congestion with other users, such as wind farms, devices can be put on the ocean bottom, which also makes it easier to do repeated surveys. Gravity monitoring may also have a role.

We are looking for signs that the CO2 column and plume is behaving as we expected, he said.

It is important to get a good baseline – a starting idea of how the plume will evolve. If you can demonstrate that the plume is evolving as you expected, that gives you confidence.

Robert Hines, CCUS consultant

If the storage is in an aquifer, another indication that storage is happening as expected is if the CO2 is pushing water into a water production well, designed to release the pressure.

Chemical tracers

There has been some consideration of the use of chemical tracers in CO2 storage – adding a chemical with a unique signature into the CO2 being injected. This would, in theory, make it possible to determine whether any leaking gas comes from this source.

One concern is detectability of the tracer. With such huge amounts of gas involved, to detect any tracer in any leaking gas would require huge amounts of tracers to be added, he said.

A second concern is whether the tracers would be viable over geological scales of storage.

Being sure

Best practice storage monitoring means getting data from multiple sources and putting them together to get a "really good impression," he said.

It's nothing we need to be particularly scared of, there's lots of technically mature options. It is just about joining the dots between them, so we have a solid understanding of our storage."

Knowing if a storage site is leaking or not is quite a simple question; but to know how much is leaking, if it is distributed leaks or a single source, is incredibly difficult to answer. "You need this layered [monitoring] capability," he said.

UK legislation for CO2 monitoring puts the emphasis on the operator to demonstrate best practice. It boils down to, "you tell us what you think good looks like," he said.

The UK requires monitoring for 25 years after injection. "I think that's a fairly arbitrary limit [but can] establish a reasonable confidence and is less onerous than other jurisdictions that require 100 years of monitoring."

Distributed Fibre Optic Sensing for CO2 injection monitoring

Fibre optic cable-based sensing can be used for multiple areas of CO2 storage monitoring, including monitoring CO2 injection into the well, monitoring where the CO2 plume goes, induced seismicity and temperature effects.

Fibre optic cable-based acoustic sensing, technical name ‘Distributed Acoustic Sensing’ (DAS), can be very useful in CO2 storage. It can be used to better understand the storage site before injection starts, to monitor the injection and check for leaks in the well, to make seismic surveys of the whole storage area and monitor the progress of the CO2 plume deep below the surface, to listen for ‘induced seismicity’ which could be indicative of movement of CO2 outside the storage area, and to monitor for deformation of the well.

Anna Stork, senior geophysicist with Silixa, a company which provides the technology, explained how it is used, speaking at a Finding Petroleum forum in London in May.

Silixa’s DAS instrumentation have and are being used in CCS projects and research in Canada, USA, Iceland, Spain, Norway, Italy, Turkey, Australia, South Korea and Japan, she said. For some projects Silixa provides equipment; for other projects the company also provides data collection and analysis services.

The systems are used at the Otway Project in Australia, a CCS research site. At Otway, Silixa has 40 km of DAS cable installed in 5 different wells, put in place over 2014-2020.

After only 580 tonnes of CO2 had been injected, it was possible to identify the CO2 plume on 2D seismic images, with seismic data captured using the DAS systems.

“We were able to track very quickly, and with great detail, the movement of the CO2,” she said.

Anna Stork, senior geophysicist with Silixa

The seismic source, a surface orbital vibrator (SOV), used was the size of a washing machine drum. This is much less disruptive to agriculture than Vibroseis trucks. It can be switched on automatically – something which proved particularly useful when Covid lockdowns made it difficult to travel to the site.

A second case study is the Aquistore Project in Saskatchewan, Canada, a demonstration and technology testing site. It is connected to the Boundary Dam power plant which has carbon capture attached. Most of the CO2 from Boundary Dam is used for EOR projects elsewhere but CO2 has been injected at the Aquistore site since 2015, with over 400,000 tonnes stored so far.

Silixa has recorded repeated seismic surveys since 2013, which provide a baseline pre-injection survey and post-injection surveys, enabling imaging the CO2 plume evolution over time.

As the volume injected increased from 36,000 tonnes to 141,000 tonnes, the plume could be seen growing. If you were able to look at it from above, you would see it grow first towards the North and East, then a bit to the South, she said.

Following these deployments, Silixa has developed a monitoring “solution” specifically for CCS including a range of technologies, called Carina CarbonSecure.

It aims to provide as much processing on site as possible with an “Edge Computing” set-up to reduce the amount of data which needs to be sent off site.

The system can be configured to provide alerts if unusual activity is detected. In this case, a decision can be made to stop injecting.

The technology

DAS technology makes use of the way vibrations and sound waves modulate light going through an optical fibre. The light pulse is produced by an ‘interrogator’ which also records and processes the returning light from the fibre. The changes in the light are detected by analysing “back scattered light”, because some of the light is reflected or ‘scattered’ back to the starting point of the cable.

The distributed fibre optic sensing family also includes temperature (DTS) and strain (DSS) sensing. The light is modulated by temperature variations and changes as small as 0.01 degrees C can be detected, and strain (stretching of the cable) can be measured at one microstrain (part per million) resolution.

The technology can use the same fibre optic cables which are used for telecommunications. Or it can use a special fibre optic cable designed in a way to increase the amount of backscattering – this means that there is more information coming back to the instrument which can be analysed.

The cables can be tens of kilometres long. The cables are usually about a quarter of an inch thick, and fibres are often encased in a metal tube. The cables do not need any maintenance and are designed to last for decades. In a well, the cable can be clamped to the casing or tubing, or cemented behind the casing.

One cable can contain multiple fibres, and each fibre can be used to measure different parameters (temperature, seismic and strain signals) simultaneously.

Measurements can be made with a resolution of less than 1m along the cable. The measurement is made by taking a moving average of neighbouring points on the fibre.

It is possible to make simultaneous measurements at all points. This way, it is possible to detect changes which only happen at narrow areas of the cable, something which may not be detected if you have a recording system with a limited number of individual receivers.

With the source in one position, it is possible to take seismic ‘readings’ for each metre of the cable, thus along the full wellbore if it is a borehole deployment. By moving the seismic source to different locations and taking multiple readings, it is possible to make a 3D seismic image. The quality of the signal is monitored throughout a survey.

In acoustic sensing, as used for seismic measurements, the system can record sounds with a dynamic range of 120 dB, at frequencies from millihertz to kHz.

The alternative recording device for seismic in wells is geophones. These are much harder to deploy downhole, being bulkier, and often breaking in harsh environments, Dr Stork said.

Geoscientists needed to define more UK CO2 storage

With the currently licensed UK CO2 storage predicted to provide sufficient capacity until 2030, and new sites needing up to 10 years to characterise and license, geoscientists are needed to work on new storage sites now

The UK government has set a target to store 20-30 million tonnes a year (mtpa) CO2 by 2030. It also has a target to reach 'net zero' by 2050, which would mean 104 mtpa CO2 storage by 2050, according to modelling by the UK's Climate Change Committee, a government advisory group.

So, a significant ramp up over 2030 to 2050. "We were looking ahead at that ramp up rate and saying, what do we need by 2035," said Chris Gent, policy manager at the UK based Carbon Capture and Storage Association, speaking at the Finding Petroleum forum in London on May 18, "CO2 storage - and opportunities for geoscientists."

"We think we need around 50 mt CO2 captured and stored pa [by 2035] to keep on track to net zero."

"Working backwards, we engaged our members in projects and clusters [to discuss] how fast we can go? what does the build out rate look like."

CCSA also looked at what the obstacles might be, such as insufficient financing, storage, or new technology.

The current policy framework and funding is planned around delivering around 22 mtpa storage by 2030, and there isn't yet any framework to go beyond that.

Then there is the question of storage capacity. The current licensed storage capacity can be broken down into the storage it enables per year – showing that new storage capacity will need to be available from 2030, in order to achieve a 2035 target, he said.

Currently the process of obtaining a permit for a new storage site takes potentially up to 10 years, getting from "theoretical to operational," according to studies by the Exploration Task Force, an industry group put together by the UK government.

The process of identifying sites often involves starting with a large number of possibilities, and then whittling the list down, Mr Gent said.

Geoscience

All of this needs plenty of geoscientists to model and help select storage locations, Mr Gent said.

If you have an oil and gas field, you're looking to turn into CO2 storage, there will be a large amount of subsurface data already available. On the other hand, areas of the world which have not been explored for hydrocarbons will not have any data at all to start off with when considering CO2 storage.

Understanding pressure and stress regimes is going to be an important factor of Co2 storage, he said.

Geoscientists might be asked to make a model of all the faults in an area and work out their slip tendency, to try to work out boundaries of how much a reservoir can be pressurised.

Chris Gent, policy manager at the UK based Carbon Capture and Storage Association

There is also work for geoscientists monitoring the storage site after injection has started, to see where the CO2 is going, he said. Repeat seismic surveys will be made "every few years" to understand how the reservoir is evolving.

As the number of stores increases, geoscientists will need to look at the possible pressure interaction between them.

"The more [storage] we bring online the more there's a need for geoscientists," he said.

An example of geoscience project, looking at how stores impact each other on a regional scale, was a study of the "Bunter" formation in the UK North Sea, he said. This contains a target storage site for the Northern Endurance partnership.

The work was to model what injection rate might be feasible over 40 years, storing 600m tonnes in total. It looked at what the pressure and strain impact would be on the overburden, and if that would impact the integrity of the caprock.

CCS and the North Sea Transition Deal

Under the 'North Sea Transition Deal' agreed between UK industry and government, industry will support the deployment of UK CCUS Projects and the transition to low carbon energy by re-purposing relevant assets for CO2 storage, before any decommissioning, explained OEUK's Kareem Shafi

The North Sea Transition Deal is an agreement made between the UK government and the UK's evolving oil and gas industry on the energy transition.

The 'deal' will support CCUS deployment by using existing assets, 'Assets' here includes the reservoir, platforms, pipelines and onshore storage terminals. Operators should also consider whether wells are penetrating saline aquifers which have the potential to store CO2.

The 2020 NSTA Strategy update includes an obligation for operators to consider re-use of assets for CO2 storage, before starting any decommissioning, said Kareem Shafi, business advisor with industry association Offshore Energies UK (OEUK), which represented the sector in the negotiations.

Also in the deal, the UK oil and gas industry agreed to support development of CCS to help industry and society reach net zero emissions.

This could be through developing projects to supply hydrogen fuel, for heating, transportation and industrial use.

The oil and gas industry has agreed to help heavy industry decarbonise, and the main way to do it is with CCS, he said.

In addition to CCS, the deal includes a commitment to decarbonise supply -through using electricity to power offshore platforms and reducing methane from offshore operations. The People & Skills theme in the Deal helps people transfer existing skills to new low carbon energies.

OEUK has established a 'Deal Delivery Group', which oversees the progress made on the commitments of the NSTD. OEUK has also formed a 'CCUS special interest group and CCUS Forum', to identify challenges and develop deliverables such as guidelines to share good industry practice. OEUK has been developing guidelines for its members since 2010 and It will soon be publishing the methane action plan guidelines which will help support the decarbonisation of energy supply and emission reduction.

Kareem Shafi, business advisor with industry association Offshore Energies UK

The UK government targets for carbon capture and storage are to store 20m tonnes CO2 by 2030, increasing it to 50m tonnes by 2035, he said.