Carbon Capture Journal

CCUS in Asia

Japan's Tomakomai project - achievements and future outlook

China's policy framework to achieve 'historic ambition' of net-zero emissions

Nov / Dec 2020 Issue 78

Norway launches £2.1 billion 'Longship' project

Rystad: Europe could see $35 billion in CCS spending till 2035

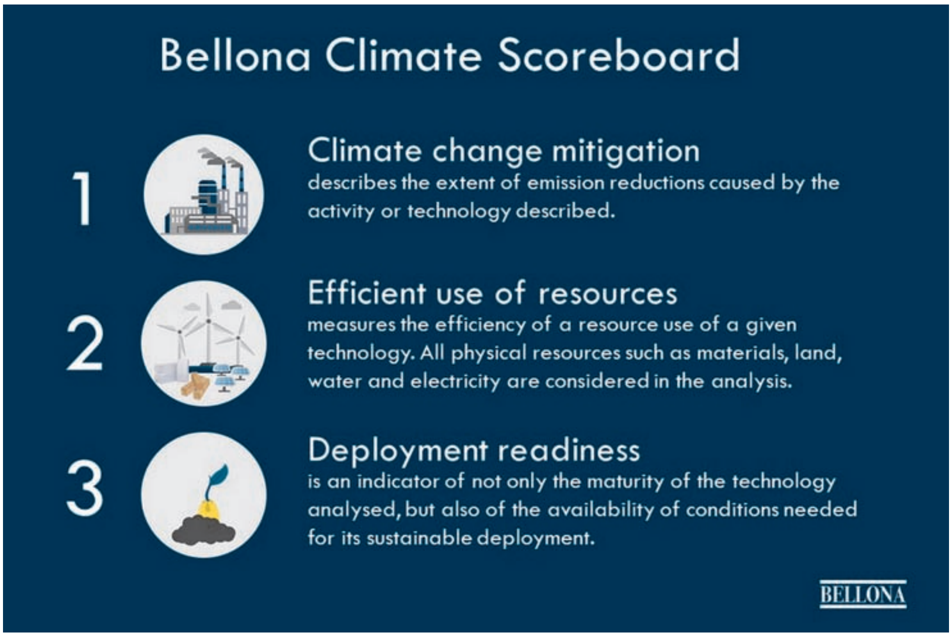
Prometheus Unbound: could the UK learn from the U.S. sector?

LafargeHolcim and Carbon Clean to develop large scale CCUS plant

Leading energy companies partner for UK North Sea carbon storage

How to navigate your way through industrial decarbonisation

Bellona's latest interactive project aims to identify, compare and evaluate potential solutions to accelerate industrial decarbonisation. By screening 15 solutions, they aim to illustrate the realistic potential and the current readiness level for each solution to make sure we start building the right framework to reach carbon neutrality.



The project's intention is not only to provide a list of solutions available, but also to assess whether these solutions are truly compatible with the EU climate goals.

Can we bring industrial greenhouse gas emissions to zero and if so, how?

This question has been at the core of Bellona's work and guided their research for several years with the belief that industry is a crucial sector that needs to take specific measures to tackle climate change.

Climate damaging emissions from heavy industries, such as steel, cement and chemicals, are responsible for a fifth of the EU's total greenhouse gas emissions. As we switch to low-carbon solutions in sectors such as transport and energy, we need to do the same for energy intensive industries. With this project, Bellona aims to delve deeper into each of the solutions which collectively contribute to climate change mitigation in industry.

Bellona looked into options for industrial decarbonisation already in 2018, outlining how heavy industry regions should be moving towards a low-carbon economy in 'Industry's Guide to Climate Action'.

However, there are still many open questions: when will these technologies be available? What are their costs? Where could they be deployed? Is one better than the other?

To answer all these questions, Bellona has created an accessible archive of climate solutions for industry that includes all the necessary information for policymakers to make more informed decision. This growing database of knowledge is a project that will grow further as we learn about new research and technologies relevant for industrial decarbonisation.

With the "Climate Solutions for Industry" project, Bellona aims to identify, compare and evaluate potential solutions to accelerate industrial decarbonisation. The aim is to present an honest account of the climate impact of the technologies at our disposal.

Climate criterias

To assess their emission reductions, the report uses three qualitative screening criteria to assess the technology's:

• contribution to climate change mitigation

• resource efficiency

• deployment readiness

With this simplified methodology, Bellona wanted to illustrate the realistic potential and the current readiness level for each solution to make sure we start building the right framework to reach carbon neutrality.

In total, they analysed 15 solutions, dividing them into 5 main building blocks. In addition to creating a standardised database, they added an overview of relevant projects currently being developed in various European countries. With a comprehensive overview of both the technologies on the table and existing project, options could be picked from the shelf, tailored to a specific context and added to the climate plans of EU member states.

As conversations around hydrogen have been filling the energy debate in the past year, they decided to start the project with the assessment of the production of the so-called green, blue and grey hydrogen, along with the analysis of their costs, availabilities and potential limitations.

Different parts of the project will be released in the coming weeks and Bellona says they look forward to sharing the findings to foster knowledge sharing and an active dialogue.

More information

www.bellona.org

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Front cover:
The Northern Lights template before installation on the seabed

Back cover: Schematic of the subsurface going from south to north through the 31/5-7 (Eos) CO2 confirmation well. The CO2 plume extent after 37.5 Mt injection is illustrated in magenta (pg. 22 and 26)

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Carbon capture journal (Online) ISSN 1757-2509

Leaders - CCUS in Asia

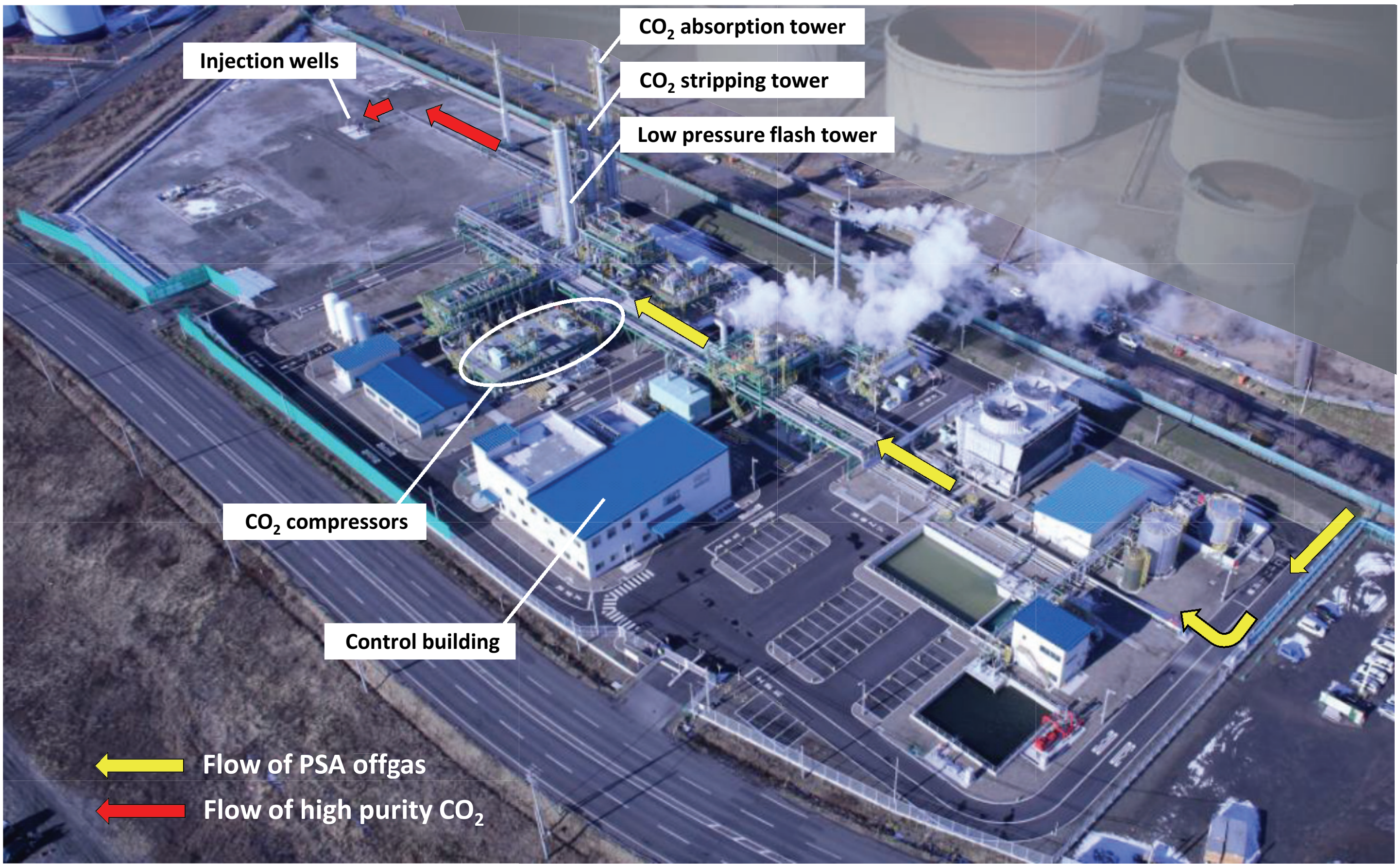
Projects and policy

Capture and utilisation

Transport and storage

Tomakomai project - achievements and future outlook

Japan's first large-scale CCS demonstration project continues to provide insights into long term CO2 storage and a new carbon recycling facility will explore the commercial use of CO2.



Aerial view of the Tomakomai capture and injection facilities. A new facility for carbon recycling will be built on the empty ground adjacent to the injection wells (Image: Japan CCS Co. Ltd.)

Tomakomai was the first large-scale CCS demonstraton project in Japan and is conducted by Ministry of Economy, Trade and Industry (METI), New Energy and Industrial Technology Development Organization (NEDO), and Japan CCS Co., Ltd (JCCS)..

During its first 4 years until FY2015, facilities to receive CO2 gas emitted from a hydrogen production unit of a refinery - the CO2 source, and to inject the CO2 underground were designed and built, and the conversion of one existing survey well into an observation well and drilling of 2 observation wells and 2 injection wells were completed.

At the same time, in order to verify that CO2 injection into the reservoir will not affect the surrounding environment, a monitoring system to record formation and earthquake data was established, and baseline data prior to injection was obtained.

Completing this preparation work, JCCS commenced CO2 injection under the seabed in the offshore area of Tomakomai Port from April 2016. CO2 injection was being carried out in FY2019 and on November 22, 2019, the target of cumulative CO2 injection of 300,000 tonnes was reached, and accordingly the injection has been suspended.

Monitoring of the behavior of CO2 in the reservoir is ongoing in order to verify that there is no leakage of CO2 and that natural earthquakes do not affect the stored CO2 by comparing the data with baseline data acquired prior to injection. In addition, monitoring of the marine environment such as observation of seawater and marine organisms will be continued.

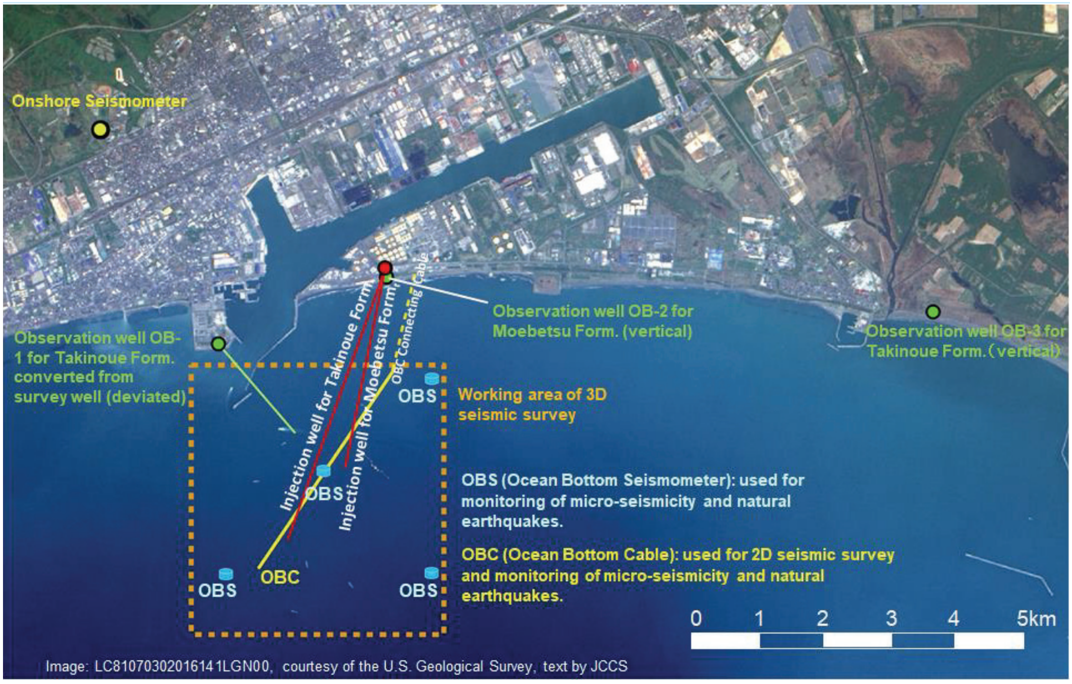
Monitoring

A monitoring network was constructed near and around the CO2 injection point, and continuous monitoring over six years comprising before CO2 injection (1 year), during CO2 injection (3 years) and after termination of injection (2 years) is being carried out.

• The formation pressures and temperatures of the wells - observation wells (3 wells) drilled around the CO2 injection point and CO2 injection wells (2 wells) are being monitored.

• Seismometers were installed in the observation well and on the seabed to monitor earthquakes (including micro-seismicity - minute tremors that cannot be felt by humans).

• Observed data is controlled centrally at the Tomakomai Demonstration Center and constant monitoring for the presence of abnormal conditions is carried out.



Layout of the monitoring network (Image: Japan CCS Co. Ltd.)

Next steps: carbon recycling

Mitsubishi Hitachi Power Systems (MHPS), Mitsubishi Heavy Industries Engineering (MHIENG) and Mitsubishi Gas Chemical Company (MGC) have been selected to conduct research on effective recycling of CO2 to produce methanol. A collaborative research project commissioned by NEDO aims at recycling CO2 from the existing demonstration plant at Tomakomai refinery.

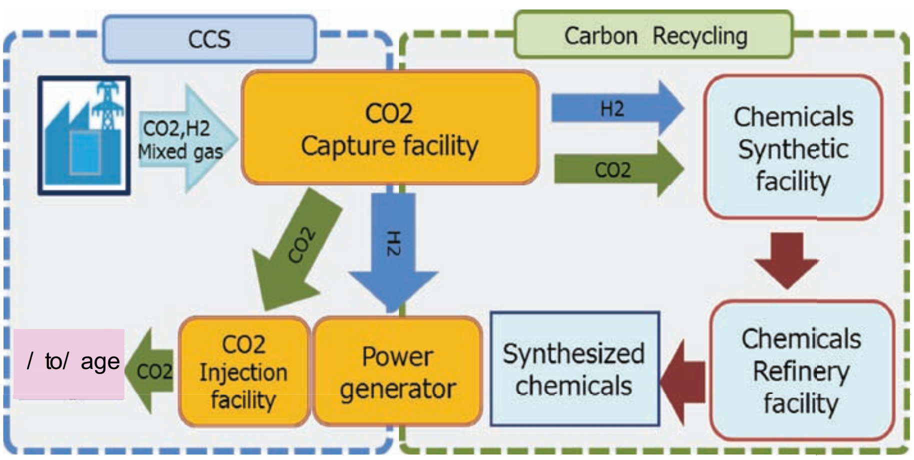
The three companies will collaborate on research activities for CO2 Capture and Utilization (CCU) in order to produce methanol from captured CO2. The research is expected to run until February 2021.

MHPS, as a leader of the consortium proposed using captured carbon dioxide to synthesize methanol, which is well known as a key fuel and raw material in a wide range of industries. The process will combine captured CO2 with hydrogen (H2) obtained either as a by-product from refineries or from water electrolysis within the existing CCS facilities.

The scope of the research includes performance assessment of key components of the proposed facilities with relevant technology survey, basic engineering for optimizing plant configuration, conducting an economic feasibility and its future outlook. The integration of CCU facilities with CCS facilities is expected to bring a benefit of sharing CO2 recovery functions and enhancing the interoperability of both facilities.

The consortium will conduct a survey project based on the assumption that an additional 20 ton/day class carbon-recycled methanol synthesis plant will be installed adjacent to the existing CCS facility. MGC will provide supply chain expertise related to methanol production and synthesis catalysts, as well as process technology for methanol production in cooperation with MHIENG.

The insights from the research also can be applied to various sources of CO2 emissions in the future. By studying technologies to capture, store and recycle carbon effectively, MHPS, MHIENG and MGC are actively contributing to the establishment of a carbon-free society and driving economic development while ensuring environmental conservation.



The potential of carbon recyclng will be explored

More information

Monthly updates on the monitoring activities are available at:

www.japanccs.com

www.mhi.co.jp

China's policy framework to achieve net-zero emissions by 2060

President Xi Jinping has pledged to cut China's emissions of carbon dioxide to net-zero by 2060. What are the policy priorities in order to make this a reality and what are the practical implication for CCUS scale up?

President Xi Jinping's address at the United Nations General Assembly included a historic pledge to cut China's emissions of carbon dioxide to net-zero by 2060.

Xi said: "China will scale up its Intended Nationally Determined Contributions by adopting more vigorous policies and measures. We aim to have CO2 emissions peak before 2030 and achieve carbon neutrality before 2060."

"This is an extremely important pledge by China, the world's largest single emitter of greenhouse gases," said Professor Lord Stern of Brentford, Chair of the Grantham Research Institute on Climate Change and the Environment at the London School of Economics and Political Science.

"China has been seeking a new form of high-quality development for some years now, and this commitment will be a major boost in that direction, promoting economic growth that is more sustainable, inclusive and resilient."

"If China leads by example with a sustainable economic recovery from the pandemic, it will not only provide an important political signal to the rest of the world, but it could also trigger a wave of new investments in clean technologies and infrastructure across the world, particularly in countries that are part of the Belt and Road Initiative."

Policy framework for CCUS in China

A recent report from the IEA, "CCUS in Clean Energy Transitions," noted that CCUS capacity is projected to grow rapidly in China, seeing the largest increase of any country or region through to 2070, in the Sustainable Development Scenario.

By 2030, the amount of CO2 captured reaches 0.4 Gt, or around half of the global total, and more than 2 Gt in 2070, the report says.

CO2 capture is applied mainly to coal-fired power plants, followed by chemicals, cement, and iron and steel production facilities. These sectors together make up the vast majority of the CO2 captured in both 2030 and 2050. The role of BECCS and DAC becomes more important over time, accounting for one-third of the CO2 captured in 2070.

Since the 12th Five-Year Plan (2011-15), China has included CCUS in its national carbon mitigation strategies. The National Climate Change Plan for 2014-20 defines CCUS as a key breakthrough technology. Since the plan came into effect, the government has issued guidance documents, such as the Notice on Promoting Demonstration of Carbon Capture, Utilisation and Storage, Industrial Green Development Plan (2016-2020) and 13th Five-Year (2016-2020) Work Scheme on Greenhouse Gas Emissions Reduction, which aim to support and advance the development of CCUS technologies. CCUS was also included in China's catalogue of strategic emerging technologies and was a major focus of the national technological innovation project, Clean and Efficient Use of Coal (Wei et al., 2020).

In May 2019, the Ministry of Science and Technology, and the Administrative Centre for China's Agenda 21 (ACCA21) jointly issued an updated version of the Roadmap for Development of CCUS Technology in China. The roadmap sets out an overall vision of the development of CCUS technology in China (ACCA21, 2019). It defines several phase goals in five-year increments to 2050.

By 2030, CCUS should be ready for industrial applications, and long-distance onshore pipelines with capacities of 2 MtCO2 should be available. It also aims to reduce the cost and energy consumption of CO2 capture by 10-15% in 2030 and 40-50% in 2040. By 2050, CCUS technology is to be deployed extensively, supported by multiple industrial CCUS hubs across the country.

Hurdles to faster CCUS deployment in China include the lack of a legal and policy framework, limited market stimulus and inadequate subsidies. Public understanding and awareness of CCUS technologies is relatively low.

China is committed to achieving a peak in CO2 emissions by 2030 or before. In 2017, China implemented a national ETS to limit and reduce CO2 emissions in a costeffective manner. The ETS, which is due to start operating in 2020, will strengthen commercial incentives to invest in CCUS and other low-carbon technologies. It will initially cover coal- and gas-fired power plants and will later be expanded to seven other sectors, including iron and steel, cement, and petrochemicals. The scheme will be the world's largest to date, covering one-seventh of global CO2 emissions from fossil fuel combustion.

Near-term opportunities for CCUS

"CCUS in Clean Energy Transitions" continues by looking at the most likely scenarios for CCUS in China to get going.

Prime locations for early development of CCUS hubs are centred on areas with good CO2-EOR opportunities, the report says. The revenue stream from CO2-EOR can help support investment in CO2 capture facilities and be a bridge towards more widespread geological storage of CO2. CO2-EOR can contribute to emissions reductions. Locations for CCUS hubs include those where CO2-EOR is already in use today, in particular in the northern provinces.

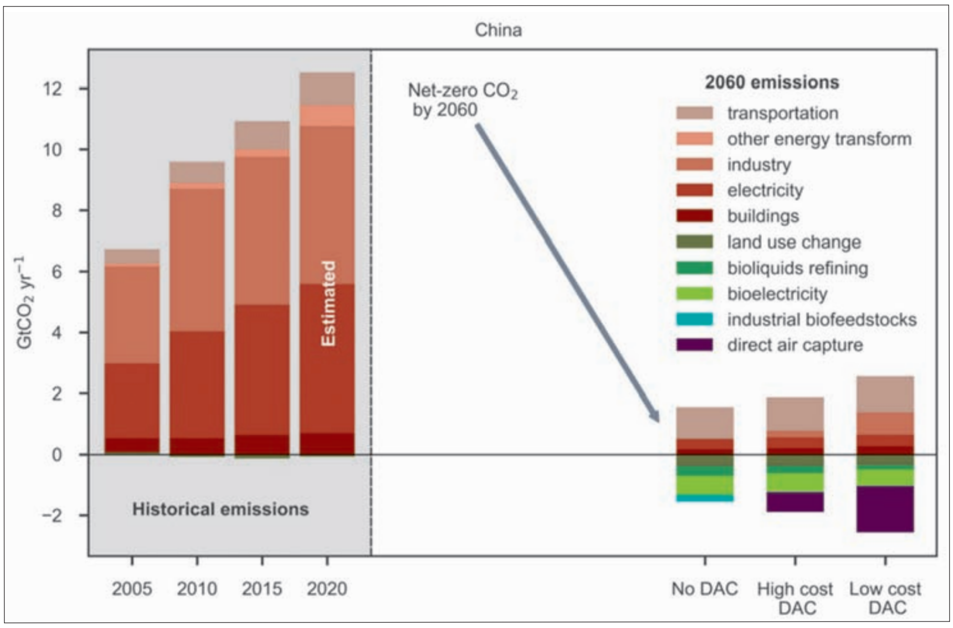
While the CO2 emissions density in some of these provinces is lower than in the coastal areas, supply of CO2 is unlikely to be a constraint.

Regions with a high concentration of coal-based chemicals and hydrogen production facilities provide other near-term opportunities for CCUS. CHN Energy, China's largest power company, is also the world's largest hydrogen production company. Its 80 coal gasifiers can produce around 8 Mt/year of hydrogen – equivalent to 12% of global dedicated hydrogen production today.

Applying CCUS to this existing capacity could deliver CO2 emissions reductions of up to 145 Mt per year, while providing a major boost to the development of both CCUS and low-carbon hydrogen. The majority of the coal-based hydrogen production facilities are located in the northern provinces of Shanxi, Shaanxi and Inner Mongolia, all of which have CO2 storage resources in relative close proximity.

In recent years, the Chinese government indicated that hydrogen energy is a vital element in China's energy technology development strategy. Coal gasification with CCUS could be a springboard for hydrogen to fulfil its longer-term decarbonisation potential across the Chinese energy sector.

Other opportunities for CCUS hubs are in large industrial ports on the east coast. Of the ten largest ports in the world, seven are in China. The development of industrial CCUS hubs with associated infrastructure in these ports presents an attractive opportunity to reduce a significant amount of China's CO2 emissions.



Pathways for China to reach net-zero CO2 emissions by 2060 all involve deep emissions reductions and CO2 removal. The availability of direct air capture technology in China enables less use of BECCS, and also offsets emissions from difficult-to-mitigate sectors such as transportation and industry, allowing higher emissions from these sectors relative to the no DAC case. Results shown here are for the China + rest of the world (ROW) net-zero 2060 scenario, which results in approximately 1.8º C of warming from preindustrial. (Source: "China's 2060 carbon neutrality goal will require up to 2.5 GtCO2/year of negative emissions technology deployment" Jay Fuhrman et al, University of Virginia)

China will require up to 2.5Gt CO2/year of negative emissions technology

The conclusion of a preprint paper from Jay Fuhrman at the University of Virginia et al on ResearchGate is that China will need to rapidly scale up Negative Emissions Technologies (NETs) and that NETs lower the cost for China to reach its net zero targets, particularly when Direct Air Capture is included. The results are summarised below:

"The recent pledge from China to achieve carbon neutrality by 2060 provides a major contribution towards limiting climate change. To achieve this goal, first China needs to demonstrate that they are on track to carbon neutrality. Second, the rest of the world should also join the coalition of carbon neutrality. Third, efforts to stabilize the climate system should continue beyond 2060."

"We modeled these different futures in an effort to understand the role of negative emissions technologies in helping to achieve the net-zero by 2060 target. Negative emissions technologies are being developed in order to offset recalcitrant emissions from transportation and industry, even though they are generally considered to be more expensive than conventional decarbonization activities."

"We analyzed China's options to go net-zero using the Global Change Assessment Model (GCAM) with three major sources of negative emissions: bioenergy with carbon capture (BECCS), afforestation (AR), and direct air capture with carbon storage (DAC)."

"Our findings show that the NETs lower the cost for China to achieve its net-zero emissions target. This is particularly true if the rest of the world is decarbonizing alongside China. The extent to which NETs are deployed depends on their cost, which is expected to go down over time as technologies improve once their use is incentivized. However, some of the radiative forcing benefit of CO2 removal with DAC is offset by fugitive methane emissions. If the leakage rate of the natural gas supply chain is higher, the net radiative forcing benefit of large-scale natural gas-fired DAC deployment would be correspondingly lower."

"We found that, without DAC, China can possibly get to net-zero CO2 emissions by 2060 with 1.5 GtCO2 negative emissions, but this would need to come from BECCS and AR at an increasingly higher marginal cost per tCO2 than if DAC could be deployed alongside them. With DAC widely available, China's carbon neutrality can be supported by more than 2-2.5 GtCO2 negative emissions to get to the net-zero CO2 emissions by 2060."

"Our results indicate that up to 30-60% of the negative emission needs would be fulfilled by DAC, while rest would be fulfilled by BECCS and AR. This level of scale up of DAC would require investment in the order of US$200-280 billion in 2060 which is about 1-2% of China's GDP in 2019."

More information

www.lse.ac.uk/granthaminstitute

www.iea.org

www.researchgate.net

Prometheus Unbound: could the UK learn from the U.S. CC(U)S sector?

Jared Franicevic, Counsel at Pillsbury Winthrop Shaw Pittman, looks at the current state of support for CC(U)S in the UK and what might be learnt from other jurisdictions.

It is widely recognised that carbon capture, utilization and/or storage (CC(U)S) has the potential to play a significant role in helping achieve global "net-zero" emissions goals through decarbonization of power generation and other industrial processes. At the same time, however, the costs and risks involved in developing CC(U)S projects at scale mean government policy support is needed to attract private sector investment for this potential to be realised.

The UK government has run two competitive procurement programmes for CCS, in 2007 and 2012 – 2015 respectively, but each was ultimately abandoned. A key reason given for this was the high implementation costs that ultimately would need to have been passed on to the consumer. This is particularly true in the latter instance due to the anticipated high strike price (approx. £170/MWh) that would have been set under the contract for difference (CfD) that was being offered to developers (and which, as with all CfDs, would have ultimately been funded through consumer levies).

These programmes assumed that the private sector could deliver CC(U)S projects and manage all risks across the CC(U)S chain – from capture to transportation, utilization and/or storage. In relation to some elements of CC(U)S projects (such as construction, integration and operation of capture technology), this is a reasonable assumption and the private sector should, arguably, be able to manage and price these risks competitively.

However, the assumption is certainly not reasonable in relation to other elements, such as the project-on-project risks associated with what is essentially the development, construction and operation of separate projects for carbon capture and carbon transportation and storage (T&S), storage reservoir performance risks (e.g. carbon leakage), storage decommissioning liabilities and insurance market limitations for T&S. The private sector could only take on these risks by charging significant risk premiums, which was what drove the high strike price mentioned above.

The UK government remains committed to deployment of CC(U)S at scale by the 2030s, as evidenced by its announcement in March 2020 that an £800 million infrastructure fund would be made available for development of CC(U)S projects in at least two industrial clusters.

In August 2020, the UK government also published its response to its consultation with various industry stakeholders on potential CC(U)S business models for industry, power, carbon dioxide T&S and low carbon hydrogen production and the action that is needed to enable CC(U)S deployment in the near term.[1] Although no definitive announcements were made in the consultation response, it would seem that their current thinking is leaning towards:

(i) separate business models for capture projects (further separated by sector into power, industry and low carbon hydrogen) and T&S projects, thereby breaking up the full-chain approach that was adopted on the earlier procurement rounds (and which the UK government, in its consultation response, now recognises was not a successful approach);

(ii) using CfDs as the business model for power and industrial capture projects and specifically in the case of:

(a) power generation projects, using a dispatchable CfD which provides:

a. a fixed availability payment, which is intended to provide developers with a stable revenue stream to offset decreased load factors that may be experienced as renewables penetration increases over time and power CC(U)S plants increasingly play a mid-merit role in the UK's energy system) and

b. a variable payment, which is intended to incentivize the power CC(U)S plant to dispatch ahead of an unabated equivalent plant but behind renewables and nuclear (assuming the additional costs of running the power CC(U)S relative to the costs of running an unabated power plant cannot be recovered through other means, e.g. high carbon prices);

Jared Franicevic, Pillsbury Winthrop Shaw Pittman,

(b) industrial projects, using a CfD that operates by reference to a carbon price;

(iii) recognition that in the case of low carbon hydrogen projects, more research is needed before a suitable business model can be put forward; and

(iv) using a regulated asset base (RAB) model as the business model for T&S projects, under which centralised T&S networks are developed, owned and operated under a licence which grants the relevant T&S company the right to charge a regulated price to users of the T&S network in exchange for the T&S company delivering and operating the T&S network.

While these measures are a significant boost for CC(U)S in the UK, the government is still to clarify key aspects of each, including:

(i) whether the £800 million funding will be allocated as grant funding to support the capital costs of constructing the CC(U)S projects, as funding for whatever business model is proposed as the value proposition to attract pri-

1. *https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/909706/CCUS-government-response-business-models.pdf*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vate sector investment into CC(U)S projects, or for other uses; and

(ii) more definitive detail on the business models under which CC(U)S projects will be developed, how they will interface with each other and how key risks such as impact of delays or outages of the T&S assets on the revenue stream available to the capture projects and the allocation of fees for use of the T&S assets will be allocated.

Further clarity is expected by the end of 2020 and, it is hoped, this will enable the pace of CC(U)S deployment in the UK to accelerate.

In the meantime, can anything be learned from experiences in other jurisdictions? After all, despite the general sentiment that more policy support is needed to drive forward deployment of CC(U)S projects globally, there is at least some frame of reference given that, as at 2019, there were approximately 50 large-scale CC(U)S facilities in operation or varying stages of development in North America US, Europe, Asia Pacific and the Middle East.[2]

The US provides a particularly good point of contrast in this regard. It has a modest number of commercial-scale CC(U)S projects in operation, with others under development and construction. Since 2008 (and expanded in 2018), the US government has also offered a policy support mechanism specifically for CC(U)S - the "Section 45Q" tax credit scheme - under which tax credits are available to CC(U)S project developers based on each metric ton of carbon captured from a project for the first 12 years of operation of its carbon capture equipment.

The availability of credit depends on whether carbon is captured and securely stored (for which a higher credit amount is available) or captured and used for enhanced oil recovery (EOR), i.e. the process of injecting carbon dioxide into existing oil reservoirs to create pressure to push oil to the surface (for which a lower credit amount is available).

However, whilst the tax credit scheme has been used successfully in the US to advance the deployment of wind and solar technologies, CC(U)S developers have been slow to respond to the availability of equivalent tax credits. This is in part due to lack of clarification around key aspects of the mechanism following its 2018 expansion, not least how the various pieces of guidance issued by the US government are intended to fit together.

There is also a view that the tax credit mechanism, in and of itself, may not be sufficient to incentivize private sector participation in CC(U)S projects, particularly those involving higher cost storage projects using geological sequestration or direct air capture, and that other policy support mechanisms and / or revenue streams may be needed as part of a revenue stack in order to build a viable business case.

Traditionally, the sale of carbon dioxide for EOR has provided a robust alternative revenue stream. A good example of this is the Petra Nova project, which was developed in Texas as an integrated CC(U)S project with related ownership by sponsor groups of a coal power plant (with retrofitted capture technology), pipeline and oilfield.

Petra Nova also benefitted from alternative policy support in the form of grant funding from the US Department of Energy, which together with export credit agency loans and equity contributions (with a relatively low gearing when compared to traditional project financed transactions) was used to fund capital costs of developing the project.

However, the recent collapse in, and projected volatility of, oil prices, together with the increased global focus on the need for sustainability, calls into question the viability of the sale of carbon dioxide for EOR as a business case. This is unlikely to spell the end for CC(U)S development in the US but does perhaps highlight the need for further policy support – particularly in relation to development of T&S assets.

Ultimately, tax credits were considered by the UK government during the abovementioned consultation on business models and, for now, it would seem they will not be taken forward as a preferred business model, though this is still under consideration for low carbon hydrogen. This is perhaps unsurprising given that private sector investors in the UK are familiar with the CfD and RAB models and there is a logic in leveraging that familiarity, provided of course that the application of these business models in a CC(U)S context is clarified.

Check out future issues for more analysis from Jared Franicevic.

More information

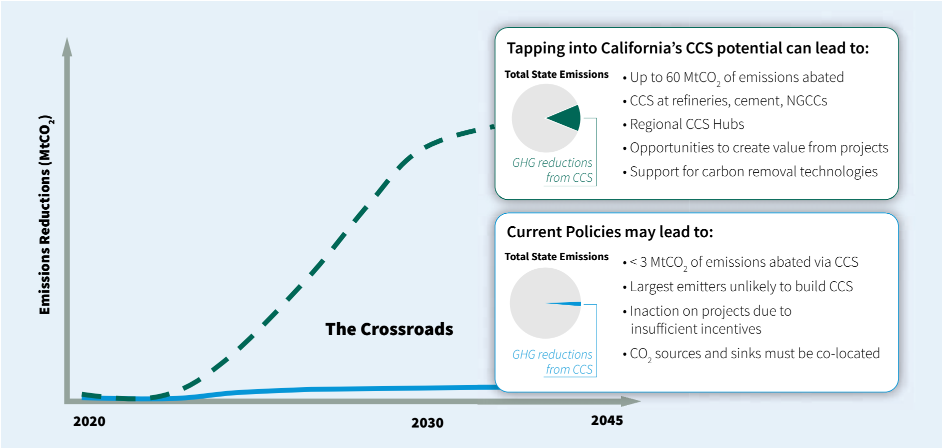
www.pillsburylaw.com

2. *Global CC Institute, 2019 Global Status Report*

EFI and Stanford Release Action Plan for CCS in California

"An Action Plan for Carbon Capture and Storage in California: Opportunities, Challenges, and Solutions" provides policymakers with options for near-term actions to deploy carbon capture and storage (CCS) to meet California's climate goals.

The study, six months in the making, concludes that CCS offers a clean technology pathway for rapidly reducing emissions from economically vital sectors that have few other options to decarbonize. It can also support clean, firm power, an essential enabler of intermittent renewable generation.



California is at a crossroads for CCS. In the current policy environment, there will likely be few projects with very limited emission reductions potential. With affirmative policy support, CCS could play a major role in enabling the state to meet its climate goals by midcentury. Source: Energy Futures Initiative and Stanford University, 2020.

The report was introduced in a virtual briefing led by Ernest J. Moniz, former U.S. Secretary of Energy and founder of EFI and Franklin Orr, Professor Emeritus at Stanford University. They were joined by the report's co-leads, EFI's Melanie Kenderdine and Sally Benson, Professor at the Department of Energy Resources Engineering at Stanford University.

"California has the most ambitious carbon reduction goals in the nation," said Benson. "Our study outlines the vital role that CCS could play in achieving carbon neutrality by 2045."

EFI, a nonprofit think tank established by former U.S. Energy Secretary Ernest J. Moniz, previously published "Optionality, Flexibility, and Innovation: Pathways for Deep Decarbonization in California," which concluded that the targeted use of CCS could be one of the single largest contributors to California's decarbonization by 2030.

"California has a strong economic base, a skilled workforce, and enviable innovation capacity at its laboratories, universities, and tech companies," said Kenderdine. "The state is well placed to accelerate its progress on developing the clean energy technologies that will decarbonize industry and the power sector, create jobs, and new industries enabled by CCS, such as a hydrogen economy, and become a global leader in deploying CCS technologies."

CCS, like all other emission reduction technologies, is not a "silver bullet" technology for decarbonization. Carbon capture paired with permanent geologic storage (i.e. deep saline reservoir) is a viable and important option for reducing emissions from the industrial and electricity sectors that are key contributors to California's economy and the reliability of its grid.

Technoeconomic analysis done for this study identified 76 existing electricity generation and industrial facilities as candidates for CCS, in total representing nearly 15 percent of the state's current greenhouse gas emissions.

Successful policy pathways for achieving California's ambitious emission reduction targets are critical. Additional and accelerated actions are needed to ensure that the state successfully transitions to a carbon neutral economy both economically and equitably. California's economy would be the fifth largest in the world as a stand-alone entity, so the state's success in meeting its emissions targets and as a technology leader have significant implications for the global climate solutions.

Some of the key findings of the report include:

• California's economy would see rapid near-term emissions reduction benefits from CCS;

• The state has a strong foundation for supporting CCS projects, and the study has identified 76 facilities suitable for carbon capture;

• California's geology makes it well suited for safe, permanent CO2 storage;

• California could prioritize CCS projects that have demonstrable local air quality benefits and local job opportunities in line with the state's climate and equity goals

More information

energyfuturesinitiative.org

The world needs to build on the growing momentum behind carbon capture

A major new IEA report, launched at an event opened by Norwegian Prime Minister Erna Solberg, shows CCUS can play vital roles of both reducing emissions and removing carbon from the atmosphere.

After years of slow progress, technologies to capture carbon emissions and store or reuse them are gaining momentum, a trend that will need to accelerate significantly for the world to achieve its energy and climate goals, according to a new special report released by the IEA today."

The report, CCUS in Clean Energy Transitions," was launched at an IEA online event opened by Prime Minister Erna Solberg of Norway, whose government announced a major funding commitment for a new carbon capture project that can help tackle emissions from Norway and neighbouring countries.

CCUS is the only group of technologies that contributes both to reducing emissions in key sectors directly and to removing CO2 from the atmosphere to balance the emissions that are the hardest to prevent – a crucial part of reaching the net-zero emissions goals that a growing number of governments and companies have set for themselves.

Part of the IEA's Energy Technology Perspectives Series, the new IEA report is the most comprehensive global study on CCUS to date. It assesses the state of play of CCUS technologies and maps out the evolving and expanding role they will need to play to put global emissions on a sustainable trajectory. It includes a detailed analysis of CO2 emissions from power and industrial facilities in China, Europe and the United States and potential for storing them.

A new era for CCUS

Carbon capture, utilisation and storage (CCUS) so far has not lived up to its promise. Although its relevance for reaching climate goals has long been recognised, deployment has been slow: annual CCUS investment has consistently accounted for less than 0.5% of global investment in clean energy and efficiency technologies.

Stronger climate targets and investment incentives are injecting new momentum into CCUS. Plans for more than 30 new integrated CCUS facilities have been announced since 2017, mostly in the United States and Europe, although projects are also planned in Australia, China, Korea, the Middle East and New Zealand. Projects at advanced stages of planning represent a total estimated investment of more than USD 27 billion, almost double the investment in projects commissioned since 2010.

CCUS technologies offer significant strategic value in the transition to net-zero:

• CCUS can be retrofitted to existing power and industrial plants, which could otherwise still emit 8 billion tonnes (Gt) of carbon dioxide (CO2) in 2050.

• CCUS can tackle emissions in sectors where other technology options are limited, such as in the production of cement, iron and steel or chemicals, and to produce synthetic fuels for long-distance transport (notably aviation).

• CCUS is an enabler of least-cost low-carbon hydrogen production.

• CCUS can remove CO2 from the atmosphere by combining it with bioenergy or direct air capture to balance emissions that are unavoidable or technically difficult to abate.

The Covid-19 crisis represents both a threat and an opportunity for CCUS: the economic downturn will almost certainly impact investment plans and lower oil prices are undermining the attractiveness of using CO2 for enhanced oil recovery. But CCUS is in a stronger position to contribute to economic recoveries than after the global financial crisis. A decade of experience in developing projects and the recent uptick in activity means that there are a number of "shovel-ready" projects with potential to double CCUS deployment by 2025.

"The scale of the climate challenge means we need to act across a wide range of energy technologies. Carbon capture is critical for ensuring our transitions to clean energy are secure and sustainable," said Dr Fatih Birol, the IEA Executive Director.

Plans for more than 30 commercial CCUS facilities have been announced globally in the last three years. And projects now nearing a final investment decision represent an estimated potential investment of around USD 27 billion – more than double the investment planned in 2017. This portfolio of projects is increasingly diverse and would double the amount of CO2 captured globally.

Although CCUS facilities have been operating for decades in certain industries like natural gas and fertilisers, they are still at an early stage of development in key sectors such as cement. These are the areas where CCUS technologies are particularly important for tackling emissions because of a lack of alternatives.

"Action from governments will be essential for establishing a sustainable and viable market for CCUS," Dr Birol said. "But industry must also embrace the opportunity. No sector will be unaffected by clean energy transitions – and for some, including heavy industry, the value of CCUS is inescapable. As our new report demonstrates, the IEA is committed to leading CCUS analysis and policy advice worldwide – and to bringing together governments, companies and other key players to work together to achieve our shared energy and climate goals."

Reaching net zero will be virtually impossible without CCUS

The report sets out the four main ways that CCUS technologies contribute to clean energy transitions:

• Tackling emissions from existing energy infrastructure. CCUS can be retrofitted to existing power and industrial plants that could otherwise emit 600 billion tonnes of CO2 over the next five decades – almost 17 years' worth of current annual emissions.

• A solution for some of the most challenging emissions. Heavy industries account for almost 20% of global CO2 emissions today. CCUS is virtually the only technology solution for deep emissions reductions from cement production. It is also the most cost-effective approach in many regions to curb emissions in iron and steel and chemicals manufacturing. Captured CO2 is a critical part of the supply chain for synthetic fuels from CO2 and hydrogen – one of a limited number of low-carbon options for long-distance transport, particularly aviation.

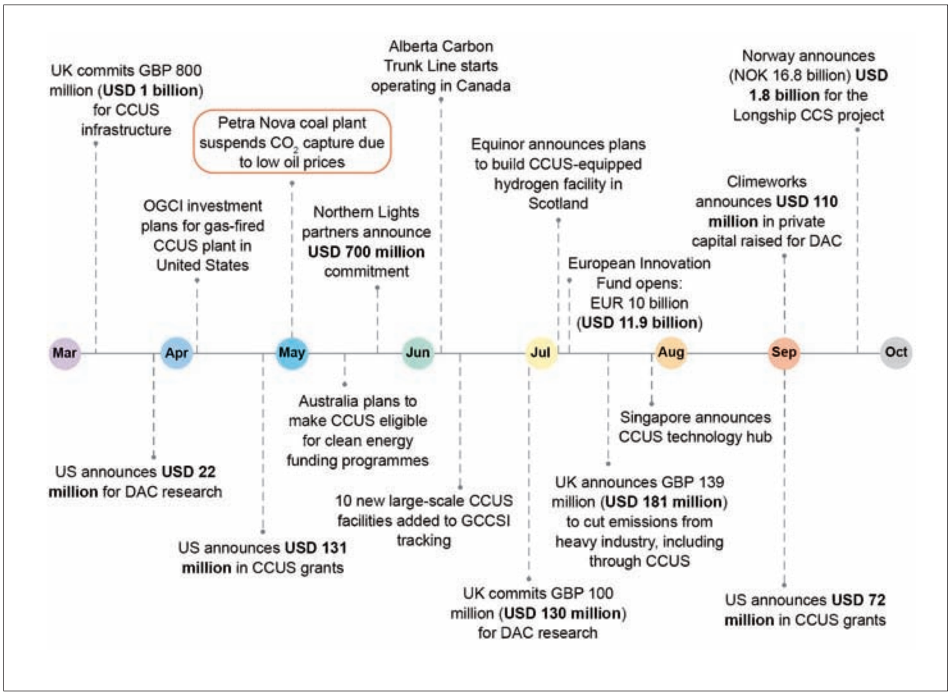
• A cost-effective pathway for low-carbon hydrogen production. CCUS can support a rapid scaling up of low-carbon hydrogen production to meet current and future demand from new applications in transport, industry and buildings.

• Removing carbon from the atmosphere. For emissions that cannot be avoided or reduced directly, CCUS underpins an important technological approach for removing carbon and delivering a net-zero energy system.

Accelerating deployment

The next decade will be critical to the prospects for CCUS and for putting the global energy system on a path to net-zero emissions. A significant scaling-up of CCUS is needed to provide the momentum for further technology development and cost reductions, and to foster progress across a broader range of applications in the longer term.

Delays in investment and innovation in CCUS technologies would have a lasting impact on future emissions trajectories and could slow the pace at which net-zero emissions can be achieved. A five-year delay in developing and deploying CCUS technologies would halve the CO2 emissions being captured worldwide in 2030 compared to the Sustainable Development Scenario.



Timeline of CCUS developments, March–September 2020

The required rate of CCUS rollout is challenging. It can only be achieved if nearterm policy action establishes the conditions for investment along the CCUS value chain. Economic recovery packages are a unique window of opportunity for governments to support CCUS alongside other clean energy technologies.

The key to successful policy is designing a framework that supports the creation of a sustainable and viable market for CCUS. There is no one-size-fits-all policy template: the appropriate choice or mix of instruments for each country depends on local market conditions and institutional factors. On their own, technologyneutral measures such as carbon pricing are generally not sufficient. Measures targeted at specific CCUS applications, including capital grants and operational support, can help build a business case for investment and drive widespread deployment in the near term.

There are four high-level priorities for governments and industry to support a rapid scaling-up of CCUS over the next decade: create the conditions to stimulate private investment; target the development of industrial hubs with shared CO2 infrastructure; identify and encourage the development of CO2 storage; and boost innovation to reduce costs and ensure that critical technologies and applications are available, including in sectors where emissions are hard to abate and for carbon removal.

Government action this decade is crucial

Four high-level priorities for governments and industry would accelerate the progress of CCUS over the next decade:

1. create the conditions for investment by placing a value on reducing emissions and direct support for early CCUS projects

2. co-ordinate and underwrite the development of industrial hubs with shared CO2 infrastructure

3. identify and encourage the development of CO2 storage in key regions

4. boost innovation to reduce costs and ensure that critical emerging technologies become commercial, including in sectors where emissions are hard to abate and for carbon removal.

More information

www.iea.org

Technical and Commercial Progress Towards Viable CO2 Storage

The report from The Catalyst Group Resources considers the technical and commercial feasibility of CCS from three critical perspectives - regulatory, transportation and storage - and provides a timely synopsis of the major enabling factors that need to be progressed for CCS to move forward.

The challenge

To meet the goals of the Paris Agreement, CCS storage projects will need to scale at an unprecedented rate. The current developmental pace for policy, legal and regulatory drivers of CCS storage is inconsistent with this need, however there are enablers that can significantly advance knowledge and scale CCS.

If the global community continues to develop and adopt international, national, and sub-national policies to mitigate global climate change, CCS will likely play a critical role. To enable this role, substantial and rapid development in CO2 pipelines will also be needed.

A scenario was put forward by J.P. Morgan to transport and store 5 gigatons (Gt) of CO2 equivalent to 15% of the current 33 Gt of CO2 emitted annually and around a third of the necessary 13-14 Gt reduction required in IPCC models. Such a reduction results in a requirement whereby the CCS infrastructure would be larger than the global oil ecosystem developed over the best part of a century.

Achieving this level of CO2 reduction through CCS is not an impossible goal, but it is a daunting one. A concerted global effort is needed to develop the technology, infrastructure, and enabling policy, legal and regulatory regimes for CCS to scale in the coming decades.

Outlook for CO2 storage to be commercially viable

The main challenges to be overcome comprise:

- Reduction of uncertainties, e.g. related to storage capacity estimates and costs
- Gaining political and societal support
- Introduction of efficient carbon taxing
- Adoption of commercial-scale full-chain CCS projects
- Introduction of comprehensive regulation
- Public perception and outreach

Reducing uncertainties that are mainly related to the geological heterogeneity of the deep subsurface are key to reducing the overall costs. Sound economical project planning with reduced uncertainties will make CO2 storage projects become an attractive business model.

This can be promoted by broad political support of CO2 storage technology. For example, when an efficient carbon taxing > 40US$/tCO2 emitted can be introduced, it is very likely that substantial investments into CO2 storage become justifiable as potential long-term revenues will be provided.

These substantial investments are necessary to promote the implementation of commercial-scale full-chain CCS projects. Only at this complex project level can CCS technology contribute significantly to solving the carbon problem. Commercial-scale CO2 storage projects also necessitate regional approaches, e.g. for estimating storage capacities and monitoring. This in turn calls for the introduction of comprehensive regulation and CCS-specific laws. These would have to address the management of environmental risks as well as regulate the long-term requirements for monitoring, stewardship and liability.

Last but not least, in order to make commercial-scale CO2 storage projects viable, unbiased information has to be provided to the public. Local stakeholders and communities have to be included in the engagement process, this also includes clear communication of the risks and benefits of CO2 storage. Without public support, further implementation of CO2 storage technology at the commercial scale will not be viable.

Regulatory drivers for storage

Supporting tax incentives, such as the U.S. 45Q program, can substantially impact the commercial viability of both CCS-EOR projects and pure geologic storage projects, however there is still ample room for policy innovation. Tax-exempt bonds, master limited partnerships, expanded CO2 storage tax credits are all options that could, if enacted, work to address the economic and financial challenges currently facing CCS storage projects.

While most recent efforts to develop and adopt policies to govern and incentivize CCS storage have only been modest adjustments to the extant legal systems and incremental developments in terms of new policies, the 2018 U.S. expansion of CCS tax credits (45Q) is a notable and important exception to this trend. In 2019, California also authorized tax credits for that can be applied to CCS projects. Importantly, these credits can be stacked with the 45Q credits, thereby substantially improving the financial profile of potential CCS projects.

Important developments are also underway as the EU ETS concludes Phase 3 (2013-2020) and moves toward Phase 4. Running through 2030, Phase 4 will increase the Linear Reduction Factor (LRF) to 2.2 percent and double the intake rate for the Market Stability Reserve (MSR) for the first five years (2019-2023) of operation from 12 percent to 24 percent if the threshold of 833 million allowances is exceeded.

However, the current pace of CCS development is modest and largely limited to projects that leverage EOR opportunities and is not sufficient to meet Paris Agreement targets. Absent is an expansion of economy-wide CO2 reduction targets, an increase in the adoption of CCS-specific legal and regulatory regimes that address the full life cycle of CCS projects, and the introduction of tax and other financial incentives. Overall CCS development will likely continue to move forward at an incremental pace.

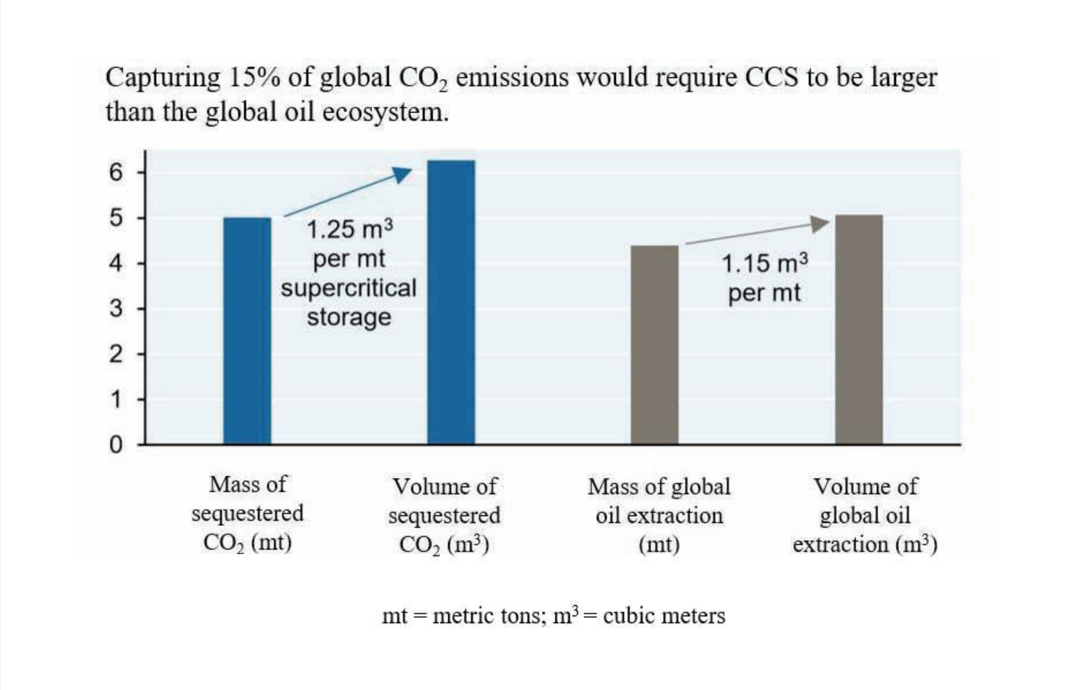


Figure 1 - Comparison of CCS Volume for 15% Global CO2 Emission to Oil Ecosystem (adapted from Cembalest, 2019)

Regulatory drivers for transport

Substantial and rapid development in CO2 pipelines will be needed to enable CO2 storage requirements. As CCS operations are deployed at greater operational and geographic scales, the current lack of policies to govern transborder transport of CO2 will become an increasing impediment to CCS development. Regional planning and coordination bodies both between and within countries will need to evolve to facilitate CO2 pipeline siting, regulation and oversight.

While jurisdictions with substantial CO2-EOR operations such as the U.S. and Canada have developed robust legislative frameworks and regulations to govern CO2 pipelines, outside of these jurisdictions there is a distinct lack of policies to govern the permitting and operation of CO2 transport systems.

CO2 pipeline projects require substantial capital investments and this factor presents a significant economic barrier to the development of CO2 pipeline networks particularly in an era of historically low oil prices. Tax policies such as 45Q that provide economic incentives for CCS projects are needed to improve project economics.

CO2 transport options

At present there is a combined total of over 8,000 km of CO2 pipelines around the world, predominantly in the U.S. Over 100,000 km of pipeline would be required to transport the 5 Gt scenario described above, this means that only 6.5% of the pipeline requirements have been realized. A more aggressive goal of 10 Gt would need 200,000 km by 2050 if the carbon neutral goals of the Paris Agreement are to be taken seriously.

The initial cost of pipeline is off-putting with the cost currently estimated at around US$10/ ton of CO2 per 100 km; the need for a booster station is required to transport CO2 in a supercritical state and this adds 16% to the unit cost of transport. Considering that a large project could be transporting CO2 over 1,000 km, the cost is currently far in excess of any carbon price. Reducing the cost to US$1-2/ ton CO2 per 100 km would likely be a more realistic level for project economics.

The choice between transportation modes, when both are feasible, should be based on the results and conclusions of an exhaustive comparative analysis. This analysis should address several parameters, including costs, environmental consequences, existent regulatory framework, public acceptance and so on.

Currently there is a lack of data in this field for CCS projects, due to its embryonic deployment, and very few studies and reports have been made to date focusing specifically on the cost of CO2 transport in the context of CCS. Furthermore, even if ship transport is an obvious complement or alternative to pipelines, few studies include this possibility.

Pipelines today operate as a mature market technology for transporting large volumes of gases and fuels and are the most common method for transporting CO2. The difference for CCS is that CO2 will be transported in a dense phase or supercritical phase at high pressures and through urban areas which changes the requirements considerably. More experience is required to text the feasibility of CO2 transport via pipeline.

CO2 also can be transported as a liquid in ships, road or rail tankers that carry CO2 in insulated tanks at a temperature well below ambient, and at much lower pressures. In some situations or locations, transport of CO2 by ship may be economically more attractive, particularly when the CO2 has to be moved over large distances or overseas.

Shipment of CO2 already takes place on a small scale in Europe, where ships transport food-quality CO2 (around 1,000 tons) from point sources to coastal distribution terminals. Larger-scale shipment of CO2, with capacities in the range of 10,000 to 40,000 cubic meters (18-75 tons), is likely to have much in common with the shipment of liquefied petroleum gas (LPG).

LPG, principally propane and butane, is transported on a large commercial scale by marine tankers. CO_2 can be transported by ship in much the same way (typically at 0.7 MPa pressure), but this currently takes place on a small scale because of limited demand. The properties of liquefied CO_2 are similar to those of LPG, and the technology could be scaled up to large CO_2 carriers if a demand for such systems were to materialize.

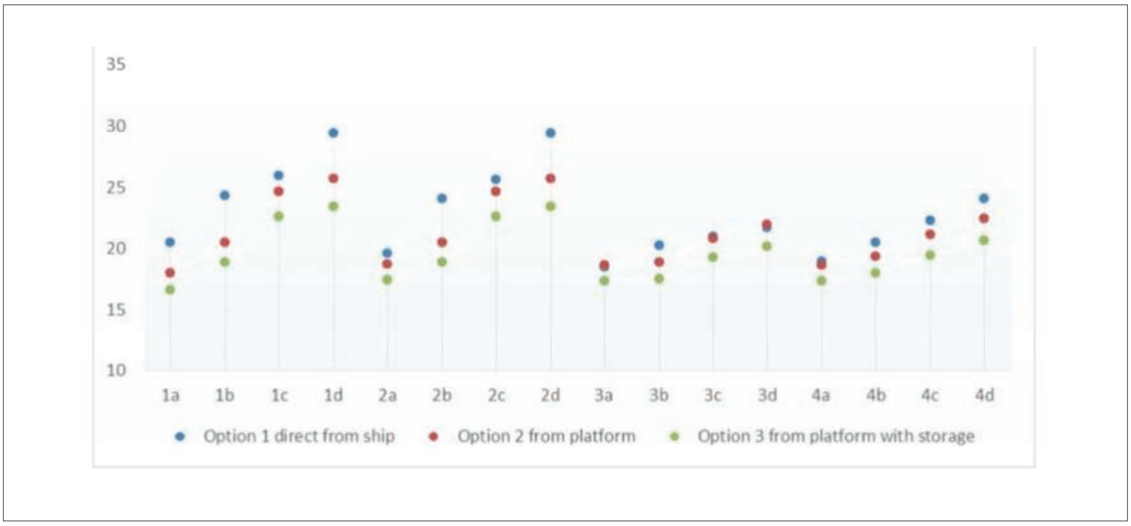


Figure 2 - CO2 Transportation Cost for the Different Reservoir Cases at a Shipping Distance of 800 Km (Source: Filip Neele et al., 2017)

Road and rail tankers also are technically feasible options. These systems transport CO_2 at a temperature of -20ºC and at 2 MPa pressure. However, they are uneconomical compared to pipelines and ships, except on a very small scale, and are unlikely to be relevant to large-scale CCS.

Closing the knowledge gap

Project risk is one of the key factors holding CCS back and processes to mitigate risk are needed for further deployment, especially as there is very little experience with transporting CO_2 outside of EOR projects. The knowledge gap includes the following categories:

• Storage necessities - greater knowledge of storage in tanks, such as buffers or ships;

• Stream composition - study the behaviour and the effects of varying the purity of the CO_2 stream in different materials;

• Transient periods - understand the start-up and shut-down routines and other transient periods;

• Negative impacts - confidence would be further enhanced by increased knowledge;

• Monitoring and instrumentation techniques - improve simulation, accuracy and cost-effectiveness; Mitigation and remediation - lack of specific emergency plans for possible accidents, as in the case of an explosion;

• Cost control - improve the knowledge of costs for the project and for regulatory compliance;

• Regulation and responsibility framework - clarify the role of each stakeholder and project.

Effective regulation is also key to managing CCS risks and needs to cover all aspects of the process and specific scenarios. Nevertheless, this regulation needs to be flexible and adaptive, allowing an empirical learning. Guidelines for building an effective regulatory system may be identified:

• Scale of activity - transportation will be larger in scale than most currently covered under legislation;

• Monitoring and instrumentation practices - carbon dioxide demand specific control necessities that should be clearly identified;

• Specific risks management requirements - CO_2 poses risks that are different from the other fluids disposed in tanks or pipelines;

• Uncertainties - associated regulation designed to manage transportation of carbon dioxide should be adaptive and emphasize learning-by-doing;

• Provide access to data and public input - transparency across stakeholders and ability to learn sequentially from projects. Moreover, input from the public should be stimulated and taken into account.

CO2 Storage economics

In order for CO_2 storage to be viable and economically competitive, the costs have to be reasonable and calculable without major uncertainties. Each storage option has individual characteristics that may be advantageous or disadvantageous for the overall project costs. Besides the dependency of the actual storage reservoir type it is also clear that site-specific categories are key in dictating the economics for an individual storage site/project.

The largest overall impact on the economics of CO_2 storage operations is the scale of operation. Economies of scale dictate that the cost per ton of CO_2 stored are lower for larger, commercial-scale storage operations with reservoir storage capacities > 200 Mt CO_2. Cost sensitivities show a scale benefit for large storage reservoirs that can lead to a reduction of up to 40 % for cost per ton of CO_2 stored.

Potentially viable reservoirs for geological CO_2 storage are depleted oil and gas reservoirs, deep saline aquifers and unmineable coal beds. The lowest overall minimum and maximum costs are associated with depleted oil & gas fields. Here, the costs for onshore storage range from 1.6 to 11.0 US$ /t CO_2 stored, when existing infrastructure can also be reused.

Depleted oil and gas fields have some key advantages, including large storage capacities in a depressurized reservoir, proven long-term caprock integrity as well as the potential for reusing existing infrastructure. Main drawbacks include unknown number, location and condition of abandoned wells, and the cost for retrofitting existing infrastructure. However, if these drawbacks are manageable with reasonable efforts, CO2 storage in depleted oil and gas reservoirs is very promising and could be implemented at commercial scale with lead times of a few years only.

	Depleted oil and gas reservoirs	Deep saline aquifers	Unmineable coal beds
Lower Estimate for Global CO_2 Storage Capacity (Gt)	675	1000	3-15
Upper Estimate for Global CO_2 Storage Capacity (Gt)	900	possibly > 10^4	200
Reservoir characteristics	+++	+[a]	+
Caprock characteristics	++[b]	+	+
Operational characteristics	+	++	+
Regulatory constraints	+	+-	+-

aThe efficiency (and safety) of storing CO2 in deep saline aquifers can significantly be increased by the extraction of reservoir brine and the use of several injection wells. bThe safety (and efficiency) of storing CO2 in depleted oil and gas reservoirs is governed mainly by presence and status of old (abandoned) wells.

Table 1: Storage capacities and efficiencies of the three main geological CO2 storage options (after IPCC, 2005)

For deep saline aquifers located onshore, the costs are slightly higher ranging from 3.1 to 18.8 US$ /t CO2 stored, the main reason for the difference being the initial exploration, characterization and development phase prior to storage operation.

Deep saline aquifers have the advantage of enormous storage capacities and widespread geographical distribution resulting in good source-sink matching. Drawbacks include long lead times of approximately 15 years, pressure build-up during CO2 injection and the requirement to monitor an extensive area. However, these drawbacks are manageable and commercial-scale CO2 storage is likely to be viable in deep saline aquifers.

The largest range for costs is associated with unmineable coal beds. In these reservoirs, costs can range from -30 to 174 US$ /t CO2 stored, although negative costs may occur when large volumes of methane can be sold at significant commodity prices.

Unmineable coal beds have the lowest storage capacities for CO2 compared with the other two potential storage candidates, and while methane recovery may provide an economic offset, they are are therefore not suitable for the large-scale implementation of CO2 storage. However, if advanced injection procedures, such as hydraulic fracturing, can be used to effectively manage reservoir permeability, storage efficiency may be high enough to make CO2 storage in unmineable coal beds viable.

Based on storage efficiency and safety, depleted oil and gas fields are most suitable reservoirs and are the most significant during the early phase of commercial activity. This mainly relates to the favourable reservoir (low pressure) and caprock characteristics (proven integrity). In the context of sustainability, deep saline aquifers are also very suitable reservoirs and will be the most suitable for the next phase of development.

Storage efficiency and safety can further be increased when reservoir brine is extracted from the reservoir and several injection wells are used to improve CO2 migration in the reservoir. The storage of CO2 in unmineable coal beds is likely to be the least sustainable option.

The largest source of uncertainty related to long-term CO2 storage is the limited availability of empirical data from commercial-scale projects. On the one hand, empirical data is important to understand and precisely predict the CO2 trapping mechanisms over the long-term. On the other hand, it is also necessary for generating sophisticated and site-specific monitoring and verification strategies for the long-term post-injection period.

The storage of large quantities of CO2 in geological reservoirs produces environmental risks. These risks must to be addressed by law and regulatory frameworks. At present, these frameworks are not well developed. However, when regulations are set in place that precisely define post-injection monitoring, long-term stewardship as well as project liability, also the uncertainty of economic estimates for commercial-scale CO2 storage will be reduced.

In the next issue

This is the first in a series of articles summarising key reports from The Catalyst Group Resources Carbon Dioxide Capture and Conversion (CO2CC) Program.

The next issue will feature “Compact Light-Weight CO2 Capture Technologies for Small to Medium scale CO2 Emitters” and the following issue “Advances in Direct Air Capture of CO2”.

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More information

More information about this and other services of the CO2CC Program can be found at:

www.catalystgrp.com/php/tcgr_co2cc.php

Clean Energy Ministerial releases key financing principles for CCUS

The ten simple Principles outline key tasks and activities that need to be undertaken by industry, government and the financial sector, to help create the necessary business cases for CCUS projects.

The 11th Clean Energy Ministerial meeting was held between 15-22 September 2020, hosted by the Kingdom of Saudi Arabia. The meeting's focus was on "actions, not words", and on raising the levels of ambition for clean energy deployment, especially in the light of the COVID-19 pandemic.

Drafted in close consultation with various financial sector organisations, including multilateral development banks, commercial banks and other financial firms, the Initiative has launched the "Key Financing Principles for CCUS". The ten simple Principles outline key tasks and activities that need to be undertaken by industry, government and the financial sector, to help create the necessary business cases for CCUS projects.

The Principles stress the fact that investing in CCUS is a "three-legged stool", requiring joint action from government, industry and the financial sector, each of which has a unique role to play. The Principles are meant to provide a framework that can be tailored to each country, also recognising the differences between developed countries and emerging economies.

Key Financing Principles

1. Industry, governments and the financial sector should communicate the importance of CCUS. According to the IPCC, meeting climate change mitigation targets will be significantly harder and more expensive without CCUS. CCUS is therefore fully aligned with sustainable, green, low-carbon taxonomies. The importance of CCUS needs to be clearly communicated by governments, industry and the financial sector through policy and strategic decisions and directly to their constituents, customers, shareholders, environmental organisations, and to the broader public.

2. Government policies should establish a revenue stream for CCUS to facilitate private sector investment. Governments should apply lessons learned from successful CCUS projects and policies globally as well as from analogous technology policy to establish a business case for CCUS projects and de-risk private sector investment.

3. The financial sector, industry and governments should work together to facilitate CCUS investment and help mitigate the risks of CCUS deployment. No single stakeholder can provide the investment necessary and accept all risks associated with establishing a CCUS industry. CCUS projects in operation today are true public-private partnerships with investment shared and risks assumed by the appropriate risk owner. As the sector is being established, high levels of government support may be required however the private sector need to play their part. The role of the private sector will increase over time as the sector matures.

4. Industry, the financial sector and governments should work together to establish a pipeline of CCUS projects. Support mechanisms should shift focus from individual projects to the establishment of a CCUS industry. Government policies and incentives should be repeatable and support a portfolio of projects. Industry and the financial sector should identify prospective projects and determine the interventions and support required to bring them to operation. Pre-commercial investment is required to characterise and confirm viable storage locations globally.

5. The financial sector should ensure CCUS is part of their climate change strategies and is eligible for sustainable finance. More and more shareholders are demanding the financial sector invests sustainably, in line with environmental, social and governance (ESG) standards and goals. Given CCUS can achieve significant and verifiable CO2 emissions reductions, as demonstrated by numerous operational projects, financial institutions should include CCUS in their climate change strategies and ensure its eligibility in sustainable investment policies and mechanisms.

6. The financial sector should strive to accelerate the development of novel financing approaches to CCUS. The finance sector is actively looking for new financial mechanisms and business models for CCUS projects. These efforts, in partnership with governments and industry, should continue and expand to find ways of addressing the specific investment requirements and characteristics of CCUS projects.

7. Governments should consider CCUS as part of their Nationally Determined Contributions (NDC) under the Paris Agreement.

8. Governments should utilize existing development and climate institutions to advance CCUS in developing countries.

9. Governments should consider CCUS investment as a means of creating and preserving sustainable jobs and providing a low-carbon stimulus to the economy.

10. Industry, governments and the financial sector should consider CCUS investment as a means of driving innovation and supporting broader industrial development. Investment in CCUS research, development and demonstration leads to spill over benefits across industry and the broader economy including, but not limited to catalysis, material science, process engineering and energy efficiency. Investment in CCUS performance improvement and cost reduction has already led to the deployment of innovative low-carbon technologies and processes in power generation as well as cement, steel and chemical production.

More information

www.cleanenergyministerial.org

Europe could see $35 billion in CCS spending till 2035 - most in UK

As much as 75 million tonnes of CO2 could be captured and stored per year by 2035 a Rystad Energy analysis shows, with the UK contributing almost 80%.

It's been a long and costly two decades of carbon capture and storage (CCS) studies and test centers. Now Europe has reached a stage where big-scale developments make financial sense and could trigger up to $35 billion in development spending until 2035 according to a Rystad Energy analysis.

In Europe alone there are around 10 larger projects, with both carbon capture and storage, that are planned and have a high chance of being operational by 2035. Most of them are located around the North Sea in Norway, the UK, Denmark and Netherlands, but there are also projects on the drawing board in Ireland and Italy.

Although most of the projects are expected to be on-line from the middle of this decade, investments and contracts awarded to suppliers will already start to grow significantly from 2021–2023, as most projects have a development timeline of three to five years. Total capital investment for these projects is expected to reach $30 billion, in addition to operational expenditure totaling $5 billion until 2035.

About half of the capex will be consumed by the facilities at the source, with CO2-capture equipment and facility construction making up the largest part. Storage investments will make up 15% and will mainly comprise well-related services to store the CO2 safely in underground reservoirs. Transport and operations take 35% and relate to trunk lines, shipping and infrastructure maintenance costs.

The first three projects that are due to become operational are Acorn CCS, Northern Lights and Porthos, which will be game-changing as they will de-risk the overall CCS uncertainty. More than twice as many projects, in count and size, are likely to follow.

With the projects so far planned in Europe, we expect that 3 million tonnes per annum (tpa) of CO2 capture and storage capacity will be added each year from 2021 to 2025, then jumping to 7 million tpa in the next five-year period 2026–2030. By 2035 we are looking at total installed capacity of around 75 million tpa, where almost 80% will come from UK projects.

Currently, there are only two complete full-scale CO2 projects operational in Europe: The CO2 injection projects at Norway's offshore fields Sleipner and Snohvit, with a combined CO2 capture and storage capacity of around 1.5 million tpa.

Looking at the bigger picture, Europe has about 1,000 larger industrial sites, such as cement plants, steel producers, fossil power and waste-to-energy plants, that could all be candidates for capturing CO2. About 250 of these of these have reasonable shipping distance to send CO2 to be stored in the North Sea.

Worldwide there could be around 6,000 industrial plants suitable for CO2 capture. Although only a fraction of these sites are expected to utilize CCS technology, the number represents a massive potential for more investments to bring down global CO2 emissions in the decades to come – which could bring new opportunities to contractors that currently get most of their business from the oil and gas industry.

An opportunity for OCTG and linepipe suppliers

"Developing CCS projects is also an opportunity for the linepipe and oil-country tubular goods (OCTG) industry, with a new market about to open up for suppliers looking to expand beyond oil and gas," says James Ley, Rystad Energy's Senior Vice President of Energy Service Research.

Equinor, Shell and Total's Northern Lights CO2 storage project in Norway will for example require around 12,000 tonnes of carbon seamless linepipes for the export line, Rystad Energy estimates, and tenders for these tonnages could be expected soon. For subsea installation, Saipem, Technip FMC and Subsea 7 are all competing for this job and we believe that Saipem and Subsea 7 are leading the race.

From an OCTG perspective, the initial requirements for Northern Lights are likely to be low as the project just calls for one well to be drilled in the first phase, following a test well drilled in March 2020. This injection well is expected to require high-chromium grades of OCTG tubing. Northern Lights Phase 1 is expected to cost $760 million, with 56% of the contracts going to Norwegian suppliers.

Several European policymakers and non-governmental organizations (NGOs) have previously indicated they are ready to rule out CCS as a climate mitigation tool, saying the technology is not proven and available and has unrealistic expectations. For CCS to have a significant future, it's therefore important that Northern Lights and Acorn run through their pilot stages to show that this can be a proven technology, says Rystad Energy's Head of Energy Service Research Audun Martinsen.

"As standard renewable technologies that have some maturity in Europe such as solar installations and offshore wind farms are increasingly gaining market share, CCS projects will face competition and have to prove cost-worthy," says Martinsen.

Rystad Energy is an independent energy research and business intelligence company providing data, tools, analytics and consultancy services to the global energy industry.

More information

For more analysis, insights and reports, clients and non-clients can apply for access to Rystad Energy's Free Solutions.

www.rystadenergy.com

Measurement Challenges in CCUS

Accurately measuring how much CO2 has been sequestered is crucial in any system that seeks to monetise carbon dioxide removal. Marc MacDonald, Project Engineer at TUV SUD National Engineering Laboratory, looks at some of the challenges in a real world large scale CCUS network and outlines current research into hydrogen flow standards.

Through the Climate Change Act, the UK is committed to drastically reducing its emissions of carbon dioxide and other greenhouse gases, achieving net zero emissions by 2050. This will require substantial changes to the ways in which energy is generated, stored, transported and consumed. One potential route to decarbonisation involves the use of hydrogen as an energy vector, including the use of hydrogen to power low emissions vehicles, for heating homes and buildings and for industrial applications.

The hydrogen pathway; as it is described in the UK Government Clean Growth Strategy; is attractive for several reasons. First and foremost, hydrogen is clean burning and produces only water. This is true whether it is used in direct combustion or with fuel cells to generate electricity. It should be noted that hydrogen itself is not a primary energy source (i.e. naturally occurring) and must be produced, but it can be thought of as a means of storing energy.

For the overall process to be climate neutral therefore, the hydrogen must be produced in manner that produced net-zero emissions. This is possible in several ways. First of these is through electrolysis of water; if the electricity used is generated from clean sources such as solar or wind. The hydrogen produced in this way is often referred to as "green" hydrogen.

It could be argued that using the renewable electricity directly would be more energy efficient, rather than splitting water to produce hydrogen, to subsequently convert it back into water. In many cases this is true, but it is important to consider that the supply of renewable electricity is generally intermittent. Solar and wind power are both subject to diurnal and annual fluctuations. At times the supply will be insufficient to meet demand and during times periods of peak generation, there can be an excess which means that generation must be curtailed.

Producing hydrogen via electrolysis would flatten those peaks and troughs, providing an energy buffer and even a long-term storage mechanism. The overall inefficiency caused by converting energy between various forms could be tolerated if it allowed for energy which could otherwise not have been generated to be put to good use.

There are also processes where it may be preferable to use hydrogen produced from renewable electricity rather than use electricity directly. Electric battery vehicles are increasingly common and represent a major step towards the decarbonisation of transport. This works well for light duty vehicles, but the weight and charging times of lithium ion batteries are prohibitive for use with heavy duty vehicles and long distance transport.

Hydrogen has a gravimetric energy density of 140 MJ/kg, which is higher than natural gas (53.6 MJ/kg) and diesel (45.6 MJ/kg), and much higher than lithium ion batteries (<5 MJ/kg). However, in volumetric terms, hydrogen is the least dense gas and takes up more space than both natural gas and diesel. But when stored as a compressed gas, the volumetric energy density of hydrogen (2.7 MJ/L at 350 bar or 4.7 MJ/L at 700 bar) is still greater than that of a lithium ion battery (2.2 MJ/L), making it a serious contender for use with larger vehicles such as HGVs.

Similarly, for the decarbonisation of home heating, one option is to use heat pumps and electric cooking appliances. But the replacement of natural gas with hydrogen in the gas grids is also being considered in many countries including the UK. This could potentially minimise disruption to end users and allow the UK gas network infrastructure and the cumulative skills and experience of its work force to be repurposed.

It would also negate the need to upgrade the UK electricity grid and greatly increase electricity generation. The Clean Growth Strategy estimates that under the electricity pathway, 647 TWh of electricity would need to be generated annually, a 93% increase compared to the 335 TWh generated in 2018. Under the hydrogen pathway, the annual electricity requirement would be similar to today, at 339 TWh. Use of hydrogen could also decarbonise industrial direct flame applications, which are essential to provide many chemical products but cannot be replaced with an electrical equivalent.

A strong case can be made for the use of green hydrogen in the decarbonised energy supply of the future. However, today most of our hydrogen is not produced from electrolysis but from a chemical process called reforming, which comes in two flavours Steam Methane Reforming (SMR) and AutoThermal Reforming (ATR). In these processes, methane is reacted with high temperature steam in the presence of a catalyst and at elevated pressures. Syngas is produced, which is a mixture of hydrogen and carbon monoxide.

A further "water-gas shift" reaction is used to convert the carbon monoxide into carbon dioxide and more hydrogen. In the final step, hydrogen is separated from the carbon dioxide and other impurities by pressure swing adsorption, a process which exploits the differing tendencies of pressurised gases within a mixture to adhere to solid surfaces.

Since the feedstock includes a fossil fuel and the products include carbon dioxide, this process in itself is neither renewable, nor carbon-neutral. It is however a viable route to producing vast amounts of hydrogen, which could enable the market for hydrogen vehicles and appliances whilst the infrastructure for renewable electricity and electrolysers required to produce green hydrogen, at scale, develops.

The key then is how to deal with the carbon dioxide produced, which is where Carbon Capture, Storage and Utilisation (CCUS) comes in, to make the overall process have net-zero emissions. The UK Government

Clean Growth Strategy envisions that 700 TWh of energy could be produced from hydrogen in 2050, with the vast majority of hydrogen produced from reforming, coupled with CCUS to keep the process carbon neutral. The hydrogen produced from this route is known as "blue hydrogen".

As the UK's Designated Institute for Flow and Density measurement, we are particularly interested in the metrological aspects of both the hydrogen pathway and the CCUS operations required to enable it. With CCUS in particular, there are many potential measurement challenges expected due to both the physical properties of carbon dioxide (CO2) and the processes involved in CCUS projects.

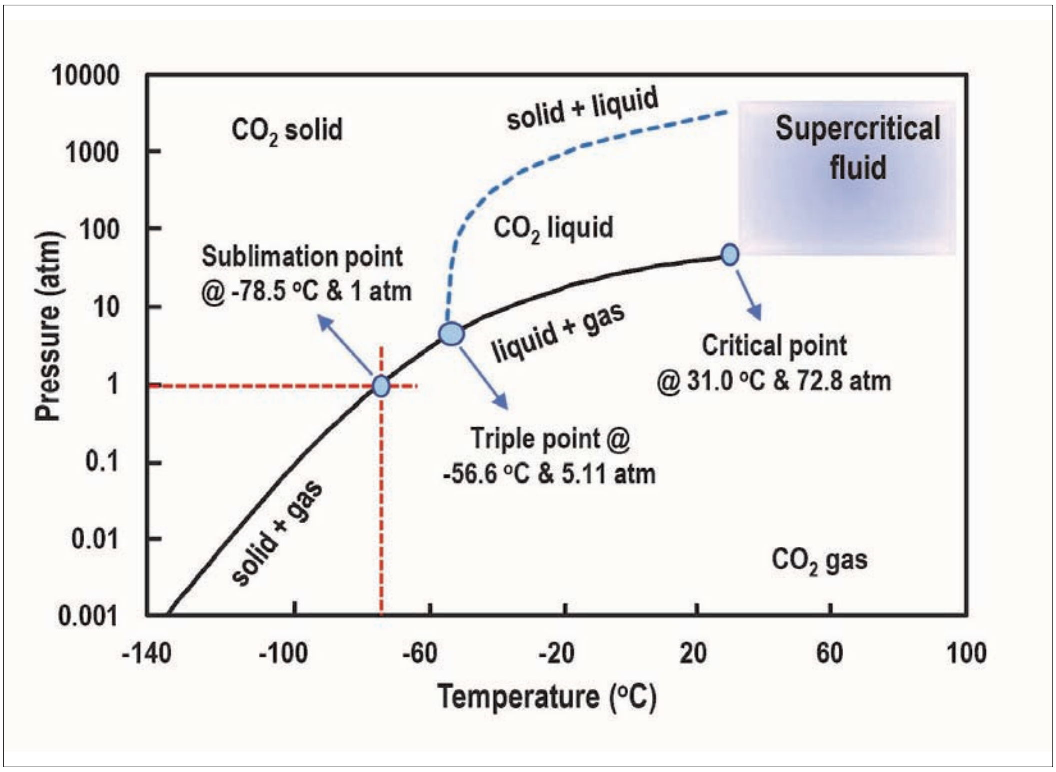


Figure 1: Carbon Dioxide Phase Envelope

Crucial to the implementation of large-scale CCUS is the method by which it will be monetised, with numerous different approaches being considered from taxation through to credit-based systems. Whichever mechanism prevails, monetisation requires accurately knowing how much carbon dioxide has been sequestered, much the same as custody transfer metering in the oil and gas industry today.

For context, the UK Oil & Gas Authority requires measurement uncertainty of ±1% for fiscal metering of natural gas, whilst uncertainties of ±1.5% or less are required for mass flow measurements of carbon dioxide under the EU Emissions Trading System.

In addition to the pecuniary aspects, the ability to accurately measure the flow rate of process streams at various points and reconcile this data to provide a holistic mass-balance across the whole system will be important for two other reasons. First is reservoir management, which will require knowledge of the amount of carbon dioxide and other process stream components fed into the geological formation. Second is safety; carbon dioxide is a heavy, asphyxiant gas that can readily pool upon leakage if conditions are correct, and so any breach of system integrity will need to be detected and located quickly.

CO2 is unusual because of the closeness of its triple point and critical point to the temperatures and pressures commonly found in industrial processes. Compared to other substances that are transported by pipeline (e.g. oil, natural gas and water) the critical point of CO2 lies close to ambient temperature. This means that even small changes in pressure and temperature may lead to rapid and substantial changes in the physical properties of CO2 (e.g. phase, density, compressibility).

In CCUS applications, tightly regulating the temperature and pressure could be a difficult undertaking, particularly over long distances. Pipelines will span hundreds of miles, and be subjected to various climates and conditions, which will naturally affect operating pressure and temperature.

When operating near a phase boundary line, there is a risk that the fluid will change phases, or even that multiphase flow conditions will arise. Phase changes and multiphase flow occurring at measurement points will have a significant detrimental effect on measurement accuracy, where flow meters are designed to operate in one specific phase only.

Another major challenge for measurement will be coping with impurities in the CO2 stream, which will be present and vary depending on the capture process, capture technology and fuel source used. Even low levels of impurities will significantly perturb the fluid properties and open up two-phase region boundaries. Without knowing the exact phase envelope and physical properties of the CO2 stream, it will be extremely difficult to control the CCUS processes and undertake accurate flow measurement.

Three main measurements are essential to monitor CO2 across the CCUS chain:

• Composition measurement of the CO2 mixture

• Determination of physical properties

• Flow measurement

Sampling of the CO2 stream will be necessary to determine the CO2 concentration and for the regulatory reporting of other non-CO2 components in the CO2 stream. As the composition of the CO2 stream will vary continuously (particularly where a number of different sources with different CO2 mixtures will be introduced to shared pipelines), sampling points will be necessary at the capture plant and at various points throughout the transportation network where the composition can vary.

Once the composition of the CO2 stream has been measured, the physical properties can then be calculated to provide the necessary data for handling and transporting the CO2 throughout the different parts of the CCUS network and for flow measurement purposes. There will be a need to establish new equations of state and phase diagrams to cater for the many different CO2 mixtures that are likely to arise in CCUS schemes.

Physical properties software modelling packages could be used to generate new data for the different CO2 mixtures. However, any such models would have to undergo validation to demonstrate the level of accuracy, as even small errors may result in serious problems during the processing and transport of CO2.

There can be a wide variation in results between different software packages and algorithms when used to model the same CO2 mixture. It may be necessary, therefore, to establish validated industry standards and tools (i.e. hardware/software) to minimise inconsistencies and ensure a uniform approach throughout industry.

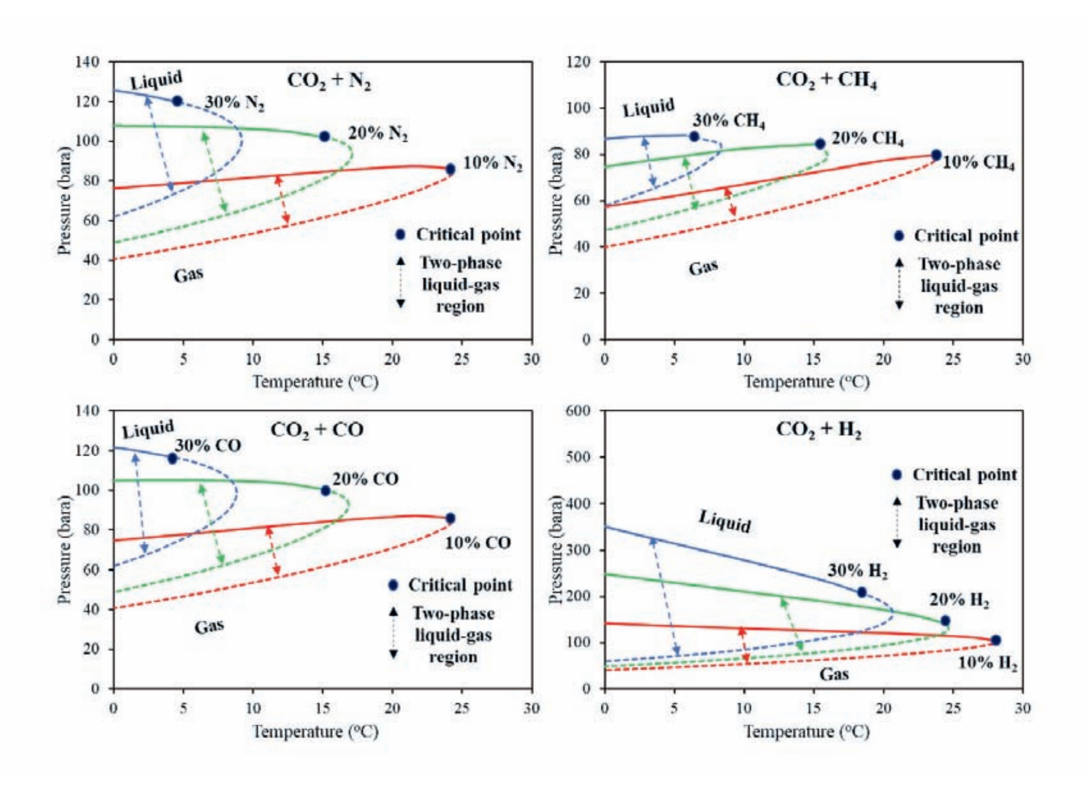


Figure 2: Phase Envelopes for Carbon Dioxide with Impurities

This would be particularly important in cases where different parties are sharing the same CCUS network. Flow measurement, in conjunction with the CO2 concentration derived from sampling of the CO2 stream, will be required to calculate the transfer of CO2 on a mass basis across the CCUS chain.

In order to meet the measurement uncertainty of 1.5% required by the EU ETS, it will be essential to install the correct type of flow meter at locations along the network where the flow conditions are stable, and in the specific phase under which the flow meter is designed to operate. This may necessitate the use of gas meters at certain locations and liquid meters at other locations along the network.

To ensure and maintain a traceable measurement uncertainty for the purpose of regulatory reporting, flow measurement systems should be calibrated, maintained and checked at regular intervals. Flow meters should be calibrated at traceable laboratories in CO2 under the conditions and ranges under which they will be required to operate.

Any secondary instruments used to convert into mass flow, such as pressure, temperature and density instruments, should be calibrated and traceable to national standards and located as close as possible to the flow meter.

The ability to accurately measure the amount of carbon dioxide sequestered will be a fundamental foundation of large-scale CCUS, but presents some interesting technical challenges that require an integrated approach to real-time determination of process stream composition, bulk flow rate and fluid properties. The essential technologies exist, but the challenge of integrating these and making them economically viable, should not be underestimated.

We are committed to providing new research, testing and calibration capability to support the energy transition to clean fuels. A traceable hydrogen calibration facility for domestic gas flow meters and a primary flow standard for validating hydrogen refuelling station dispensers are both currently in development.

Capabilities previously developed for CCUS include gas flow meter calibration with CO2 and CO2/N2 mixtures at up to 1000 m3/hr at 25 bar, and a facility for testing densitometers, sampling systems and various sensors with CO2 and CCUS mixtures in liquid, gaseous or supercritical states.

About TÜV SÜD National Engineering Laboratory

The company is a global centre of excellence for flow measurement and fluid flow systems and is the UK's Designated Institute for Flow and Density Measurement, with responsibility for providing the UK's physical flow and density measurement standards

TÜV SÜD National Engineering Laboratory is a trading name of TUV SUD Ltd, a company of the TÜV SÜD Group, an international service organisation. More than 24,000 employees work at over 1,000 locations in about 50 countries to continually improve technology, systems and expertise. They contribute significantly to making technical innovations such as Industry 4.0, autonomous driving and renewable energy safe and reliable.

More information

www.tuvsud.com/en-gb/nel

UK concrete and cement sector sets out roadmap for beyond net zero

The 'Roadmap to beyond net zero' calculates the potential of each technology and the carbon savings which can be achieved. CCUS technology is vital to delivering net zero manufacturing and according to the roadmap will deliver 61 per cent of the required carbon savings.

The UK concrete and cement industry has launched a roadmap to become net negative by 2050, removing more carbon dioxide from the atmosphere than it emits each year.

Launching the ambitious roadmap, UK Concrete, part of the Mineral Products Association (MPA), has identified that net zero can be met through decarbonised electricity and transport networks, fuel switching, greater use of low-carbon cements and concretes as well as Carbon Capture, Use or Storage (CCUS) technology for cement manufacture.

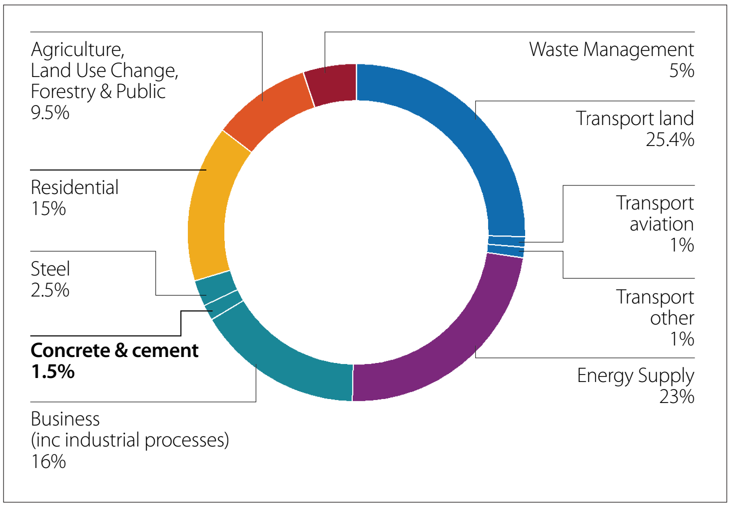
A net negative industry by 2050 will be achieved by using the natural, in-use properties of concrete which include its ability to absorb carbon dioxide during use, and the benefit of using the thermal properties of concrete in buildings and structures to reduce operational emissions.

The concrete and cement industry has already taken considerable early joint action and due to investment in fuel switching, changes in product formulation, and energy efficiency including plant rationalisation, its direct and indirect emissions are 53% lower than 1990 - decarbonising faster than the UK economy as a whole.

The MPA is currently building on this progress by undertaking demonstrations of hydrogen and plasma technology, which are being partly funded by the Department for Business, Energy and Industrial Strategy (BEIS) and will demonstrate the potential of these technologies to reduce carbon emissions through fuel switching from fossil fuels in cement and lime production.

The industry is now calling on Government for a robust financial support model including for the capital and operational costs of carbon capture by no later than 2021. This would ensure the technology can be developed, deployed and become an investable proposition in the 2030s.

Nigel Jackson, Chief Executive, Mineral Products Association commented, "Concrete, and the aggregates and cement used to make it, are essential materials for our economy and our way of life. New homes, schools, hospitals, workplaces, roads and railways, as well as the infrastructure that provides us with clean water, sanitation and energy all depend on these materials.



Sector contributions to 2018 UK greenhouse gas emissions

"We have already made significant progress to reduce carbon emissions but are under no illusion about the scale of the net zero challenge. Achieving this will require the wholesale decarbonisation of all aspects of concrete and cement production, supply and use. The concrete and cement industry as one sector alone cannot deliver net zero and we will only be able to go beyond net zero with concerted support from Government, as well as with significant changes across the wider construction, energy and transportation sectors.

"Critically, our roadmap will be delivered without offsetting emissions or offshoring production facilities. We believe that net zero should be achieved by reducing emissions from the construction materials manufactured in the UK, rather than by 'carbon leakage' where UK production is replaced with imports that simply moves the emissions responsibility abroad. The aim should be to retain jobs and economic value in the UK whilst ensuring that the UK takes responsibility for the emissions it creates."

Key takeaways

1. Delivering beyond net zero requires the industry and all levels of Government together with the wider construction, energy and transportation sectors to work collaboratively.

2 We need to accelerate the uptake of lower carbon concrete and embed more sustainable behaviours across the construction industry.

3 The concrete and cement industry will report progress against the projects and innovations outlined in the roadmap that will enable it to reach and go beyond net zero.

More information

UK Concrete is part of the Mineral Products Association, the trade association for the aggregates, asphalt, cement, concrete, dimension stone, lime, mortar and silica sand industries.

www.thisisukconcrete.co.uk

Projects and policy news

Norway launches £2.1 billion Longship CCS project

www.gassnova.no

It will see Norway invest in three major CCS projects contributing around two thirds of the total costs to build and run them.

The Norwegian Government proposes to first implement carbon capture at Norcem's cement factory in Brevik. In addition, the Government also intends to fund Fortum Oslo Varme's waste incineration facility in Oslo, providing that the project secures sufficient own funding as well as funding from the EU or other sources.

Longship also comprises funding for the transport and storage project Northern Lights, a joint project between Equinor, Shell and Total. Northern Lights will transport liquid CO2 from capture facilities to a terminal at Øygarden in Vestland County. From there, CO2 will be pumped through pipelines to a reservoir beneath the sea bottom.

Longship facilitates the further development of CCS both in Norway and Europe, said the Government. The project has been matured to a level required for an investment decision, and the decision basis shows that all parts of the project are feasible.

The project also involves risks. For Longship to have the desired effect, an ambitious development of climate policies in Europe is needed. The risks are primarily connected to the economy of the project, such as the technical integration of the different parts of the project, the scope of following projects and necessary support schemes for such projects from the EU and individual countries. What is not at risk is the safety and integrity of the storage solution for CO2.

For many years, various Norwegian governments have supported technology development, test and pilot projects, and underscored the importance of carbon capture and storage as an important climate tool internationally. The present Government has followed up this work and made targeted efforts on CCS since 2013.

"Building bit by bit in collaboration with the industry has been important to us in order to be confident that the project is feasible, said Minister of Petroleum and Energy, Tina Bru.

Norcem's cement factory in Brevik is one the locations for a CO2 capture plant as part of Norway's 'Longship' project

"This approach has worked well, and we now have a decision basis. Longship involves building new infrastructure, and we are preparing the ground for connecting other carbon capture facilities to a carbon storage facility in Norway. This approach is a climate policy that works."

The total investments in Longship are estimated at NOK 17.1 billion. This includes both Norcem, Fortum Oslo Varme as well as Northern Lights. The operating costs for ten years of operation are estimated at NOK 8 billion. The total cost estimate is thus NOK 25.1 billion. Longship will receive state aid in accordance with negotiated agreements. The state's part of these costs are estimated at NOK 16.8 billion.

Equinor collaborates with Microsoft on Northern Lights carbon capture and storage value chain

www.equinor.com

Equinor has signed a Memorandum of Understanding with Microsoft to explore ways to support the Northern Lights carbon capture and storage project as a technology partner.

Microsoft will explore using the project to enable the transportation and storage of captured CO2. Equinor is developing the project together with Shell and Total as equal partners.

Equinor and Microsoft have agreed to:

• Explore a technology collaboration to integrate Microsoft's digital expertise into the Northern Lights project.

• Microsoft will explore the use of Northern Lights' CO2 transport and storage facility as part of Microsoft's portfolio of carbon capture, transportation, and storage projects.

• Explore ways for Microsoft to invest in the effective development of Northern Lights.

• Explore and establish advocacy of policies that help accelerate the contribution CCS can make to meeting Europe's climate goals.

"One of the world's imperatives is the need to develop new ways to capture, transport, and permanently store carbon. This will require enormous investment and innovation, including a huge amount of computing power and data," said Brad Smith, president of Microsoft. "As a company, Microsoft is excited about and committed to supporting promising carbon capture approaches. Our goal is not only to contribute our technology and know-how, but explore how new solutions like the Northern Lights project can help us meet our own carbon negative goals by 2030."

Leading energy companies partner to accelerate UK integrated CCUS

www.bp.com

bp, Eni, Equinor, National Grid, Shell and Total form Northern Endurance Partnership to develop offshore CO2 infrastructure in the UK North Sea, with bp as operator.

This infrastructure will serve the proposed Net Zero Teesside (NZT) and Zero Carbon Humber (ZCH) projects that aim to establish decarbonised industrial clusters in Teesside and Humberside.

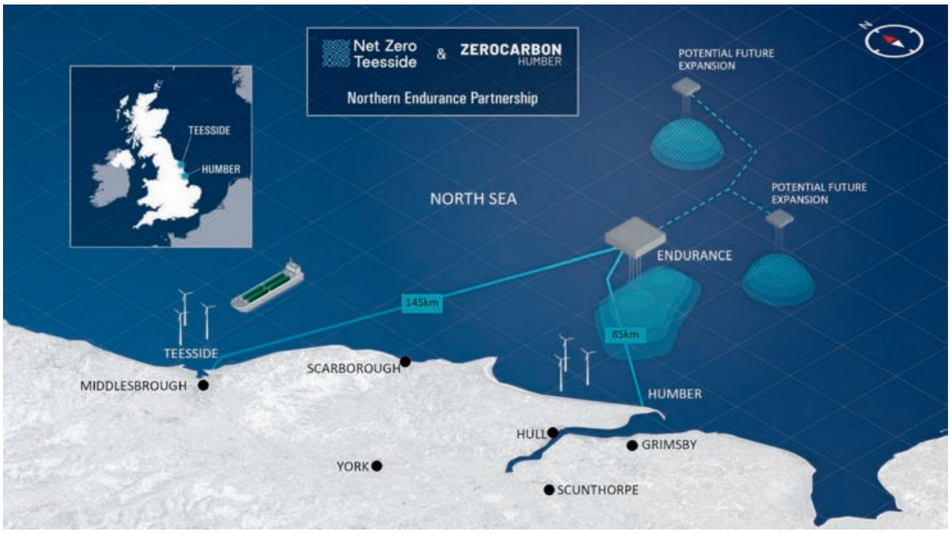
NZT and ZCH are at-scale decarbonization projects that will kick start decarbonization of industry and power in two of the UK's largest industrial clusters. Both projects aim to be commissioned by 2026 with realistic pathways to achieve net zero as early as 2030 through a combination of carbon capture, hydrogen and fuel-switching. If successful, NEP linked to NZT and ZCH will allow decarbonization of nearly 50% of the UK's industrial emissions.

NEP has submitted a bid for funding through Phase 2 of the UK government's Industrial Decarbonisation Challenge, aiming to accelerate the development of an offshore pipeline network to transport captured CO2 emissions from both NZT and ZCH to offshore geological storage beneath the UK North Sea.

The £170 million Industrial Decarbonisation Challenge is part of the £4.7bn Industrial Strategy Challenge Fund set up by the UK government to address the biggest industrial and societal challenges using research and development based in the UK. NEP's application for funding is an important step towards enabling the development of integrated offshore carbon storage for NZT and ZCH in the UK Southern North Sea.

The application follows the approval by the Oil and Gas Authority (OGA) of the addition of bp and Equinor alongside National Grid to the Endurance carbon storage licence. This affirms the strategic importance of the Endurance reservoir as the most mature and large scale saline aquifer for CO2 storage in the offshore UK Continental Shelf, that can potentially enable industrial decarbonization from both clusters.

bp will lead the Northern Endurance Partnership as operator and the team progressing the project will draw on expertise from across all the partners.



Planned offshore infrastructure for the Northern Endurance Partnership

Andy Lane, vp of CCUS solutions at bp and managing director for Net Zero Teesside, said, "The formation of the Northern Endurance Partnership is another significant milestone towards developing the offshore infrastructure that will be needed to safely transport and store CO2 from CCUS projects along England's east coast."

Copenhagen aims to become carbon neutral through CCS project

news.cmport.com

A facility for the capture of CO2 will reduce emissions from the Amager Resource Center (ARC) by 500,000 tonnes of CO2 annually and can thus significantly contribute to the City of Copenhagen's goal of becoming the world's first capital city in the world to become carbon-neutral.

Copenhagen Malmö Port (CMP) will become a central party in storing and distributing the captured CO2 to ships that sail the CO2 to storage in old oil fields in the North Sea.

The ARC receives waste from 640,370 inhabitants and 68,000 businesses in the Copenhagen metropolitan area and mits 560,000 tonnes of CO2 annually, and from 2025 couldd capture 500,000 tonnes annually if the project's prerequisites are met.

The project will be the first of its kind in Denmark and will contribute not only to the City of Copenhagen's goal of becoming the first carbon-neutral capital in the world by 2025, but also to the national goal of reducing Denmark's emissions of CO2 70 percent by the year 2030. Specifically, an annual reduction of 500,000 tonnes CO2 will correspond to approx. one percent of Denmark's total emissions.

As one of the first and crucial steps in the project, at the end of October ARC in collaboration with CMP will submit an application to the climate action EU Innovation Fund to receive funding for both the establishment of the facility, which is scheduled for completion in 2025, and its operations.

The amount of financial support being applied for is in the range of DKK 0.5-1 billion, which will finance up to 60 percent of the costs of the establishment of the facility and its operations for the first ten years.

The fact that Amager Bakke and Prøvestenen (which is part of CMP's commercial port) are located in close proximity to each other, contributes to the good preconditions for a partnership between ARC and CMP.

Once the CO2 is captured, it will be transported via a short pipeline to special tanks at CMP's nearby terminal on Prøvestenen. From here, the CO2 will be pumped aboard ships, which sail it further out to the North Sea, where it will be stored in drained and empty underground oil reservoirs.

CO2 as a chemical feedstock for valuable consumer products

NETL researchers such as Dominic Alfonso are using advanced computational tools to repurpose carbon dioxide (CO2) from a waste product into chemical building blocks to manufacture fuels and a range of high-value items.

The work undertaken by Alfonso and other members of NETL's Computational Materials and Engineering Team focuses on recycling CO2 generated by fossil energy plants and other industrial sources into chemicals, alcohols, acids and syngas, which are used to manufacture fuels, polymers and fertilizer.

"For more than a century, we have used fossil fuels to produce our electricity and for a variety of other purposes. However, when we extract energy from fossil fuels, we create CO2, the primary greenhouse gas emitted through human activities," Alfonso said.

"We can address this issue by using CO2 from factories and power plants as a chemical feedstock. Waste CO2 emissions can become something you can recycle into valuable products, providing a strong financial incentive to reduce the amount of CO2 released into the atmosphere," he added.

Alfonso's research is dedicated to advancing the development of CO2 recycling through electrochemistry. In the presence of electricity, CO2 molecules and protons from splitting water molecules react on an appropriate catalyst to form chemical building blocks for hundreds of useful products.

Whereas traditional reaction processes often require high temperatures and pressures, electrochemistry can be conducted at near room temperature and ambient pressure using electricity from a renewable energy source such as wind, solar or geothermal, which makes the process more efficient and environmentally benign.

NETL researchers use a variety of cutting-edge experimental and computational techniques to understand and optimize catalysts and open new doors to CO2 conversion. The type of chemical building blocks to be produced by recycling CO2 is also determined by the identity and characteristics of the catalyst.

Nanometallic-based catalysts are especially effective because their high surface area can dramatically increase catalytic activity. The ability to identify low-cost, abundant and high-activity catalysts that can guide the reaction toward making only the desired product is the challenge that NETL is addressing through advanced computer modeling and simulations.

NETL's goal is to discover precise catalyst recipes. Researchers want to know what types of catalysts work best to selectively and efficiently turn CO2 into specific chemical compounds. A major objective of nanocatalyst research is to create efficient catalysts that have high stability and long lifespans by controlling the size, shape, surface composition and electronic structure.

"When it comes to improving a catalyst's performance, one of the key things is how to make them more selective, so they generate just the target product and nothing else," Alfonso said.

Tools such as NETL's Joule 2.0 supercomputer are used as platforms to simulate experiments and develop models to identify active sites and understand how the reactions proceed.

Supercomputing is essential in achieving NETL's mission to discover, integrate and mature technology solutions that enhance the nation's energy foundation and protect the environment for future generations. By expediting technology development through computational science and engineering, Joule 2.0 helps NETL cut costs and save time. "Joule is our workhorse," Alfonso said.

A patent developed by Alfonso, a co-inventor, and NETL researchers Douglas Kauffman, Christopher Matranga, Paul Ohodnicki, Xingyi Deng, Rajan Siva, Rongchao Jin and Chenjie Zeng defined a method to control and isolate differentially charged gold (Au25) nanocatalyst clusters from a mixed solution.

The invention (USPN 10,385,726) was significant because charge specific Au25 clusters have demonstrated the ability to convert CO2 to carbon monoxide (CO) with 99-plus percent efficiency. CO is a feedstock in the production of chemicals ranging from acetic acid, which is used in many household cleaning products, polycarbonate plastics and methanol, which is used in thousands of everyday products, including fuels, paints, adhesives, fertilizers and windshield fluid.

Gold is one of the most selective catalysts for electrochemically converting CO2 into CO, but its expense is a major drawback. Meanwhile, cheaper copper catalysts typically show poor product selectivity and produce a larger variety of chemicals with lower efficiency.

In a research study, NETL's gold-copper alloy nanocatalysts demonstrated four to eight times higher performance than state-of-the-art gold nanocatalysts on a precious metal basis. NETL research combined effective expertise in experimental catalyst testing, computational modeling and synchrotron-based X-ray characterization to obtain an atomic-level understanding about how the catalyst structure and surface groups sustained selective CO2 conversion.

"The bottom line is we are paving the way to developing less-expensive CO2 utilization catalysts that can convert CO2 into useful products society needs while dramatically reducing the amount of carbon emitted into the atmosphere," Alfonso said.

DOE's Carbon Utilization Program aspires to develop technologies to transform CO2 and other carbon byproducts and wastes into valuable products in an efficient, economical and environmentally friendly manner.

More information

www.netl.doe.gov

Capture and utilisation news

LafargeHolcim and Carbon Clean to develop large scale CCUS plant

www.lafargeholcim.es

www.carbonclean.com

Carbon Clean has signed an agreement in Spain with LafargeHolcim, ECCO2 and Sistemas de Calor to develop a large-scale carbon capture and utilisation plant.

The project, based in LafargeHolcim's cement plant in Carboneras (Almeria, Spain), will aim to capture CO2 emitted through the cement production process to be further transformed, cleaned and reused locally. The CO2 will be captured from the cement plant's flue gas and will be recycled for agricultural use for accelerated crop production.

By imitating and accelerating the natural photosynthesis process, this technique has the potential to increase farm efficiency by reducing water and soil ratio per kilogram of vegetable production. Starting with 10% of CO2 emissions from 2022, the commercial applicability of this viable circular carbon economy business model can potentially leverage 700,000 tonnes of CO2 and achieve 100% decarbonisation at the plant.

This agreement is a natural fit for Carbon Clean, as its proven proprietary technology will reinforce LafargeHolcim's rapidly expanding portfolio of CCUS projects. This follows on from LafargeHolcim's announcement at the end of 2019, that it would invest about €20 million in Spain (close to €150 million in Europe) to help support the reduction of carbon emissions as part of its Green Transition Strategy

Launch of Dinamx industrial CO2 capture pilot in France

www.ifpenergiesnouvelles.com

The four-year Dinamx "Demonstration and innovative applications of the DMX™ process" project* has been launched by partners IFPEN, Total Refining & Chemicals and ArcelorMittal France.

Coordinated by Axens, the objective is to demonstrate the DMX™ process designed to capture carbon dioxide from blast furnace gases and extend its scope of application to other types of emitters in order to reduce CO2 emissions in France.

The process will initially be demonstrated on the pilot unit built for the European H2020 3D project at ArcelorMittal's site in Dunkirk, with a capacity of 0.5 t CO2/h. Other applications will be examined with a view to validating the potential benefits of the process for cement works, glassworks, urban heating and electricity production from biomass.

The result of a decade of research, the DMX™ process, developed by IFPEN and marketed by Axens, uses a solvent for separating CO2 via absorption with a high capture capacity. Made up of a mixture of 2 amines in aqueous solution and initially forming a single phase, this so-called demixing solvent splits into two phases when in contact with flue gases laden with CO2.

Since the CO2 is concentrated in one of the two phases, this significantly reduces the volume to be treated during the energy-intensive phase, i.e., solvent regeneration by steam injection at a temperature of 160°C.

This competitive technology should make it possible to reduce the cost of CO2 capture by 30% compared to more traditional processes and have an energy penalty of below 2.3 GJ/tCO2 for the capture of at least 90% of emissions from a steelworks or coal-fired power plant. E

very ton of CO2 "avoided" will cost between 30 and 40 euros, compared with 50 euros with existing methods. Moreover, the CO2 produced is extremely pure (99.7%) and under pressure (up to 7 bara), which facilitates the subsequent pressurization required to transport it either by boat or pipelines.

U.S. DOE grant supports development of unique technology to capture CO2

rpi.edu

Scientists at Rensselaer Polytechnic Institute are developing a novel material that can capture even small concentrations of CO2 from the air and produce fuels.

With the support of a grant from the Department of Energy, Miao Yu, the Priti and Mukesh Chatter '82 Career Development Chair of Chemical and Biological Engineering at Rensselaer Polytechnic Institute, will develop a novel porous material capable of capturing even very small concentrations of CO2 in the air and collecting the gas for further use.

This challenge is more nuanced than it may sound. Yu and his team will use amine molecules to trap the CO2, but the bond formed during that chemical reaction must be broken so that the gas can be gathered. And in order to do that, the material has to be heated. The problem, Yu said, is that when the amine molecules are heated they will evaporate.

Yu and his team will take a unique approach that involves loading amine molecules into a porous material, such as carbon or silica, through which CO2 can pass and get trapped. Another porous coating will cover this material, trapping the amine molecules inside.

"The porous coating will have a pore size smaller than the amine molecules, so they can't get out," said Yu, who is also a member of the Center for Biotechnology and Interdisciplinary Studies at Rensselaer (CBIS).

The material will be electrospun into porous fibers, which can be woven into mats that could be hung vertically so that air could easily pass, or be blown, through them.

In addition to reducing carbon emissions, Yu believes this technology has the potential to generate clean energy in remote places or after natural disasters.

"In those areas, we can use this technology to capture CO2 from the air and then combine that with the hydrogen generated from solar energy in order to produce liquid fuel," Yu said.

This work furthers Yu's research aimed at making carbon capture technologies that are more efficient and cost-effective. In his previous work, he's developed membranes capable of capturing CO2, while filtering-out other molecules like water.

"Professor Yu's approach to capturing carbon in new and novel ways plays an integral role in developing the next generation of clean energy technologies," said Deepak Vashishth, the director of CBIS.

Transport and storage news

Sharing data from Northern Lights well

data.equinor.com

The Northern Lights project will disclose datasets from the confirmation well 31/5-7 Eos drilled in the North Sea and completed earlier this year.

Extensive amounts of data have been acquired through coring, logging, sampling and a production test. Equinor is developing the Northern Lights project with Shell and Total as equal partners.

The data acquired from drilling well 31/5-7 confirmed a suitable reservoir for the storage of CO2. Sharing knowledge in a transparent manner the Northern Lights projects, partners have decided to give open access to 31/5-7 Eos well data and make such data available for download.

“The Northern Lights project believes data sharing can play an important role in building trust in the technology as well as unlocking value and innovation potential in the CCS industry”, says Sverre Overå, project director.

“Disclosing the Northern Lights dataset is in line with our focus on external collaboration and more open innovation. We believe open innovation will contribute to new ideas and new digital solutions enabling acceleration of decarbonisation of the world’s energy systems. We encourage data sharing to support partners, suppliers and academia with the latest data and developments in the industry”, says Torbjørn Folgerø, chief digital officer at Equinor.

The gathered data will be made available via Equinor’s OMNIA platform. The released data discloses relevant subsurface data including well log data, core data and well test data. They can be used by interested parties for evaluation and research for the benefit of the emerging CCS business.

The dataset comprises approximately 850 files and more than 83 Gigabytes, and can be accessed through the Equinor data portal.

The Norwegian Full-Scale CCS project “Langskip” is the first industry scale project for capture and storage of CO2 on the Norwegian continental shelf.

Exploitation license EL001 for CO2 storage, was awarded to the partners in January 2019. The 31/5-7 confirmation well (Eos) within EL001 licence was drilled and tested from 2nd December 2019 to 7th March 2020.

The Eos well targeted the Dunlin Group Geological formation as the primary storage, where the sandstone-bearing Cook and Johansen formations both can serve as storage units for the injected CO2.

The cap rock consists of impermeable claystones called Drake Formation, which prevents the CO2 from migrating out of the Dunlin Group.

BGS study to investigate potential for CO2 storage testbed

www.bgs.ac.uk

A new study to be undertaken by the British Geological Survey (BGS), on behalf of the Natural Environment Research Council (NERC), will scope out the potential for a deep borehole carbon dioxide (CO2) storage research testbed.

The project objectives include defining the options for future investment from UKRI and NERC in CO2 storage research; outlining the Carbon Capture and Storage (CCS) landscape to provide the wider context for NERC’s future investment decisions; gathering technical and business case evidence to de-risk further investment and engaging stakeholders to help define the required capabilities and scientific objectives of a testbed.

A range of location and design options for a research testbed will be identified using preliminary technical and permitting evidence and will help provide the basis for recommendations that will inform future investment decisions.

The scoping project will build on the expertise already acquired by BGS in facilitating the UK Geoenergy Observatories (UKGEOS) and will be a joint undertaking between BGS’s CO2 Storage and UKGEOS teams.

It is anticipated that a testbed would help to fill knowledge gaps in geological CO2 storage, answering some specific science questions around demonstrating long-term containment and the processes for the way a site is closed.

It would provide an innovation platform on which to develop new techniques and equipment to improve monitoring; reduce costs; further enhance safe storage and open access to, and sharing of, data, for the benefit of the research community and storage developers.

Non-technical developments would be enabled such as supporting wider public discussions of the merits of CO2 storage that are vital for underpinning future full-scale commercial systems; evidence would be provided for policymakers and regulators and data gathered would support appropriate regulation for the emerging CO2 storage industry.

Crucially, the infrastructure would be publicly owned and would be a facility for transparent research and innovation exploration.

Santos announces successful carbon injection trial at Moomba

www.santos.com

Santos has successfully injected approximately 100 tonnes of carbon dioxide into depleted gas reservoirs as part of the final field trial for the Moomba CCS Project.

Santos Managing Director and Chief Executive Officer Mr Gallagher said the successful injection occurred earlier this month in the Strzelecki field in the Cooper Basin and Santos would now finalise technical and commercial arrangements with the aim of having the 1.7 million tonne per annum project ready for Final Investment Decision by the end of the year.

Ultimately, the Moomba CCS Project has the potential to store up to 20 million tonnes of carbon dioxide per annum.

“We will need an approved methodology for CCS to be in place with the Clean Energy Regulator before we take a final investment decision on our Moomba CCS Project because carbon credits are essential to make it stack up economically with the cost of abatement still at around A$30 per tonne,” Mr Gallagher said.

“Our aim is to drive these costs lower with scale and experience, but the first step is to generate carbon credits to enable initial development.

U.S. DOE-NETL CO2 storage projects

A blog from the IEA Greenhouse Gas R&D Programme summarises a recent meeting updating on DOE NETL funded CO2 storage projects.

To accelerate the deployment of CCUS, the US DOE has recently created a network of Regional Initiatives to identify and address regional storage and infrastructure challenges currently facing the development of CCUS in the US and to advise / assist on the geologic carbon storage projects being done by others. Representatives involved in the four Regional Initiatives gave updates on their progress.

The SECARB-USA (Southeast Regional Carbon Utilization and Storage Partnership) is a 5 year project, with two phases starting in 2019. Ongoing work includes updating and continuing work on an initial inventory of non-technical challenges to CCUS deployment and a preliminary assessment of storage potential in the region. This assessment will look in detail at the storage opportunities as well as identifying the costs throughout the region, with a large area already having been mapped and information to be added to the recently published SCO2T tool.

The SAS VIYA Decision Support System is developing decision making systems, looking at data mining, advanced analytics and machine learning for decision support, with work ongoing to input the data and to further build out the program. In terms of the storage complex, the programme is looking at the cost of characterisation and using individual state geological survey work to bring together regional characterisation. Commercial interest in CCS is expanding rapidly in the SECARB region, which is diverse in terms of its sources and sinks, and the success of this programme will increase the number of projects in the region following support from and education provided by the partnership.

The Midwest Regional Carbon Initiative (MRCI) covers 20 states in the Midwest and Northeast of the United States.Its aim is to accelerate CCUS deployment with collaboration between researchers, industry, government and non-governmental organisations. This initiative leverages extensive past experience with multiple pilot and full scale projects to create a solid foundation to move forward.

There are multiple CO2 storage provinces in the region within multiple basins, with some similarities throughout but key differences across the provinces and so storage solutions need to be investigated further. To address the key technical challenges there are three ongoing tasks. These activities are investigating stacked storage solutions, structural complexity, facilitating data collection, sharing and analysis, evaluating regional infrastructure and the promotion of regional technology transfer.

The expected outcomes of this work includes the improvement of geologic characterisation, identification of storage reserves, outline of source-sink scenarios and pipeline routes.The application of a risk-based probabilistic model to value potential CCS risks, and the further assessment of policy, economic and social issues, are also covered.

The PCOR (Plains CO2 Reduction Partnership) programme aims to address regional capture, transport, use and storage challenges to help drive the commercial deployment of CCUS, within the PCOR region. The expansion of this new phase (2019-2024) builds on 17 years of applied research in this active region. Technical challenges being addressed include geological characterisation, storage performance / optimisation, MVA strategies and risk management, through data collection, sharing and analysis.

Regional infrastructure is being assessed and analysed as well as non-technical challenges. Active engagement with regulators, and the construction of business models, will help identify clear pathways to commercial deployment. There are positive opportunities for synergy in the region, with PCOR acting as a catalyst for CCUS development.Results can then be duplicated to support the DOE program goals.

The Carbon Utilization and Storage Partnership of the Western United States (CUSP) has been set up by taking parts of three original RCSPs (SWP, WESTCARB and Big Sky).The current programme runs from November 2019 to October 2024. The original scope was a 3 year project to collect, synthesise and use the existing data set to analyse and incorporate into analytical and optimisation models to evaluate CCUS readiness and its potential in the region.

There is a strong emphasis on technology transfer. With an additional allocation of DOE funds, the new extended scope will also cover education, support for the NETL's SMART Initiative, and a boost to jumpstart 45Q ready projects in the western US. This partnership has carried out initial surveys of the region for CCUS opportunities and related issues, and is now looking at sources, sinks and potential as well as existing transportation pathways with the aim of developing regional hubs.

The partnership is now working towards the integration of machine learning tools to help analyse the results. A key notable component of this program is public outreach, with emphasis on the communication and education of the general public as well as specific stakeholders.

Two offshore partnership projects were presented. SECARB-Offshore will be looking at a range of technical and non-technical issues for the Eastern Gulf of Mexico. Of particular interest was the work underway by Aker in developing seabed systems for CO2-EOR in the Gulf of Mexico in order to separate, compress and inject CO2 at depths deeper and warmer than those typical of the North Sea, e.g., 300m.

Recent developments by the GomCARB project include looking at a new "fetch and trap" concept in formations, to avoid the formation traps which are penetrated by wells for oil and gas production. They are also looking at infrastructure for offshore, developing screening criteria for re-use of pipelines and identifying data gaps.

More information

www.netl.doe.gov

www.ieaghg.org

Leading energy companies partner to accelerate UK North Sea carbon storage

bp, Eni, Equinor, National Grid, Shell and Total form Northern Endurance Partnership to develop offshore carbon dioxide infrastructure in the UK North Sea, with bp as operator.

This infrastructure will serve the proposed Net Zero Teesside (NZT) and Zero Carbon Humber (ZCH) projects that aim to establish decarbonised industrial clusters in Teesside and Humberside.

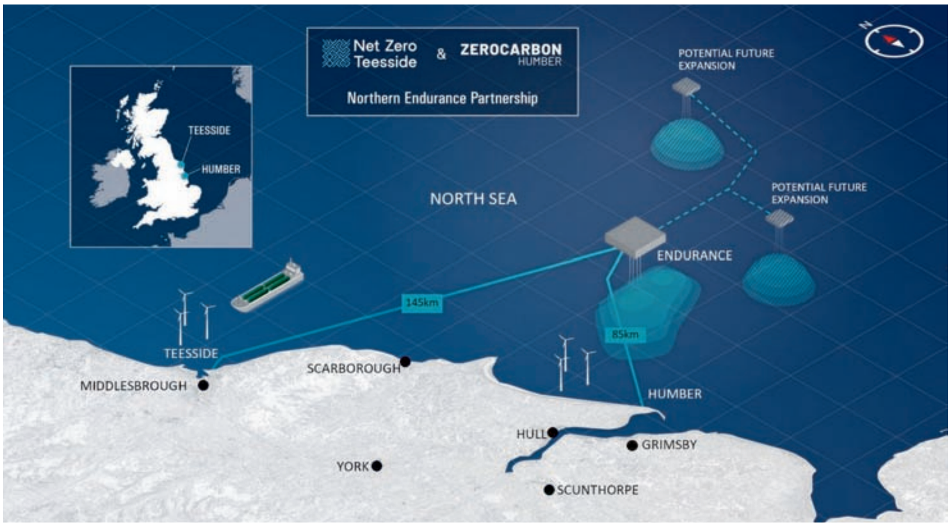
NZT and ZCH are at-scale decarbonization projects that will kick start decarbonization of industry and power in two of the UK's largest industrial clusters. Both projects aim to be commissioned by 2026 with realistic pathways to achieve net zero as early as 2030 through a combination of carbon capture, hydrogen and fuel-switching. If successful, NEP linked to NZT and ZCH will allow decarbonization of nearly 50% of the UK's industrial emissions.

NEP has submitted a bid for funding through Phase 2 of the UK government's Industrial Decarbonisation Challenge, aiming to accelerate the development of an offshore pipeline network to transport captured CO2 emissions from both NZT and ZCH to offshore geological storage beneath the UK North Sea.

The £170 million Industrial Decarbonisation Challenge is part of the £4.7bn Industrial Strategy Challenge Fund set up by the UK government to address the biggest industrial and societal challenges using research and development based in the UK. NEP's application for funding is an important step towards enabling the development of integrated offshore carbon storage for NZT and ZCH in the UK Southern North Sea.

The application follows the approval by the Oil and Gas Authority (OGA) of the addition of bp and Equinor alongside National Grid to the Endurance carbon storage licence. This affirms the strategic importance of the Endurance reservoir as the most mature and large scale saline aquifer for CO2 storage in the offshore UK Continental Shelf, that can potentially enable industrial decarbonization from both clusters.

bp will lead the Northern Endurance Partnership as operator and the team progressing the project will draw on expertise from across all the partners.



Plans for the offshore infrastructure that will support the Net Zero Teesside and Zero Carbon Humber projects

Andy Lane, vp of CCUS solutions at bp and managing director for Net Zero Teesside, said, "The formation of the Northern Endurance Partnership is another significant milestone towards developing the offshore infrastructure that will be needed to safely transport and store CO2 from CCUS projects along England's east coast."

"The partnership and our joint bid demonstrate industry's willingness to come together and collaborate wherever possible to accelerate making CCUS a reality in the UK, helping to decarbonize the local economy and contributing to the UK's climate goals."

The UK government has committed to the country achieving net zero emissions by 2050 and, as the Committee on Climate Change (CCC) has stressed, CCUS is critical to achieving this. Without it, the target poses a real challenge to the future of British industry and jobs, as CCUS is the only way to decarbonize many industries.

The Humber is the most carbon-intensive industrial cluster in the UK, emitting 12.4 million tonnes a year, while Teesside industries account for 5.6% of the country's emissions. The region is also home to five of the UK's top 25 CO2 emitters.

The existing concentration of heavy industries in these relatively compact areas, where captured CO2 can be gathered and transported to the storage sites, makes Teesside and Humberside ideal locations for CCUS projects.

More information

www.bp.com

www.netzeroteesside.co.uk

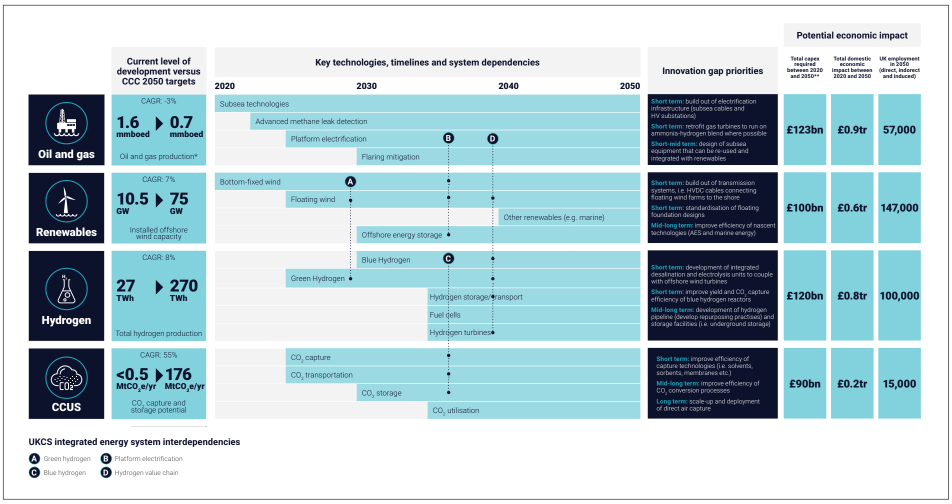
www.zerocarbonhumber.co.uk

Report: 'Closing the Gap' - realising a net zero North Sea

Delivering a tech-enabled integrated net-zero energy future will cost £430 billion but generate more han £2.5 trillion in value to the UK economy, says a report from the Oil & Gas Technology Centre.

Closing the Gap: Technology for a Net Zero North Sea, produced by global natural resources consultancy Wood Mackenzie for the OGTC, with support from Chrysaor and the Scottish Government, sets out a technology roadmap for an integrated energy future in the North Sea.

The report outlines how accelerating the development of new energy technologies can dramatically reduce emissions, and how adopting new technologies will harness the full potential of the UK's world-class natural resources from renewable power sources and oil and gas, to hydrogen and long-term carbon storage.



Technology gap priorities for unlocking the UKCS' potential
**Based on Roadmap 2035 extrapolated to 2050*
*** Total capex required, i.e. includes UK content capex and capex spent internationally*
Source: Wood Mackenzie, Lux Research

Maximising the opportunities to innovate across the renewable and fossil fuel sectors could create more than 200,000 new jobs across the UK and contribute more than £2.5 trillion to the nation's economy by 2050. It would also create a diversified energy sector, support a new generation of highly skilled jobs and open up exciting export potential.

The oil and gas sector, including its workforce, supply chain and infrastructure, can enable and accelerate the growth of the renewables sector, while renewable energy sources will be critical in supporting the oil and gas industry on its journey to net zero.

Realising this integrated vision will require £430 billion of new investment to close the gap on a number of crucial technologies and accelerate their deployment. These include:

• Oil and gas platform electrification, methane leak detection and flaring mitigation

• Larger blades, taller towers and automated inspection technology for fixed offshore wind

• Optimised and standardised floating offshore wind foundation designs

• Innovative hydrogen membranes and CO2 sorbents to improve blue hydrogen yield

• New saltwater electrolysis technologies to reduce the cost of green hydrogen production

• Advanced catalyst materials for hydrogen fuel cells to reduce costs and improve durability

• New solvents, sorbents, membranes and conversion solutions to reduce the cost of CCS

• Power take off solutions and support systems for marine renewables such as floating solar

Colette Cohen OBE, CEO at OGTC said, "Reimagining the North Sea as an integrated energy system is essential for the UK and Scotland to achieve their net-zero ambitions. But we need to invest now to close the gap on the key technologies needed to make this ambition a reality."

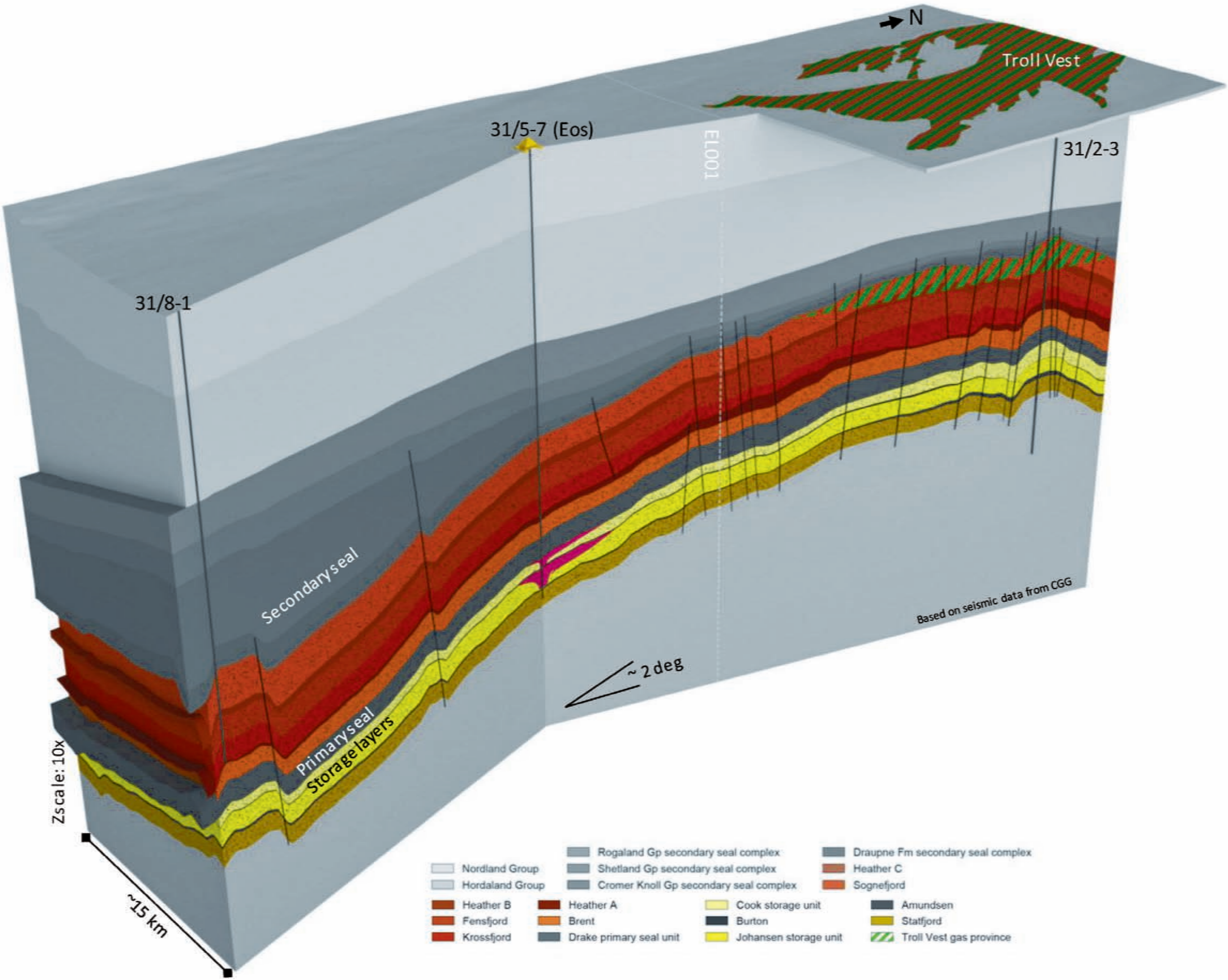
"We need to digitise our offshore energy sector and solve big challenges like energy storage, infrastructure redeployment, transmission systems and cost-competitive floating wind structures. By doing this, we can create strategic advantage and valuable export opportunities."

"With its decades of energy expertise, the UK has a huge opportunity to become a leading manufacturer, designer, installer and operator of net-zero energy systems."

"Leveraging our strength in oil and gas, we can also partner with the renewables sector to accelerate the delivery of the next generation of energy in the UK – and internationally. This is where governments and industry should focus investment at pace in the coming years."

More information

www.theogtc.com



N
Troll Vest
31/5-7 (Eos)
EL001
31/2-3
31/8-1
Secondary seal
Primary seal
Storage layers
~2 deg
Based on seismic data from CGG
Zscale: 10x
~15 km
Nordland Group
Hordaland Group
Rogaland Gp secondary seal complex
Shetland Gp secondary seal complex
Cromer Knoll Gp secondary seal complex
Draupne Fm secondary seal complex
Heather C
Sognefjord
Heather B
Fensfjord
Krossfjord
Heather A
Brent
Drake primary seal unit
Cook storage unit
Burton
Johansen storage unit
Amundsen
Statfjord
Troll Vest gas province