Carbon Capture Journal

CCUS in EMEA

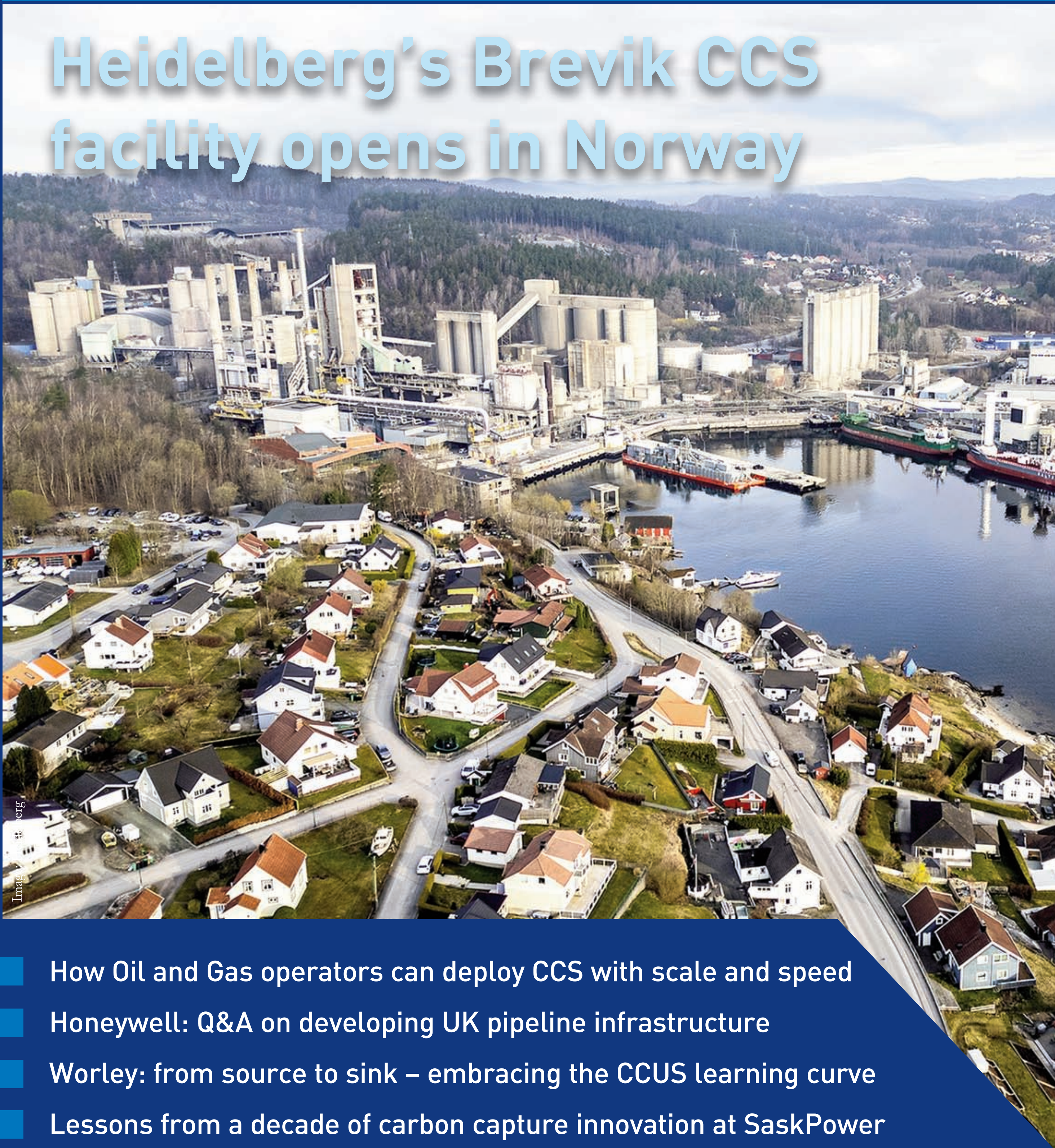
Longship complete, moves to Phase 2

Nationwide CCS map for Nigeria

Deloitte: overcoming barriers to enable CCS deployment at scale in Europe

July / Aug 2025 Issue 106

Heidelberg's Brevik CCS facility opens in Norway



How Oil and Gas operators can deploy CCS with scale and speed

Honeywell: Q&A on developing UK pipeline infrastructure

Worley: from source to sink – embracing the CCUS learning curve

Lessons from a decade of carbon capture innovation at SaskPower

Wood Mackenzie forecasts trillion-dollar boom in carbon offsets and CCUS markets

Wood Mackenzie's Carbon Markets and CCUS research teams predict that rising demand, policy evolution, strategic corporate deals, and technological advancements will fuel steep growth trajectories for both sectors.

Global carbon markets are poised for transformative growth. Two key strategic areas have emerged as critical components of global decarbonisation efforts: CCUS and carbon offsets. Wood Mackenzie's two long-term outlook reports forecast substantial market size growth, surpassing trillions of dollars in value by mid-century.

"CCUS will likely become crucial for abating process emissions in hard-to-abate industries," said Hetal Gandhi, Lead – Global forecasts and APAC research at Wood Mackenzie. "Our analysis reveals global capture capacity expanding 28-fold to 2,061 Mtpa by 2050, with similar growth expected in storage. CCUS has established its space in key stakeholders' minds, leading to US$1.2 trillion of investment in point-source emissions alone."

Peter Albin, senior research analyst of Carbon Markets at Wood Mackenzie, added, "The carbon offsets market will mature, with improved standards driving demand for flexible mitigation options. We project the carbon offset market will exceed US$150 billion. The synergy between carbon offsets and CCUS will play an increasingly sizeable role in climate strategies."

Key findings from the reports include:

Decarbonisation demand outpaces supply growth: Corporate sustainability pledges, tightening regulations and hard-to-abate sector needs will drive unprecedented demand for emissions reduction solutions. Energy producers and heavy industry lead this charge, exploring cutting-edge technologies to slash carbon footprints. As these sectors balance operational needs with environmental responsibilities, potential supply bottlenecks loom. This shift reshapes industry landscapes, with innovative strategies emerging to achieve deep emissions cuts.

"Our analysis reveals diverse CCUS adoption drivers and unique opportunities across various sectors," said Gandhi. "Blue hydrogen leads growth until 2035, outcompeting green alternatives on cost. Energy security boosts upstream adoption, with pre-combustion's affordability supporting global gas demand. Young coal power and steel plants drive uptake in Asia Pacific despite high costs. Cement and refining invest in CCUS due to high process emissions and limited alternatives."

Net zero targets drive dual decarbonisation strategies: Companies increasingly integrate carbon offsets and CCUS technologies to meet ambitious climate goals. This approach addresses carbon footprints comprehensively, with CCUS advancements scaling up future efforts. Carbon offsets provide flexibility and immediate practicality, particularly for hard-to-abate or unavoidable emissions.

"Long-term demand for carbon removal is essential for meeting net zero targets, but avoidance and reduction offsets will play a crucial role," said Albin. "These offsets will compensate for scope 3 emissions as companies grapple with supply chain decarbonisation complexities."

A dynamic ecosystem benefits both markets: Government policies, particularly incentives and compliance carbon pricing regimes, are catalysing synergy between CCUS and carbon offset markets. Emphasis on additionality, permanence and verifiability raises standards across sectors. Growing standardisation needs to bolster trust in authentic emission mitigation strategies. This evolution creates a cohesive framework for climate action, spanning technological and nature-based solutions.

"The carbon offset market will grow remarkably, with volumes expanding sixfold by 2050," said Michelle Uriarte-Ruiz, senior research analyst at Wood Mackenzie. "Carbon removal will make up over 40% of offsets by mid-century, signalling a pivotal shift in climate strategies. This blend of solutions forges a more resilient carbon value chain, potentially accelerating global decarbonisation efforts."

Prices and investment poised for significant growth: The average carbon offset price will increase more than fivefold by 2050. CCUS investments will reach at least US$1.2 trillion, fuelled by point-source capacities and carbon removal value chain additions. These trends highlight rapid expansion and increasing interconnectedness of both markets. They reshape corporate sustainability strategies, offering businesses a comprehensive toolkit for addressing carbon footprints.

"Sustainable deep decarbonisation technologies rely on robust carbon markets to gain widespread adoption," added Albin. "Rising carbon offset prices will boost CCUS sector viability, reducing reliance on government support, driving rapid adoption post-2035."

"The carbon offset and CCUS markets are on the cusp of a transformative era," concluded Mhairidh Evans, Vice President, Global Head of CCUS research at Wood Mackenzie. "This growth, driven by net zero ambitions, offers immense opportunities for early movers. Success hinges on navigating policy uncertainties and infrastructure challenges. As these markets mature, they will become cornerstone elements of global climate strategies, reshaping the energy transition landscape."

Wood Mackenzie cautioned that realising the full potential of these markets faces near-term hurdles. These include enhancing offset quality, defining clear use cases, securing government support, and scaling carbon removal technologies. Both sectors require rapid policy evolution. CCUS, in particular, will need continued government financial backing for at least the next decade. These challenges underscore the complexity of the evolving carbon management landscape and its implications for decarbonisation efforts.

More information
www.woodmac.com

Carbon Capture Journal

July / Aug 2025 Issue 106

Carbon Capture Journal
United House, North Road, London N7 9DP
www.carboncapturejournal.com
Tel +44 (0)208 150 5295

Editor
Keith Forward
editor@carboncapturejournal.com

Publisher
Future Energy Publishing
Karl Jeffery
jeffery@d-e-j.com

Subscriptions
subs@carboncapturejournal.com

Advertising & Sponsorship
David Jeffries
Tel +44 (0)208 150 5293
djeffries@onlymedia.co.uk

Carbon Capture Journal is your one stop information source for new technical developments, opinion, regulatory and research activity with carbon capture, transport and storage.

Carbon Capture Journal is delivered on print and pdf version to a total of 6000 people, all of whom have requested to receive it, including employees of power companies, oil and gas companies, government, engineering companies, consultants, educators, students, and suppliers.

Subscriptions: £250 a year for 6 issues. To subscribe, please contact Karl Jeffery on subs@carboncapturejournal.com Alternatively you can subscribe online at www.d-e-j.com/store

Front cover: Heidelberg's Brevik CCS is an important blueprint for future CCS projects worldwide: injection into the subsea reservoirs is scheduled to begin in August (pg. 2)

Back cover: Captura: why the UK is well placed and should lead the direct ocean capture revolution (pg. 29)

Carbon capture journal (Print) ISSN 1757-1995
Carbon capture journal (Online) ISSN 1757-2509

Leaders - CCUS in EMEA

Projects and policy

Capture and utilisation

Transport and storage

Heidelberg Materials opens Brevik CCS facility in Norway

The facility has been officially inaugurated by H.R.H. Crown Prince Haakon of Norway and more than 320 guests, including Terje Aasland, Energy Minister of Norway. It will capture around 400,000 tonnes of CO2 per year, representing 50% of the cement plant's emissions.

The facility is part of the Norwegian government's Longship project, developing Europe's first full-scale value chain for carbon capture, transport, and storage from hard-to-abate industries.

Within Longship, the Northern Lights initiative – a collaboration between Equinor, Shell, and TotalEnergies – is the partner responsible for the carbon transport and storage. The CO2 captured in Brevik will be liquefied and shipped to an onshore terminal on the Norwegian west coast. From there, it will be transported by pipeline to permanent storage under the North Sea.

During a festive ceremony at the Brevik cement plant, H.R.H. Crown Prince Haakon of Norway officially unveiled a concrete-made plaque. More than 320 guests, including industry leaders, international high-level government officials and representatives from NGOs and start-ups were in attendance.

As a first-of-its-kind project in the cement sector, Brevik CCS is an important blueprint for future CCS projects worldwide. First CO2 already successfully captured, liquefied, and temporarily stored; injection into the subsea reservoirs is scheduled to begin in August

"Today marks a historic milestone and tectonic shift in the built environment. The opening of Brevik CCS is a tremendous technological achievement that will serve as a blueprint for entire industries as we progress towards Net Zero and into a new era of sustainable construction," said Dr Dominik von Achten, Chairman of the Managing Board of Heidelberg Materials during the ceremony.

"Above all, it is a testament to what can be accomplished when exceptional minds with a shared vision and strong determination come together. I am very proud of our teams and the partners who have contributed to the success of this project. We owe it to each one of them that supplying net-zero concrete is no longer a future ambition but a reality."

As part of the ongoing ramp-up of Brevik CCS, first volumes of CO2 have already been successfully captured, liquefied, and temporarily stored. Northern Lights have started first shipments to their intermediate storage site in Øygarden in June. Subsequently, Heidelberg Materials will begin to deliver evoZero®, the world's first carbon captured cement enabling net-zero concrete, to customers in Europe.

"Brevik CCS is a true pioneering project. Thousands of people from all over the world have already visited the facility to learn from our experience. This is not just a technical masterpiece, but a concrete example of industrial leadership on climate issues," said Giv Brantenberg, General Manager of Heidelberg Materials Northern Europe.

As part of the project, the carbon capture facility has been integrated into the Brevik cement plant without disrupting ongoing cement production. Heidelberg Materials recruited 30 employees, who have undergone intensive training and are now responsible for operating the carbon capture facility.

"As a key part of Norway's Longship programme, Brevik CCS is a powerful example of how businesses and government can work hand in hand to pave the way for a more sustainable future," said Norwegian Minister of Energy Terje Aasland. "This form of collaboration can foster innovation and kick start development of nascent markets for climate technology."

Brevik CCS is the first in a growing portfolio of CCUS projects across Heidelberg Materials. The project will contribute to further scaling carbon capture solutions in the industry as the company is leveraging the lessons learned in Norway.

More information

www.heidelbergmaterials.com

Longship complete, first offloading and a royal visit

Several milestones have been reached for the Northern Lights JV and Norway's ambition to lead the development of a full-scale value chain for carbon capture and storage as the project moves to Phase 2.

Longship, the Norwegian government's full-scale CCS project, is officially complete. Northern Lights is responsible for operating CO2 transport and storage facilities, open to third parties, as part of Longship.

It is the first ever cross-border, open-source CO2 transport and storage infrastructure network and offers companies across Europe the opportunity to store their CO2 safely and permanently underground.

Illustration of the Northern Lights Phase 2 expansion plans, capacity will rise to at least 5 million tonnes of CO2 per year

First CO2 onboard

The first custom-built ship, Northern Pioneer, has started commissioning and carried out its first CO2 loading and offloading from Heidelberg Materials in Brevik.

At the same time, sister vessel Northern Pathfinder took part in the official Longship completion events and is now ready to enter into commissioning phase. During the ceremony, the vessel was formally blessed by its godmother, Kari Nessa Nordtun, Norway's Minister of Education and a Stavanger citizen.

The 130-meter-long vessel is the second of four custom-designed sister ships, each capable of transporting up to 7500 tonnes of liquid CO_2. It is registered in Stavanger, Norway and managed by Kawasaki Kisen Kaisha, Ltd. ("K" LINE).

The importance of this milestone was underlined by the visit of H.R.H. The Crown Prince of Norway and Minister of Energy Terje Aasland, who explored a CO2 simulator and boarded the Northern Pathfinder. Their visit highlights the strong political backing for Norway's leadership in CCS.

PDO approval for Phase 2

As an important next step, Northern Lights has now received official approval from the Ministry of Energy for the Plan for Development and Operation (PDO) for Phase 2. With this approval, it will increase the transport and storage capacity from 1.5 million tonnes to at least 5 million tonnes of CO2 per year.

Phase 2 is supported by a grant from the EU's Connecting Europe Facility for Energy and will be financed primarily through commercial investments. An agreement has already been signed with Stockholm Exergi to handle up to 900,000 tonnes of CO2 from their bioenergy facility in Sweden – the third commercial customer, alongside existing contracts with Yara in the Netherlands and Ørsted in Denmark.

With Longship completed, vessels operational, and Phase 2 moving ahead, Northern Lights said it remains committed to delivering a robust, scalable CO2 transport and storage value chain for Europe.

More information

More about the project at:
https://norlights.com

Boosting photosynthesis for carbon capture

Using light to break down and bind CO2: two new research groups at the Max Planck Society want to make what nature already does much more efficient.

On 1 July 2025, the Max Planck Society will launch two new research groups that aim to make the core of photosynthesis significantly more efficient. With the help of sunlight, CO2 will be broken down into its components and fixed. The research is still in its early stages, however if scaling proves successful, large amounts of atmospheric CO2 could potentially be captured.

The two research group leaders and biochemists Adrian Bunzel and Andreas Küffner are aware that today's carbon capture solutions are too expensive and inefficient, and that the risks associated with underground storage or injection are, in some cases, impossible to assess. Nevertheless, capturing carbon from the atmosphere will remain necessary for decades to come, especially since emissions from sectors like chemicals and cement cannot be completely eliminated. It is therefore better to close the current research gaps today rather than tomorrow.

Andreas Küffner (left) and Adrian Bunzel (right) head two new research groups at the Max Planck Society that are investigating biological carbon storage.. Image © V. Geisel / Max Planck Institute for terrestrial Microbiology

'Nature is conservative'

Adrian Bunzel was already researching so-called photoactive enzymes for biological photovoltaics as an early career-research group leader at ETH Zurich. Enzymes are nature's catalysts and accelerate biochemical reactions. His photoenzymes generate electricity using sunlight. At the Max Planck Institute for Terrestrial Microbiology, Bunzel is now targeting new enzymes that, like plants, use the energy of sunlight to break down CO2 molecules into their individual components and bind them.

In nature, however, photosynthesis only binds about one percent of the theoretically available carbon in biomass due to very complex reaction pathways. "Nature is conservative," saidTobias Erb, Director at the Max Planck Institute for Terrestrial Microbiology. With photosynthesis, it has established a sufficient but inefficient way of breaking down CO2 using sunlight.

In his research, Adrian Bunzel aims to produce artificial photoenzymes that greatly simplify natural photosynthesis and significantly boost its efficiency. He is relying on two cutting-edge methods: computational protein design (– the computer-aided development of new proteins – and directed evolution, a technique that mimics natural evolution in the lab to optimise enzymes through mutation and selection.

Both methods have been awarded the Nobel Prize in recent years. "It's like learning to fly," said Erb. "We observed how birds fly and studied lift. Then we built airplanes, but without wings. They don't look like birds, but they do what they are supposed to do and, in some respects, even better, more specifically, and more efficiently." For Adrian Bunzel, this opens the door to entirely new possibilities: This is precision bioengineering. It's no longer about how we manipulate biology, but what we want to design," he says. The new possibilities in protein design allow us to ask: Which proteins add value, for example, in achieving sustainability goals?

Better bacteria for photosynthesis

Andreas Küffner will increase the efficiency of photosynthesis at the Max Planck Institute for Multidisciplinary Sciences in a completely different way. He ensures that more CO2 accumulates in the organelles of plant cells as a starting material than is usual in nature. Andreas Küffner developed and demonstrated the concept during his postdoc in Tobias Erb's laboratory in vitro – which means in a test tube. After all, the more CO2 that's available, the more can be used.

The concept also helps to circumvent a fundamental limitation of nature, which fixes significantly less CO2 in cells with an enzyme. Küffner focuses on cyanobacteria, which are bacteria with the ability to photosynthesise. "Organelles in bacteria are like small reactors. They are there to capture and concentrate CO_2," he explained. And cyanobacteria have another advantage: they grow easily and quickly and are relatively easy to genetically manipulate. "We could also work with algae, but they are more difficult genetically," said Küffner.

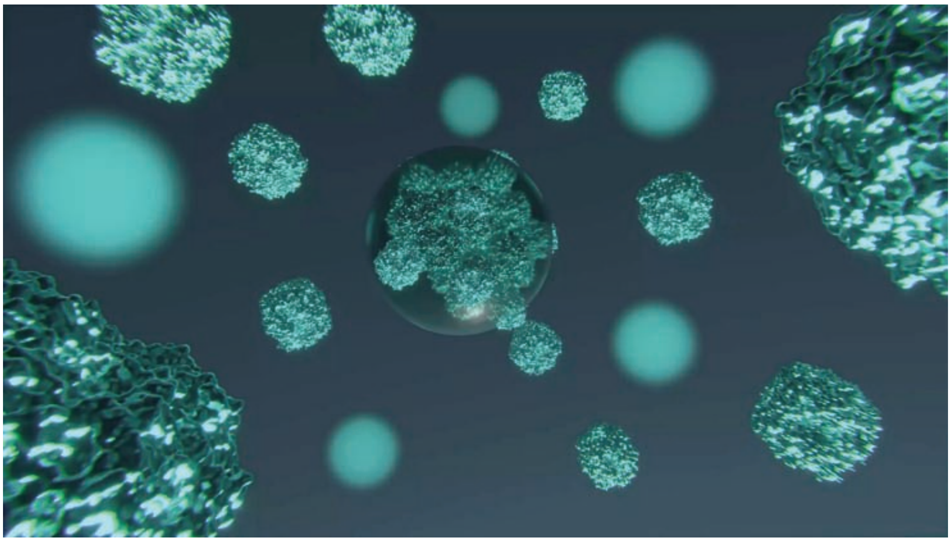
Both algae and cyanobacteria can perform photosynthesis, and both can be scaled up in specialised processes. Looking ahead, some people might envision multi-storey greenhouses with Plexiglas cylinders containing shimmering green streaks. That could work well for algae. But cyanobacteria thrive best in open waters or shallow pools. Many people are familiar with the sight of thick, bright green, shimmering blooms from the Baltic Sea, for example.

The disadvantage in the wild is that the bacteria extract oxygen from the water. So would artificial pools be conceivable? "My research is not aimed at scaling," said Küffner. Instead, he is tackling another issue: cyanobacteria require nitrogen and phosphorus to thrive, and producing these fertilizers consumes significant resources, while also generating CO_2.

A long way to go before application

What connects the two research groups is photosynthesis. "Light is everywhere; it's one of the most sustainable energy sources there is," said Tobias Erb. Otherwise, both groups are pursuing their own goals. While Andreas Küffner works with and on cells, Adrian Bunzels begins by testing his photoenzymes 'in vitro', i.e. in a test tube, before incorporating them 'in vivo' into the metabolism of a real organism for photosynthesis.

Smears of cyanobacteria that have been genetically modified to fix more CO_2. Image © A. Küffner / MPI for terrestrial Microbiology



Artistic representation of the interior of a cyanobacteria cell. Here, condensates (spheres in the image) concentrate enzymes that fix CO_2 during photosynthesis. Image © MPI for terrestrial Microbiology/A. Küffner

"It can easily take more than ten years from enzyme idea to plant," said Tobias Erb. Much can happen along the way, which is a hallmark of basic research. "If something doesn't work, that has value, too. If you don't try, you'll never know if it could have worked," says Küffner. In order to conduct the best possible research in this field today – and contribute to a more liveable future tomorrow – the Max Planck Society is pursuing two entirely new lines of research with Andreas Küffner and Adrian Bunzel.

Storing and using carbon

The basic problem is well known: Germany emitted around 600 million tonnes of CO_2 in 2023, and globally over 40 gigatonnes (billion tonnes) of this greenhouse gas are still released into the atmosphere every year – directly leading to global warming. "Assuming we wanted to remove up to 40 gigatonnes of CO_2 from the air each year, no single technological concept could achieve this. And it doesn't have to, because the solution will ultimately be a mix of different strategies," said Bunzel.

This always includes preventing emissions from being produced in the first place. And what if 90 percent of emissions were avoided in the future? "According to predictions, we would still have to actively capture three to five gigatonnes of CO_2," said Tobias Erb.

The only large-scale technical facility for capturing CO_2 directly from the ambient air is currently located in Iceland. There is still heated debate about whether and to what extent such technologies should be used in global decarbonisation. While they offer clear benefits, technical capture processes also pose challenges, especially when it comes to storing CO_2 safely. Hence the abbreviation CSS for carbon capture and storage. And the filter plant in Iceland is prohibitively expensive: each tonne of filtered CO_2 costs over 1,000 euros to remove.

In addition to capturing and storing CO_2, for example directly at emission sources, the carbon obtained can be also be reused. Chemically incorporating it into plastics or other materials that are needed in everyday life is called carbon capture and utilization (CCU). Andreas Küffner and Adrian Bunzel are pursuing both goals. "By incorporating CO_2 into the biological metabolism, we can use it to produce virtually any chemical that can be made biologically," said Adrian Bunzel.

Possible products include biofuels or raw materials for the chemical industry that are produced sustainably. Once carbon capture and utilisation is operating efficiently, it will be an important component of a circular economy in the chemical industry.

More information

www.mpg.de/en

IFC and World Bank to help Nigeria pave the way for domestic carbon storage

The initiative will produce a nationwide atlas of CO2 emissions sources and potential sites for underground sequestration. IFC will work with the government to identify the most promising sectors and private companies that can pilot new technologies for capturing, using, and storing carbon.

The International Finance Corporation (IFC) and the World Bank have begun to work with the Government of Nigeria to develop a domestic market for carbon capture, utilization, and storage for industrial emissions - an area that could accelerate the energy transition and help Nigeria reach its emissions targets.

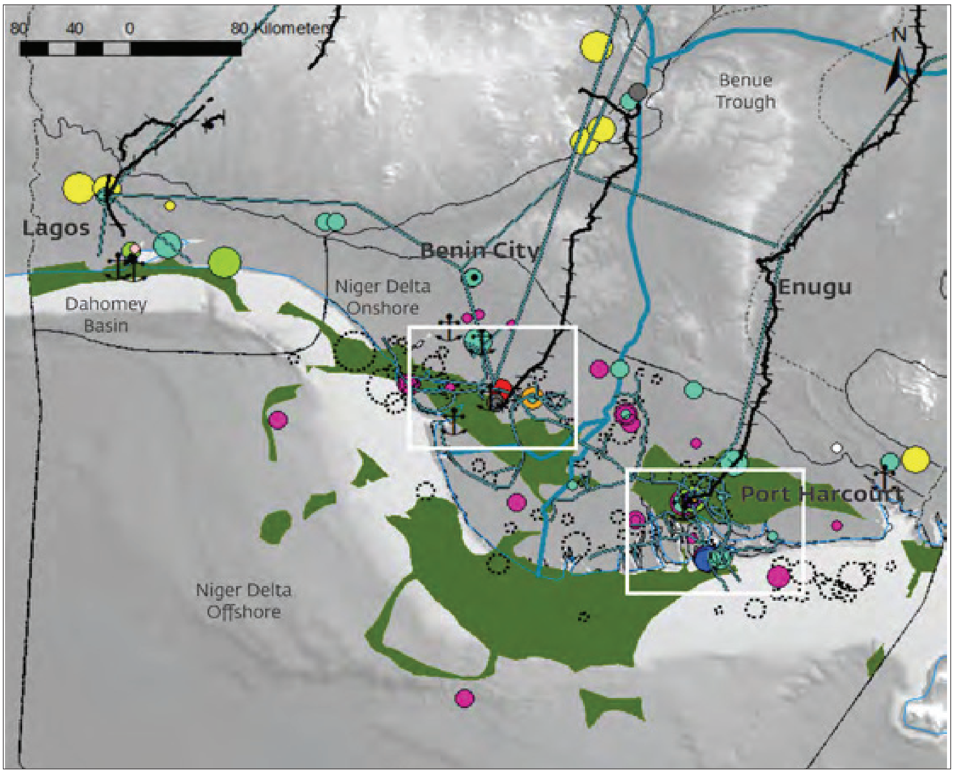
The initiative will produce a nationwide atlas of CO2 emissions sources and potential sites for underground sequestration. IFC will work with the government to identify the most promising sectors and private companies that can pilot new technologies for capturing, using, and storing carbon.

In parallel, the World Bank will collaborate with the Nigerian Government to outline policies and regulations that can accelerate the technologies' uptake while helping the local CCUS industry meet international standards. The project is funded by the World Bank's CCS Trust Fund under the Energy Sector Management Assistance Program (ESMAP). The Trust Fund is supported by the Governments of the United Kingdom and Norway.

"The Federal Government, through the Office of the Vice President, is excited to work with the World Bank Group towards developing and implementing CCUS as part of the country's pathways to accelerate energy transition by 2060," said the Office of the Vice President of the Federal Government of Nigeria.

"The country believes that with the World Bank Group's support and partnership with Nigeria, it's only a matter of time before CCUS becomes an important force in global technology, innovation policy for climate action and deep decarbonization, especially for hard-to-abate-sectors.

"If we can combine carbon capture with a decisive push on renewables, countries like Nigeria could be poised for a real breakthrough," said Vivek Pathak, IFC's Global Head for Climate Change. "For developing countries, imagine what a game-changer a financially-viable carbon capture industry could be."



Map showing the co-location of industrial emission sources, transport networks, high graded Miocene CO2 storage fairway areas and depleted oil and gas fields. The boxed areas near Warri and Port Harcourt show a favorable cluster of all the components for a CCS value chain. Largest circles for depleted hydrocarbon fields represent sites with resources over 100Mt

In 2021, Nigeria's updated Nationally Determined Contribution (NDC) set a target of at least 20% and up to 47% reduction of greenhouse gases compared to business as usual by 2030. Capturing carbon, which could help reduce emissions across a range of sectors, has become a key element of the government's climate plan.

In addition, the West African country is likely to have significant space for geological carbon storage, in part due to the widespread availability of depleted oil and gas fields. Their potential will be mapped using government and industry data. The project will also use geological surveys and closely examine the issue of obtaining the rights to conduct the sequestration.

IFC will work closely with local industries throughout the process. The engagement will not support the development of carbon capture, utilization, and storage in association with fossil fuel production.

More information

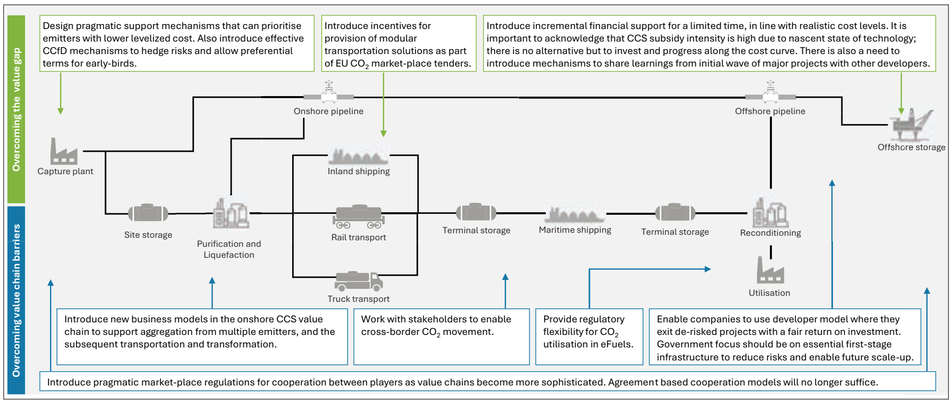
www.ifc.org

Deloite: overcoming barriers to enable CCS deployment at scale in Europe

There is a need to demonstrate flexibility in funding and regulations to swiftly operationalise major projects and recalibrate the level of support as the market matures says a report from Deloitte.

CCS faces significant challenges, including high costs and value chain barriers. The priority now is to push major next-generation projects by providing enhanced and tailored support, which will then accelerate progress along the cost curve. CCS projects are gaining momentum globally with more than 800 projects and use-cases under consideration, of which nearly 40% are in Europe.

Along with an increase in number of announced CCS projects, the design of the CCS value chain is also evolving. While 1st generation value chains were designed for captive use, recent 3rd generation FIDs, such as the 2nd phase of Northern Lights in Norway, are a stepping-stone to an open and mature market. Transition to 2nd and 3rd generation value chains faces two key challenges: value gap due to high and uncertain costs; and value chain barriers due to delayed availability of infrastructure.



Key interventions required for unlocking CCS deployment at-scale (not exhaustive) from "Carbon Capture and Storage in Europe - Unlocking deployment at-scale 2025"

Overcoming the value gap

Costs across the CCS value chain in Europe remain high, resulting in an average value gap of ca. €150/t CO2 compared to prevailing EU Emissions Trading System (ETS) price levels. The cost of transporting CO2, ETS prices, and purity of CO2 are three key variables that add uncertainty to the already high costs, which in turn is negatively impacting investor confidence. The high costs and uncertainties mean that CCS subsidy intensity is typically higher compared to that of other decarbonisation technologies.

Due to high cost-levels, there is a need to prioritise low-hanging fruits to scale-up the ecosystem (i.e., high purity CO2 streams with lower levelized CCS cost). To derisk projects, governments should adopt a hub-based approach for CO2 transport, put CO2 price hedging mechanisms in place, and promote dissemination of knowledge from the initial wave of large-scale projects (e.g., impact of CO2 purity on storage capacity).

It is important for governments to acknowledge that CCS subsidy intensity is high due to the nascent state of technology; there is no alternative but to invest and progress along the cost curve. Use cases where emitters can complement ETS revenues with strong local schemes and alternate revenue mechanisms (such as voluntary carbon rights) are likely to lead deployment. Countries such as the Netherlands have created additional support mechanisms (e.g., SDE++) to bridge the gap and scale of success will depend on total fund size and speed of subsidy award. So far, all leading CCS projects in the EU have relied on extensive government support, a trend which will continue in the short to medium term.

Overcoming value chain barriers

While there exists a structural gap between the available storage capacity and the increasing need for carbon capture, market uncertainty creates a climate of hesitation among emitters for long-term contracts with fixed dates. Governments should consider financial support for essential first-stage infrastructure projects to reduce risks and enable future scale-up.

Early adopters should get extra incentives. Moreover, as the CCS value chains evolve to become increasingly sophisticated with an increasing number of players, the cooperation model for the value chain participants will need to rely on standard market regulations instead of tailored agreements between the participants.

The ecosystem has so far developed for point-to-point and often captive CCS, leading to a gap in transport infrastructure and services required by emitters for a plug-and-play approach. Therefore, initiatives to scale-up the ecosystem, such as a CO2 market-place, also need to focus on modular (and at times temporary) transport solutions such as inland shipping. New business models in the onshore CCS value chain, in the form of specialised 3rd party players, are required to support aggregation from multiple emitters, and the subsequent CO2 transportation and transformation solutions (e.g., liquefaction or purification).

Due to high costs and uncertainty, project developers in the offshore part of the value chain are constantly on the look-out for additional optimisation opportunities. Regulatory flexibility is required for CO2 utilisation and cross-border movement, especially in the initial years. O&G CCS players need an option to exit developed projects to derisk their portfolio.

More information

www.deloitte.com

Hafslund Celsio 10-year carbon removal agreement with Microsoft

Microsoft bought 1.1 million tonnes of permanent carbon removals over a 10-year period, a significant contribution to the commercial success of the full-scale CCS project on a waste-to-energy plant in Oslo.

Future carbon capture and waste incineration plants at the Klemetsrud plant in Oslo

As part of the Norwegian Longship project, Hafslund Celsio is adding carbon capture to Norway's largest waste-to-energy plant, making it one of the world's first carbon capture projects in the waste management industry and part of a full value chain from capture to permanent storage. The plant will commence capturing CO2 from 2029 and the captured CO2 will be permanently stored by Northern Lights beneath the seabed on the Norwegian continental shelf.

"The agreement with Microsoft is a significant contribution to the commercial success of Hafslund Celsio's carbon capture and storage project. Microsoft's purchase is a strong recognition of our CCS project and highlights the crucial role of the waste-to-energy sector as a credible provider of permanent carbon removals," said Martin S. Lundby, CEO, Hafslund Celsio.

Waste-to-energy with carbon capture and storage is a three in one solution for handling pre-sorted residual waste with no alternative use: it solves society's challenge of non-recyclable waste, provides carbon-free energy through use of the excess heat, and removes CO2 from the atmosphere by capturing and permanently storing biogenic CO2.

"This contract marks an important milestone for waste-to-energy and demonstrates the carbon removal potential in this industry, which will help new projects establish a pathway towards a sound business case. Our CCS project will contribute to Microsoft meeting its carbon negativity goal while also supporting national Norwegian commitments under the Paris Agreement," said Jannicke Gerner Bjerkås, Director CCS and Carbon Markets, Hafslund Celsio.

Hafslund Celsio is Norway's largest waste-to-energy and district heating company. The company is currently building a carbon capture facility at its waste-to-energy plant at Klemetsrud in Oslo. Operationally from 2029, the facility will capture about 350,000 tonnes of CO2 annually. equivalent to the annual emissions of 200,000 cars. About half of this CO2 will come from biogenic sources like unsorted food waste, with the remainder coming from fossil origin sources like non-recyclable plastic. Only the biogenic portion, as measured using a well-established radiocarbon analysis, will create carbon dioxide removals, while the fossil portion will reduce the City of Oslo's annual emissions by 20 percent.

The carbon capture project is made possible through a public-private partnership between the Norwegian government, the City of Oslo and Hafslund Celsio. As part of Norway's state-supported demonstration project, Longship, the project will contribute to establish a full value chain for the capture, transport and permanent storage of CO2 in geological formations below the seabed in the North Sea. The value chain has already been expanded with commercial agreements with large emission points in Northern Europe.

The ambition of the project is to create a model that can serve as a roadmap for the 500 other waste-to-energy plants in Europe.

Key Facts:

On October 23, the City of Oslo approved the city's financial commitment to the Hafslund Celsio CCS project.

On December 18, 2024, the Norwegian Parliament approved the government's proposal for a state support agreement.

On January 24, 2025, Hafslund Celsio's Board of Directors made the final investment decision to establish a carbon capture project at the waste-to-energy plant at Klemetsrud in Oslo.

On January 27, 2025, the company signed an agreement with Aker Solutions AS and SLB Capturi Norway AS in a joint venture to implement the project.

The facility will be operational by the third quarter of 2029.

On April 1, 2025, Hafslund Celsio entered an agreement with Frontier for removal of 100,000 tonnes of CO2 in 2029 and 2030.

More information

www.hafslund.no

EMEA news

EUR 400m Olympos cement CO2 capture project launched by Holcim in Greece

www.holcim.com

Holcim has broken ground at the OLYMPUS project at its plant in Milaki, Greece, which is designed to produce 2 million tons of near-zero cement per annum from 2029.

Holcim is partnering with Air Liquide on the project with EUR 125 million in support from the Innovation Fund, financed by revenues from the EU Emissions Trading System. The plant's groundbreaking was held in the presence of Kyriakos Mitsotakis, Prime Minister of Greece.

The Prime Minister said, "This is a project of strategic importance, a project made possible thanks to the combination of private funding from the parent company — and we thank you for the trust you place in our country — as well as significant European funding. And surely, this investment did not receive the name of the legendary OLYMPUS by chance. We are talking about an investment of nearly EUR 400 million, of which EUR 125 million are European funds. But, of course, I would say that the most important aspect is the creation of well-paid jobs: more than 1,000 new positions during the construction phase alone, and an additional 100 jobs during the operational phase. I would say this is the social footprint left by the advancement of industry in our country."

OLYMPUS will deploy a combination of OxyCalciner and Cryocap™ FG technologies as a novel cost-efficient innovation for carbon capture. At the regional level, it is expected that OLYMPUS will create more than 1,000 direct and indirect jobs, contributing to the overall economic development of the surrounding area in Evia.

Miljan Gutovic, CEO Holcim Group, said, "Holcim is on course to make near-zero cement and concrete a reality at scale this decade, as the leading partner for sustainable construction. The OLYMPUS project in Greece is one of our seven large-scale, European Union-supported carbon capture, utilization and storage projects that are setting the Clean Industrial Deal in motion. Together, these will enable Holcim to offer over 8 million tons of near-zero cement each year across Europe by 2030."

Nordic Carbon Removal Association launched

https://nordiccarbon.org

The NCRA, a new trade association leveraging Nordic climate leadership to create a thriving carbon removal industry, has launched and published its first report.

The Nordic Carbon Removal Association, in partnership with Implement Consulting Group, unveils the first region-wide blueprint showing how Denmark, Finland, Iceland, Norway, and Sweden can move "from talk to tonnes" and scale permanent carbon dioxide removal (CDR) fast enough to matter.

The report finds the Nordics could remove 85–160 MtCO2 each year by 2050, covering up to 60 % of Europe's expected need and creating upwards of €9–17 billion in annual GDP and 148,000 jobs — about 1% of regional GDP — if governments act now to close policy and infrastructure gaps.

Yet today, fragmented regulation, underdeveloped CO2 transport links, and weak demand signals keep most projects on the drawing board.

NCRA calls on Nordic leaders to combine their natural endowments — including abundant renewable power, world-class geology, and bio-industrial clusters — into a single, coordinated CDR strategy that can serve as a model for Europe.

NCRA recommendations for Nordic & EU policymakers:

• Set explicit, separate targets for permanent removals alongside emission-reduction goals to give investors clarity.

• Draft a joint Nordic CDR strategy that pools each country's comparative advantages, sets shared milestones and budgets, and considers empowering a single coordination body to steer cross-border projects.

• Create predictable demand through the inclusion of CDR in the EU ETS or a joint Nordic compliance market, backed by a mix of support mechanisms, such as early-stage reverse-auction subsidies and contracts-for-difference.

• Build a shared CO2 backbone—pipeline corridors, port hubs, and matched capture-to-storage build-out—so each country can efficiently specialise its ecosystem.

• Unlock finance and innovation through key institutions such as the Nordic Investment Bank, the EU Innovation Fund, and targeted R&D grants for emerging methods, including ERW and ocean-based removals.

• Leverage voluntary markets and Article 6 to crowd-in corporate offtake while guarding integrity and transparency.

• Speak with one coordinated Nordic voice to proactively shape EU and international policy items, such as CRCF, EU ETS, marine frameworks, or Article 6, to reflect Nordic realities.

• Earn public trust through transparent risk communication and community engagement around storage and novel methods.

Norne and Port of Aalborg launch construction of CO2 hub

www.norneccs.com
https://portofaalborg.dk

Backed by an EU Connecting Europe Facility Grant and a 30 year exclusive lease agreement, the project will deliver world-scale CO2 reception infrastructure and unlock economies of scale for Denmark and the European Union.

A new 500-metre quay in the Port of Aalborg, corresponding to an area of 60,000 square metres of quay space will host the CO2 reception and connecting infrastructure, advancing Denmark's carbon capture and storage ecosystem.

Norne will provide European emitters access to an excellent deepwater port and cost-effective and safe onshore and nearshore CO2 storage. Norne's Project of Common Interest (PCI) status ensures prioritised permitting, as the project is recognized as an urgent project of the highest national significance and it is considered a project of overriding public interest by the EU when carrying out the relevant environmental assessments. The PCI status also opens the door for additional CEF Energy grants, which Norne is actively pursuing to support further development across the CO2 value chain.

How Oil and Gas operators can deploy CCS with scale and speed

CCS offers a viable path for the oil and gas industry to decarbonize operations while maintaining energy security. With 2030 climate targets looming, the time for deliberation is at an end, and deployments must accelerate. However, deploying and scaling CCS projects presents a complex set of challenges for oil and gas operators. By Stefano Villa and Kathleen Rebello, Rockwell Automation.

Challenges include financial concerns about high capital investment, especially as fluctuating carbon pricing makes returns uncertain. There are also regulatory complexities to navigate, including lengthy permitting processes. And many technical hurdles remain, such as low capture efficiency, retrofitting difficulties and the need for long-term monitoring to maintain storage integrity.

These challenges demand a coordinated approach that uses the latest technologies to implement CCS at scale in a way that's compliant, sustainable, and optimized both operationally and financially.

A standardized automation and digitalization platform can empower confident investment decisions

A technology-driven CCS accelerator

Much of the same advanced automation and digitalization technology that's already used to optimize oil and gas operations can also enhance the scalability and efficiency of CCS initiatives in the industry.

By integrating various data-based solutions, oil and gas operators can more effectively monitor and control CCS and operational processes. Additionally, technologies like modern distributed control systems (DCS) that are based on industry standards and designed for scalability can be rightsized to any CCS project and simplify integration with other technologies.

All this can help oil and gas companies conquer CCS challenges to optimize operations at scale while reducing risk and overhead costs.

As part of the CO2 capture process, for instance, a lot of engineering can be required to help operators understand operating conditions and mitigate risks. One of those risks is the formation of solids that can result in pressure losses and create corrosive environments that can affect equipment integrity.

Dynamic process simulation can help engineering teams understand operational conditions with an accurate representation of CO2 equilibrium over different phases and CO2 changes caused by impurities. This can help them design a CCS solution that operates at optimal efficiency and within safety constraints.

More complexity arises when CO2 is being stored. A typical arrangement for conditioning CO2 for storage consists of a three-part process: low-compression pressure, dehydration and high-pressure compression. Precisely controlling this process is essential to meeting specific conditions at the point where the CO2 is injected into a reservoir.

However, operators can have limited visibility into what's happening inside the process, which can impact their decision making. For example, uncertainty about CO2's water holding point sometimes results in operators over dehydrating CO2.

Here, real-time process simulation and autonomous control can provide the needed visibility and optimize the process in real time. For instance, simulation technology can identify the liquid holding capacity of the CO2 during the conditioning process and how much it needs to be hydrated. It can then adjust the control strategy in real time to not only optimize the hydration process but also minimize emissions.

Finally in the storage stage, protecting the reservoir's integrity is crucial whether the CO2 is being permanently stored or reinjected for enhanced oil recovery. Understanding the interactions between the CO2 and the reservoir can help reduce damage to the reservoir and in particular its cap rock, or seal.

Using readily available, data-driven tools can help oil and gas operators manage reservoir integrity and avoid containment losses at this stage. The tool can track key performance indicators that are central to reservoir integrity. These include:

• The pressure range appropriate for injecting CO2 without compromising reservoir integrity and generating damage.

• CO2 movement or oil displacement in the reservoir.

• Containment and seal efficiency during injection and post-injection.

This can help oil and gas operators maintain operational integrity and compliance as part of the storage process.

Scale through standardization

A key need for all CCS projects is being able to scale them effectively to maximize their efficiency and repeatability while minimizing costs.

By using standardized and modular technologies for their CCS projects, oil and gas operators can embrace a "design one, build many" strategy. When technologies are standardized, process are standardized and simplified as well. This helps streamline implementation and reduce costs for CCS projects.

Another benefit of this strategy is it equips operators with a unified digitalization platform that they can use across several sites. This further reduces costs and creates consistency across operations.

A single digitalization strategy can also serve as a catalyst for digital acceleration of current and future business models. For instance, it could enable oil and gas operators to embrace the likely shift towards service-based models for CCS, such as CCS-as-a-service offerings that could someday become normal practice in the energy sector.

Bringing it all together

CCS isn't just a technological solution; it's a strategic imperative as oil and gas producers race toward net-zero. But for CCS projects to be successful, oil and gas operators must be able to create a solid business case to justify the effort and investment required to transform the way they do business.

By using advanced automation and digitalization, oil and gas operators can make a business case for CCS built around a data-driven approach that empowers confident investment decisions from CO2 capture to storage.

About the Authors

Stefano Villa is a strategic account manager at Rockwell Automation. Kathleen Rebello is EMEA industry marketing lead, process, at Rockwell Automation.

More information

www.rockwellautomation.com

DNV introduces new service specification for CCUS projects

The industry-first framework addresses critical gaps in carbon capture verification, enabling safer, more bankable projects.

The new service specification (DNV-SE-0696) provides a structured methodology to de-risk CCUS projects across design, construction, and operation—addressing a key industry need as carbon capture scales globally.

With CCS projected to grow from 41 MtCO2/yr today to 1,300 MtCO2/yr in 2050, mitigating 6% of global CO2 emissions according to DNV's Energy Transition Outlook: CCS to 2050 report, standardized verification is critical to ensure safety, regulatory compliance, and investor confidence.

SE 0696 fills this gap by:

• Defining risk-based verification levels (High/Medium/Low) for CCUS subsystems, from CO2 capture to temporary storage.

• Aligning with existing DNV documents (e.g. DNV-SE-0479 for process facilities) while addressing CCUS-specific challenges like material selection and CO2 liquefaction.

• Supporting both onshore and offshore applications, including hybrid projects (e.g., blue hydrogen with CCUS).

• Supporting stakeholder management with defined scopes and DNV statements and certificates.

The new service specification ensures that CCUS projects are developed with rigour, safety, and transparency, supporting industry players as they scale up deployment.

"CCUS is no longer a niche technology - it's a decarbonization imperative," said Lucy Craig Senior Vice President, Growth, Innovation & Digitalization, Energy Systems at DNV. "DNV-SE 0696 gives developers a clear roadmap to verify facility integrity, reducing uncertainties that could delay Final Investment Decisions. This is how we accelerate the energy transition pragmatically."

Up to the end of the decade, cumulative investments in CCS are expected to reach USD 80 billion (£60bn) and DNV forecasts that capture and storage capacity is expected to quadruple by 2030. CCS is crucial for reaching net-zero targets, especially in sectors that are challenging to decarbonise.

More information

www.dnv.com

From source to sink – embracing the CCUS learning curve

While carbon capture, utilization and storage is essential to meeting global net-zero targets, progressing projects from concept through Final Investment Decision (FID) can be challenging due to the steep learning curve. By Peter Hunszinger, Director, CCUS Project Delivery, Worley.

First-of-a-kind projects often navigate technical, economic, and operational uncertainties with limited precedent to follow.

But we're learning fast. First-of-a-kind projects may be challenging, but the engineering work carried out to deliver them has highlighted key barriers to deployment and how we can overcome them. The more we apply these lessons, the faster we can standardise approaches, drive down costs, and deliver operational projects.

Alignment across the entire value chain from CO2 source to final storage creates significant opportunities to reduce costs, streamline schedules, and reduce uncertainty. Proactively addressing potential supply chain bottlenecks, design misalignments, and operational gaps early in the process helps projects progress more efficiently and with greater confidence.

Worley have supported over 390 CCUS projects across various industries to date, including VPI's Immingham power plant, which will capture up to 3.8 Mt of carbon per year by 2029

FEED to FID

That's why the Front End Engineering Design (FEED) phase plays such a crucial role. A well-executed FEED makes it easier to secure FID by reducing uncertainties that could slow progress. Technical integration, cost viability, regulatory approvals, and supply chain readiness all need careful consideration before major financial commitments are made.

The focus isn't just on designing a capture system but on ensuring the entire source-to-sink value chain has been assessed and is set up for operational success.

The best projects use FEED to bring every key player into alignment from the start. CCUS depends on multiple parties working together, and if expectations aren't aligned early, integration challenges will eventually surface when they're more expensive to overcome.

On a typical project, you will have distinct groups: the design team, the technology licensor, supply chain, and facility operations and construction. These contributors and stakeholders have their own commercial structures, technical considerations, and regulatory frameworks and if these are not aligned early, integration challenges will inevitably surface.

No one wants to complete FEED and then realise that stakeholders had different expectations. That is why getting everyone on the same page early is essential and ensures that when the time comes to make an investment decision, the project is ready to proceed with no major gaps or uncertainties.

Getting stakeholder alignment

One of the most effective ways to prevent misalignment is to involve facility operations from the start. A capture facility does not operate in isolation, so integrating it smoothly with the power plant, industrial facility, or refinery producing the CO2 is essential.

Engaging operations teams early helps address key questions such as how the capture unit will interface with flue gas streams, how energy will be supplied, and how the system will be maintained, all of which sets the stage for a more efficient and reliable operation.

Operations and construction teams bring valuable insight into process efficiency and layout. A well-designed capture unit should not just work effectively but also be easy to construct, operate and maintain over the long term. If operability and maintenance planning are left too late projects may need costly rework to fix issues.

Technology licensors and supply chain partners also need to be involved early to ensure that key equipment decisions align with procurement timelines. Some early CCUS projects designed highly specific compression and dehydration systems only to find that equipment lead times were too long to meet their needs, which is exactly the type of issue that we must set out to avoid.

This is where experienced project integrators play a critical role, ensuring that technology licensors, supply chain, and execution teams work toward a single, coordinated plan while bridging gaps between design, procurement, and delivery.

Supply chain readiness & equipment commissioning

Logistics, supply chain, and lead times are now some of the defining challenges for CCUS. Certain categories of equipment are already facing supply constraints, which will only intensify as more projects secure FID.

Of course, when considering supply chain risks, availability is just one piece of the puzzle. Transport and logistics also play a key role. For large and complex components with long fabrication and delivery timelines, designing with supply constraints in mind helps keep the project on track. When demand for a component is high, having a plan in place ensures it does not become a bottleneck.

CO_2 compressors, for example, have some of the longest lead times. Planning for this early helps avoid delays, and standardizing specifications rather than relying on bespoke solutions significantly reduces bottlenecks. Incorporating modularity and transport constraints into design decisions makes execution smoother and more efficient.

Another key factor is ensuring that equipment specifications are fit for purpose without being over-engineered. Specifications developed for petrochemical and refining applications may increase costs without improving performance. Using standards developed specifically for CO_2 compression, transport, and injection optimizes cost and efficiency.

Lessons from first-of-a-kind projects

Much has been made of CCUS as a new technology, but there is a gap to close from first-of-a-kind to business-as-usual where the industry moves beyond demonstration and pilot projects to execution at scale. That means standardization, cost reduction, and applying lessons from what has already worked. If every project is treated as a bespoke engineering challenge, it will be difficult to deploy at the necessary speed. Applying first-of-a-kind project learnings is critical.

A major lesson is the importance of water management in CO_2 systems. Water formation, corrosion, and material selection should be well understood before construction begins. If these factors are not accounted for in FEED, projects may run into long-term operational issues that are expensive to overcome.

Energy integration is another opportunity to reduce costs. Some early projects missed opportunities to optimize power use and heat recovery, leading to higher operating costs. There is significant value in designing CCUS facilities that integrate efficiently with host facilities. Waste heat recovery and optimizing compression power requirements can have a significant impact on long-term economics.

Material selection has also been a key learning. Some projects initially applied existing process plant standards for compression and materials, assuming they would work for CO_2. That was not always the case. CO_2 behaves differently from hydrocarbons, and materials must be selected accordingly to prevent unexpected issues during various operating modes.

CCUS projects are global, and sharing the knowledge gained improves deployment. At Worley, we have supported over 390 CCUS projects across various industries to date, including Gorgon LNG, VPI Immingham, and Kasawari CCS. These experiences have reinforced for us how early planning, supply chain alignment, and standardization drives efficiency and reduces risk as we work to accelerate the deployment of CCUS.

We're learning fast to standardise approaches, drive down costs, and deliver operational projects - Peter Hunszinger, Worley

From first-of-a-kind to nth-of-a-kind

The industry now needs to focus on execution at scale, requiring disciplined project delivery, greater standardization, and robust supply chain planning. A well-executed FEED phase is the foundation for success and projects that integrate technology, supply chain, and operations planning early will progress faster, with less risk, and with fewer surprises.

By applying these proven approaches, projects are in the best position to secure funding, accelerate timelines, and achieve successful execution. The lessons learned from first-of-a-kind projects are now paving the way for CCUS to become a scalable solution to achieve net-zero ambitions. Those who implement these insights now will not only reduce risk but also gain a competitive edge as CCUS moves forward with increasing momentum.

More information

www.worley.com/ccus

Honeywell: Q&A on developing UK pipeline infrastructure

Willie Coetzee, Government Relations Director for Sustainable Technology Solutions, Honeywell gives insights into the critical importance of pipeline infrastructure for scaling UK CCS, the role of the private sector and the urgent gaps that need addressing.

Q: With the UK targeting net-zero, how significant is the challenge of scaling carbon capture and storage, and why is pipeline infrastructure central to that effort?

A: Achieving net-zero by 2050 requires the UK to reduce emissions across every part of the economy, including heavy industries that are particularly challenging to decarbonise, such as cement, steel and large-scale hydrogen production. Carbon capture and storage (CCS) is one of the few technologies available today that can significantly reduce emissions at the point of generation. It also plays a vital role in the production of low-carbon hydrogen and delivering the negative emissions needed to offset those that remain in the system.

But capturing carbon is only part of the equation. The UK government has previously announced the intent to capture 20–30 million tonnes of CO2 every year by 2030. To deliver on that ambition, we'll need a transport system capable of moving vast volumes from industrial hubs to offshore storage sites. Pipelines are the most cost-effective, efficient and scalable way to do this safely. They offer significant advantages over road or rail, particularly when it comes to long distances.

At Honeywell, we believe the future of CCS depends on building smart, resilient pipeline networks equipped with real-time monitoring, automation and safety systems. These capabilities will be essential in ensuring that CO2 transport infrastructure is both robust and ready to support the UK's net-zero goals.

Q: How prepared is the UK's current pipeline network to handle CO2 transport at scale, and what are the most urgent gaps to address?

A: The UK benefits from an established pipeline network, but much of it was originally constructed for natural gas. CO2 behaves differently under pressure and temperature, and can be more corrosive, typically requiring different materials, compression systems, and sealing technologies to maintain safe and efficient transport. While some existing infrastructure can be adapted, the wider deployment of CCS will also require investment in new, purpose-built pipelines particularly on land.

Priority should be given to upgrading materials, deploying high-integrity leak detection, and implementing smart monitoring systems to maintain reliability and safety over the long term. For example, we have pressure sensor-based solutions that can be applied within a well to monitor and confirm containment.

CO2 pipelines, such as that proposed for the HyNet Northwest CCS cluster, will be critical to scaling UK CCS infrastructure

At the same time, addressing logistical and regulatory factors such as planning permissions, skilled labour availability and long-term infrastructure ownership models will be important. By aligning technical innovation with coordinated policy development, the UK can accelerate the delivery of the infrastructure required to meet its climate targets.

Q: There's been a lot of talk about regulatory hurdles and financing gaps. In your opinion, what's standing in the way of faster progress on CCUS infrastructure?

A: The biggest challenge lies in uncertainty and risk for investors. While the technology for CCUS is well established, operators are being asked to commit to long-term infrastructure investments with some ambiguity in the practical aspects of the UK's strategy, as well as a financial risk profile that is potentially unattractive if the UK is to scale the technology at speed.

There has been some good progress in policy framework, for example through the development of the Transport and Storage Regulatory Investment Model (TRI), and the various business models, though some practical elements in these standard contracts and delivery mechanisms still need to be refined to fully enable bankability and therefore deployment.

It is encouraging that the UK remains committed to a modern Industrial Strategy that has clean energy industries at its core, enabled through the likes of industrial carbon capture and hydrogen production. It is also promising that there are funding mechanisms to support these technologies, for example through Contracts for Difference (CfD) mechanisms envisioned in the sectoral business models. It remains important that, to build on these frameworks, government and industry work to de-risk investment and make private ventures in this space viable.

From a technology standpoint, automation and real-time data analysis are able to improve operational performance and help reduce the risk of unplanned failure, helping derisk projects, along with the role that policy continues to play in derisking the sector. Developing the sector to fully merchant models as quickly as possible remains imperative to release the full breadth of private sector investors that are waiting and ready to go in this space.

Q: How is the private sector helping to move the needle on CCUS adoption, and what more can industry do?

A: The private sector is already playing an important role in advancing CCUS adoption in the UK – and it has the potential to do more, too. High-impact initiatives like the East Coast Cluster and HyNet are setting benchmarks by integrating CO2 capture from industrial sites with dedicated pipeline and offshore storage infrastructure. These projects demonstrate how industry commitment can translate climate targets into tangible progress, with construction expected to begin in the near term.

Looking ahead, there are opportunities for the sector to drive even greater impact. Strengthening domestic supply chains will help reduce procurement risks and improve project delivery timelines. At the same time, proactive engagement with local communities will be essential in building trust, especially regarding safety and environmental stewardship around pipeline infrastructure.

Technology will also continue to be a powerful enabler. Deploying predictive maintenance tools and real-time monitoring will enhance operational safety, while reinforcing public confidence. When combined, these efforts support a scalable, resilient approach to CCUS that aligns with the UK's clean energy ambition.

Q: Looking ahead, what needs to happen next to enable CCUS as a mainstream pillar of the UK's decarbonisation strategy?

A: To solidify CCUS as a core part of the UK's decarbonisation strategy, it is essential to finalise clear and consistent policies on pricing, funding, and regulation for CO2 transport and storage, as part of the broader policy and business model packages that have been diligently progressed.

Generally speaking, the greater the risk, the higher the cost so it is imperative that the process is opened to the market with innovative approaches to reducing uncertainty and risk, addressing completion and operational risk that could impair bankability of projects. This will provide the long-term confidence needed to unlock further private investment and support timely infrastructure buildout. Streamlining permitting processes and a continued effort to bolster the workforce through training and upskilling will also be key enablers of accelerated deployment.

Public engagement will play an equally vital role as infrastructure scales. Transparency, open dialogue, and robust safety standards are vital to earning public trust, particularly in areas where transport and storage facilities are located. There needs to be continued investment both in ready-now technologies and in emerging tech that will be critical as these initiatives continue to scale.

With the right combination of policy clarity, stakeholder collaboration, and technological innovation, CCUS has the potential to be a true foundational pillar in the UK's net-zero roadmap.

More information

www.honeywell.com

DNV Skylark project to enable safe scaling of CO2 pipelines

DNV is advancing Skylark, a joint industry project to enhance understanding of carbon dioxide pipeline operations ensuring regulators and operators have access to the highest quality information.
www.dnv.com

The three-year initiative was developed in collaboration with the UK Health and Safety Executive Science Division (HSE SD), University of Arkansas, Ricardo's UK National Chemical Emergency Centre, the National Centre for Atmospheric Science (NCAS), and the Department for Energy Security and Net Zero (DESNZ).

Paul Monks, Chief Scientific Advisor for the Department for Energy Security and Net Zero (DESNZ) said, "CCUS will be a critical tool in delivering on our Net Zero commitments, and decarbonisation globally. A robust regulatory framework to ensure the safe deployment of this technology across the world is paramount. Initiatives like Skylark, bringing together the best expertise to test our assumptions and deploy real-world scenarios with first responders will be a vital tool in ensuring the success of this technology and therefore in meeting our climate goals."

Early engagement has been strong, including a well-attended 2024 workshop at DNV's Spadeadam facility, which showcased prototype testing equipment and preliminary dispersion models.

The project aligns with DNV's Energy Transition Outlook 2024 report, which forecasts that CO2 pipelines will need to grow from 9,500 km today to over 200,000 km by 2050 to support industrial decarbonization. Skylark will provide essential safety insights through advanced modeling, real-world testing, and emergency response analysis to enable this expansion.

A key focus is understanding CO2 behaviour during pipeline incidents, including dispersion patterns under different terrain and weather conditions. Large-scale experiments at DNV's Spadeadam Research and Testing Centre will study crater formation and dispersion, while wind tunnel testing at the University of Arkansas will complement field studies. Emergency response protocols will also be tested in real-world scenarios with first responders. These insights will help operators enhance safety measures and regulators strengthen frameworks as CCS deployment accelerates.

Strategies for enhancing the economic viability of carbon capture projects

In this paper, the authors argue that successful project structuring is key to enhancing the economic viability of carbon capture projects. By Louis-Jean Germain, Salekh Kharov.

Do you know that, for carbon capture ('CC') projects, only 20% of announced capacity for 2030 have reached final investment decision as of 2024?

The main difficulty for project developers is ensuring the economic viability of CC projects. The challenge is to control CAPEX and OPEX from the early design phase, or FEED 'Front-End Engineering Design'), through the EPC phase ('Engineering, Procurement and Construction'), and into start-up and operation. If CAPEX and OPEX increase excessively, the project is at risk and may be deemed economically unviable or even cancelled.

These cost increases can be due to factors such as higher-than-expected prices for EPC and construction contractors, multiple design changes during the EPC phase and operation, lower CO2 capture volumes, and higher-than-expected electricity consumption during operation.

Are you aware that the primary threat to the economic viability of CC projects is the uncertainty caused by technology risk?

Excluding CO2 storage and distribution, Carbon capture projects, within its own battery limits, still need to overcome major technical challenges particularly when scaling up or dealing with complex applications like capturing carbon from cement factories or other hard-to-abate processes. Currently, only pilot plants and few plants are operational, and most of technology remains untested large-scale with no performance track record. All the current CC projects are first-of-a kind in term design and construction.

Most of the companies interested in implementing carbon capture are industrial focusing primarily on their own plants, to address environmental challenges and policies. These major companies are not structured to drive project developments independently and remain dependent on technology providers and contractors.

Through a paper published over two issues of the journal (the present issue and the Mar/Apr issue), the Authors argue that successful project structuring is key to enhancing the economic viability of CC projects.

Successful project structuring considers: (1) early involvement of the contractors, licensors and vendors to uplift risks mitigation and strengthen project cost estimate, and (2) a contracting structure allowing allocation of risk to the entities best placed to manage them, maximizing the chances of success.

The authors will outline solutions to implement successful project structures to mitigate the technology risk. The aim is enhancing the economic viability of CC Projects. While the first part of the paper addressed project development strategy (published in the previous issue of the Journal), the Author will present three contractual project structures in this second part of the paper.

2. Contractual project structures

The second part of this paper proposes three schemes for contractual project structures. The purpose is to mitigate the technology risk inherent to carbon capture projects by proposing efficient allocation of risk between developer, EPC contractor, licensor and vendors. The three schemes combine with the project development strategy addressed in the first part of the paper.

The core principle is that each party in a contracting chain must bear risk that it is able to assume or mitigate.[i] This is essential for project success. Assuming or mitigating risk is understood as the capability of a party in term of competence and finance to respond to risk. The difficulty with carbon capture projects is the risk associated with unconfirmed process at large scale and constant technology evolution. In this uncertain context, parties may fail to assume or mitigate the risk assign to them.

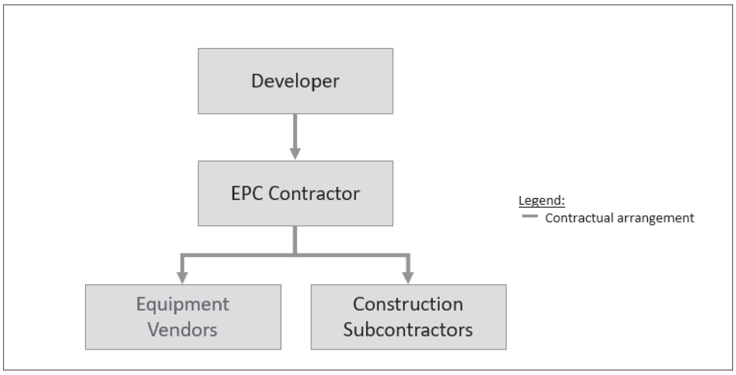
The solutions proposed comprise three contractual project structures. It should be remembered that each structure must be tailored to the specifics of each project.

Scheme 1: classical EPC scheme with adjustment to limit risk

The first project structure scheme is a classical EPC scheme, where the developer contracts the EPC of the plant to a single contractor. The EPC contractor then purchases equipment and materials to vendors and construction trades to subcontractors (e.g. civil, piping, mechanical, electrical…).

Difficulties

This scheme considers a transfer of risk from the developer to the contractor, under contractual guarantees, notably for (1) defective works and cost of repairs (equipment, includ-



Classical EPC scheme (scheme 1)

i Principle 1 from Germain L-J., 6 Principles for Project Success, (2024) ing the pressure vessel, heat exchangers, pumps, packages, and material such as valves…), and (2) performance of the production of carbon dioxide. This transfer of risk is usually a blocking point for the signature of EPC contract as it either represents an unbearable level of risk for EPC contractors (excessive financial exposure for the contractor caused by unknown risks) or the contractor includes exhaustive contingencies in its bid to cover the likelihood and severity of technology risk, which in tern surges drastically the CAPEX of the project.

Proposed adjustments

The following suggestions aims to improve this scheme by balancing the risk more fairly between the developer and contractor:

• Performance: Adjusting of performance standard of the design from a "fit for purpose" obligation to a "reasonable skills and care". It means that the responsibility of the contractor would be limited to employing competent designer and diligently developing the design until completion.

• Unforeseeable risk: Risk that could not have been identified and anticipated by a competent contractor should be excluded from contractor's responsibilities.

• Limit of liability: Clause limiting the maximum financial responsibility of the contractor under the contract to a fair level.

• Contingency plan: The developers must evaluate and consider robust contingencies, for time and costs, to cover response to the technology risk (repairs of defect, replacement, delays). The contingencies must be released to the contractor to support the execution and response to risk during the execution.

• Guarantee from vendor: Guarantee from vendors of critical equipment, including replacement, and training of operators for maintenance, purchase of spare parts…

• Guarantee from licensor: Investigate possible guarantee of performance from the licensor that possess more knowledge and control over the technology…

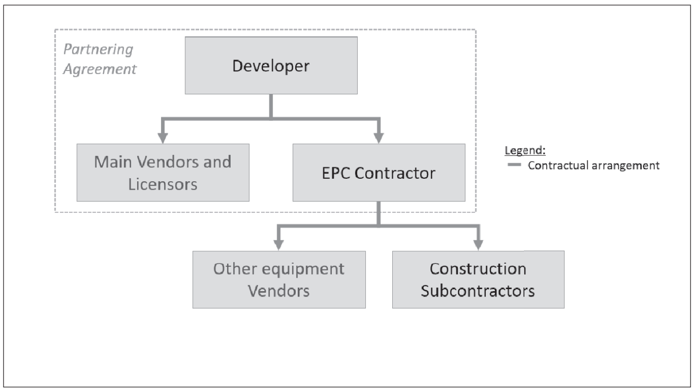
Comments

This scheme offers the advantage of being relatively easy to set up using standard contact forms, for example a FIDIC Silver book or IchemE Red book, provided the suggestions described above are considered.

The disadvantages are:

• Difficulty to involve early EPC contractor, because of a necessary bidding stage between FEED and EPC steps for competitiveness.

• Bidding price of the EPC contractors are generally expensive, to cover persisting risk, increasing the CAPEX.



Partnering scheme (scheme 2)

• Adversarial relationships generally arise between the developer and the EPC contractor, leading to conflicts and claims. If those are not properly addressed, they can l result in significant losses for both parties and cause project delays, ultimately affecting the project's revenue.

Scheme 2: Sharing risk by partnering

The second scheme considers shared responsibilities between the developer, EPC contractor, main vendors and licensors under the concept of partnering. The core principle of partnering is to maximise the effectiveness of each participant's resources and competence. A partnering scheme is project-centric, instead of party-centric, with the idea that one plus one makes more than two.

The partnering scheme is a collaborative framework, which comprises the following features:

• Collaboration: Open communication, mutual trust and cooperation between partners.

• Common objectives: Common objectives for the project are defined between partners. The purpose is to eliminate competing interests between partners.

• Governance: Established and structured decision-making, involving all partners.

• Common assessment of risk: Holistic assessment of risk on the overall project, with a shared risk register between partners.

• Common response to risk: Shared contingencies between partners to allow collective response to risk, mutualising resources and competences of partners,

• Pain and gain mechanism: Partners share financial benefits or losses based on the cost of the project development and construction, proportionately to the level of their scope and contract price. For instance, if production starts earlier than planned, the benefits obtained by the developer are shared with the partners proportionally. Similarly, if the CAPEX is lower than anticipated, the savings achieved by the developer are distributed proportionally among the partners.

• Bonus / malus for performance: For designer / technology licensor, consider bonus and malus mechanism for the long-term performance of the plant.

Partnering can either be established under the form of a single multi-party contract. Generally, this multi-party contract is a bespoke joint venture or a consortium agreement. Alternatively, it can be a partnering agreement which supplements the terms of the existing bi-party contracts. Partnering agreement can either be binding or non-binding, bespoke or using contract forms (e.g. NEC suite proposes partnering conditions under the option X12).

Comments

The clear advantage of partnering is an effective share of risk between developers, EPC contractor, main vendors and licensors. The performance of the plant will be the result of the common efforts of the partners. Partnering also supports the strategy to involve early in the project vendors and contractors (see first part of the paper).

It facilitates the reinforcement of the contractor dedicated to FEED with an experienced construction contractor if needed. The bidding price of the EPC contractors tend to be low, as it considers significantly less contingencies than in Scheme 1. The tendering price of the EPC phase (and the CAPEX estimate) can be managed through an open book process to ensure transparency between partners.

As a drawback, it is strongly recommended that the parties involved know each other well before entering into a partnering agreement. Successful partnerships require the exchange of information, sharing of knowledge, and clear communication regarding intentions and goals at the corporate level. Consequently, reaching a partnering agreement may take time. Additionally, robust governance is essential to prevent a lack of leadership. It is imperative to establish a specific project integrated team (or steering committee) with clearly defined roles and responsibilities.

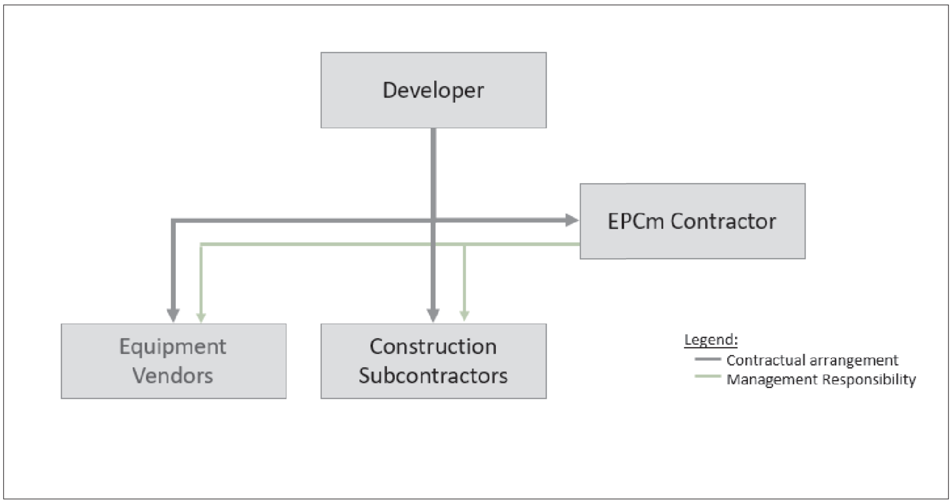
Scheme 3: EPCm contract with detailed management obligations

The third scheme is in-between the Schemes 1 and 2. The contractor is responsible for the engineering, procurement, and construction management ('EPCm') of the project. He does not have direct liabilities on performance of the construction and the plant operation (no performance guarantee) but has the obligation to coordinate the construction. It is generally priced on a cost reimbursable basis with a pain and gain mechanism, where the developer and the EPC contractor share benefits or losses of the project (target cost contract). The developer purchases directly the equipment to vendors and contracts construction trades to subcontractors.

Comments

The advantage versus the Scheme 1 is that it trades the usual unfair risk allocation for a detailed management obligations and a pain-and-gain mechanism designed to motivate the contractor to achieve the project objectives. It also facilitates the strategy of early involvement of vendors and contractors (first part of the paper). It lowers price of bidding of the EPC contractors. The advantage versus the Scheme 2, is that it might be easier to put in place (more common and quicker to agree). The main disadvantage is that the developer's financial liability is greater than for Scheme 1 and 2.

On authors' experience, the difficulty often met with EPCm scheme is the lack of detailed contractual obligations for the management of project and construction (it is usually a simple contract service based on timesheet). It is advised to provide clear and compelling obligations of project and construction management to the EPC contactor. The recent IchemeE Blue book is a satisfactory EPCm contract form.



EPCm scheme (Scheme 3)

Conclusion

This paper, published over two issues of the Journal, has presented innovative solutions to establish robust project structures to mitigate the technology risk associated with carbon capture projects. They aim helping developers to enhance the economic viability of their projects.

The first solution, detailed in the first part of the paper, emphasised early involvement of contractors and vendors, alike commencing the project as an EPC right from the start. Then, in the second part of the paper, three 3 schemes for contractual project structures were introduced to offer efficient allocation of risk between developer, EPC contractor, licensor and vendors.

The first scheme was referred as classical EPC scheme with adjustments to limit the risk of the contractor, the second as partnering scheme, and the third as EPCm with detailed management obligations.

Now, these solutions need to be meticulously evaluated and tailored to the unique specifics of your projects. By doing so, and leveraging our expertise in developing project structuring and supporting the successful execution of projects, you will maximize your chances of enhancing the economic viability of your carbon capture project.

References

Christies D, Saintier S., Viven-Wilksch J., 'Industry-Led Standards, Relational Contracts and Good Faith', Liverpool Law Review (2022) 43:287–310.

Clean Air Task Force, Carbon capture and storage: What can we learn from the project track record, (July 2024).

Germain L-J., 6 Principles for Project Success, (2024).

IEA, 'Carbon Capture Utilization and Storage' < https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage > accessed on 17 December 2024.

Mottau J., 'Licensing emerging process technologies: modern approaches to risk allocation', Allens (2024).

Rosher P., 'Partnering/alliancing - a new way of thinking about construction', I.B.L.J. 2015, 3, 237-247.

More information

Louis-Jean Germain, LLM, Meng, FCIArb, Founder and Managing Partner at Joyan Consulting
linkedin.com/in/louisjeangermain

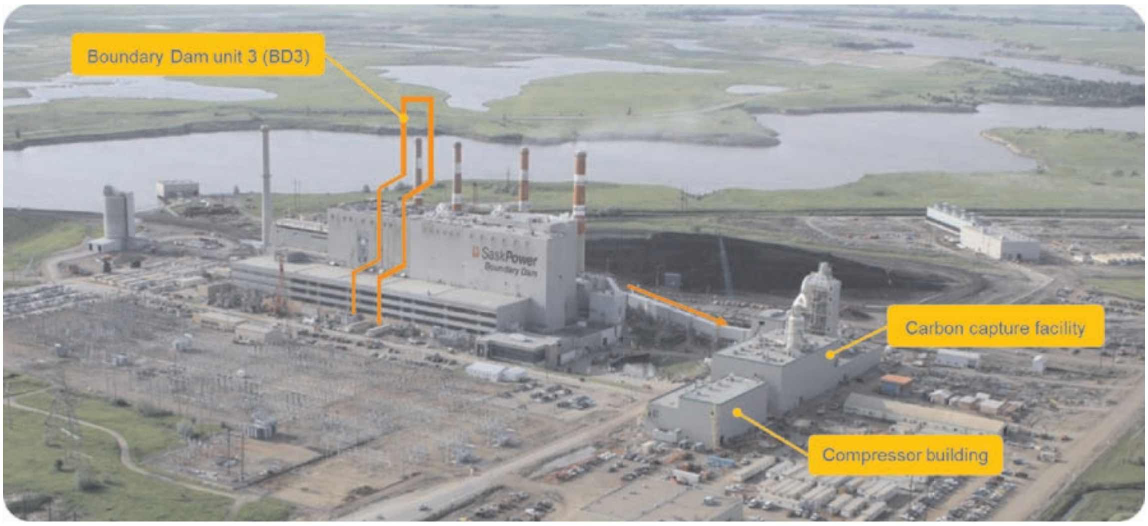
Salek Kharov, Independent Consultant

Lessons learnt from a decade of carbon capture innovation at SaskPower

SaskPower and Shell Catalysts & Technologies reflect on 10 years of carbon capture and storage (CCS) at Boundary Dam Unit 3 (BD3), sharing real-world insights and operational achievements from this pioneering CCS project.

In 2014, SaskPower's BD3 project made history as the world's first commercial-scale deployment of post-combustion carbon capture at a power plant. As a pioneering initiative, it faced challenges that came with breaking new ground – but it also helped prove that CCS does work, even on the most challenging applications.

More than 10 years on, BD3 has captured over 6.8 million tonnes of carbon dioxide (CO_2) and continues to operate with high reliability.



BD3 and the retrofitted carbon capture facility

First mover

With BD3 nearing the end of its useful life, SaskPower made the decision to try something that had never been done before: integrate a 1-mtpa post-combustion CCS unit with a commercial-scale power plant.

Determined to keep the plant running and continue generating electricity for more than 100,000 provincial homes, SaskPower chose CCS. It was a bold but calculated move that positioned the company as a first mover in power-sector CCS.

The scale, complexity and integration with an existing power plant were unprecedented and there was no blueprint to follow.

Despite these challenges, BD3 achieved 10 years of carbon capture in 2024, a milestone celebrated as a testament to the perseverance, innovation and culture of excellence fostered by SaskPower and its carbon capture technology partner, Shell Catalysts & Technologies.

Key learnings

The BD3 project has been described as a "voyage of discovery" by Gregg Milbrandt, VP Asset Strategy and Planning at SaskPower. As a pioneering facility, it encountered a number of early challenges – addressing them helped to shape the plant's long-term success and build the credibility and robustness of CCS in general.

The importance of detailed flue-gas characterisation cannot be overstated. BD3's feedstock mix required a carbon capture facility design with extensive flue-gas cleaning and solvent upkeep, tailored to a very contaminated flue gas. The coal mix used at BD3 includes lignite coal that, when burnt, produces significantly more contaminants than typical coal, including high quantities of fly ash.

Despite a working contaminants removal system (from the gas and solvent), small amounts of impurities present in the fly ash would still foul the CO_2 capture system and degrade the amine quicker than expected. With limited redundancy in the original design, frequent shutdowns were needed for cleaning.

In response, Shell Catalysts & Technologies tailored its CANSOLV* CO_2 Capture System – which included sulphur dioxide (SO_2) pre-cleaning and solvent upkeep systems – to mitigate the impact of the heavily contaminated flue gases (Figure 1).

SaskPower learnt to address this issue from multiple angles, including adding equipment redundancy to enable chemical cleaning while keeping the unit on line and adapting the coal feedstock mix to the BD3 boiler to reduce the ingress of troublesome contaminants.

From that point of view, the collaboration with Shell Catalysts & Technologies was critical to understanding the impact of the different impurities and exploring mitigation options. Indeed, having a qualified, cohesive and

*CANSOLV is a Shell trademark

determined team was equally as important as the technology itself. First-of-a-kind projects inevitably encounter unanticipated challenges, and in such cases, having a committed, collaborative relation can be the difference between success and failure.

"Our partnership with SaskPower has demonstrated how technology licensors and operations teams can work hand-in-hand to deliver results, iterate in real-time and continually improve performance," says Nick Flinn, VP Decarbonisation and Emerging Technology at Shell Catalysts & Technologies.

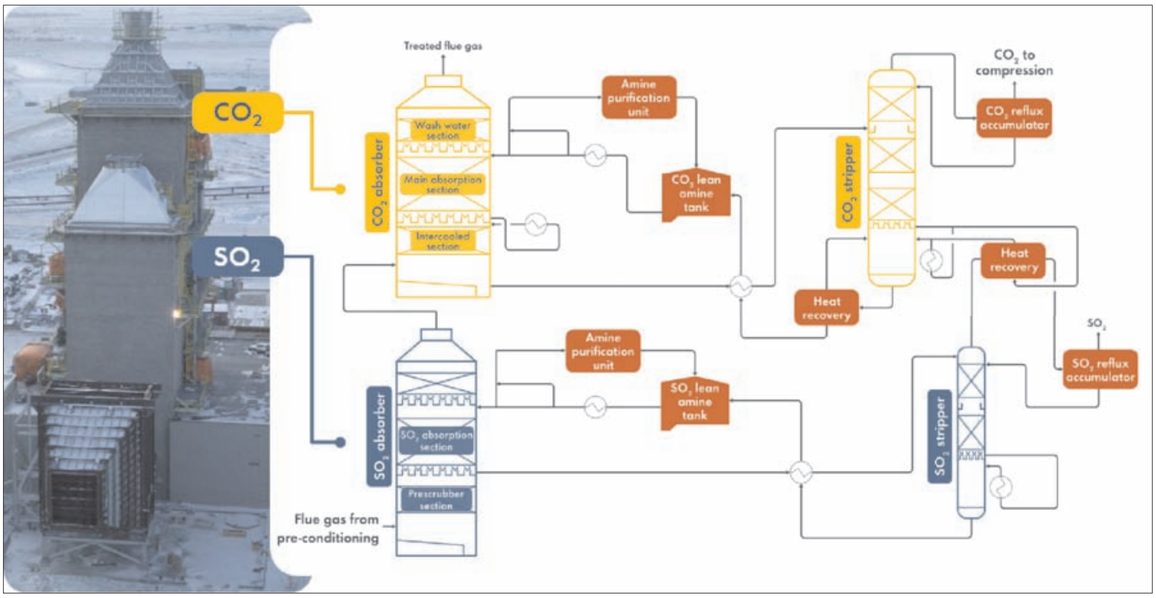


Figure 1 - the CANSOLV-based capture system includes an SO2 pre-cleaning system (smaller concrete absorber), a 44-m high concrete CO2 absorber measuring 10×10 m – one of the largest ever built – and a solvent upkeep system tailored to mitigate the impact of heavily contaminated flue gases

Some of SaskPower's most important learnings also relate to the importance of adapting maintenance and safety procedures when introducing amine-based carbon capture to the power sector. For example, by synchronising maintenance across the power and capture units, SaskPower was able to increase maintenance efficiency and reduce downtime.

Facets of success

The insights gained over the last decade have been instrumental to the project's success. But what does success really look like, and what does it mean for SaskPower and Shell Catalysts & Technologies?

For SaskPower, the definition has evolved. "In the early days, just keeping the system running felt like success," says Gregg. "Then, in November 2015, we hit nameplate capacity for three days straight. This was a turning point and proved the capture system worked."

Early attention focused on nameplate capacity. However, the capture system draws an average of 15% of BD3's electricity output, meaning that SaskPower has needed to choose between using that energy to capture CO2 or sell the electricity to the grid – a considered balance during periods of peak electricity demand.

Today, BD3's capture targets have evolved and focus on capture rates that align with operational and business needs, such as CO2 offtake agreements.

For Shell Catalysts & Technologies, BD3 demonstrates the efficacy and adaptability of its CANSOLV-based carbon capture system at scale, even under extreme conditions. This has helped reduce the perceived risk in post-combustion CCS across sectors and generated key learnings for applications like cement and steel with challenging and contaminated flue gases.

Moreover, the project reinforces the confidence that applications with cleaner flue-gas profiles, such as natural gas, are likely to face fewer technical challenges.

"The project has helped derisk CANSOLV carbon capture technology for even the most challenging large-scale projects, based on operational experience at BD3," says Nick. "The insights gained have enabled Shell Catalysts & Technologies and our Alliance partner, Technip Energies, to develop novel technical and business solutions that offer scalable, tailored and optimised carbon capture solutions."

A springboard for global CCS

When SaskPower took the final investment decision on BD3 in 2011, it was a groundbreaking step, and the company understood that, beyond the project itself, the viability of CCS would be judged on its outcome.

More than 10 years on and the project has helped pave the way for the broader CCS industry. "BD3 proves that post-combustion carbon capture works, not just in theory but in the most technically demanding conditions," says Nick. "After a decade of operations, we're seeing how these early lessons can help scale up CCS across other hard-to-abate sectors, such as natural gas, cement and steel."

Indeed, BD3 has set a precedent and contributed to the development of best practices that others can build on. For organisations pursuing their own carbon capture projects, the experience gained at BD3 helps to reduce perceived risk – making CCS more viable and more investable across a wider range of sectors.

The power sector needed a first adoptee, and SaskPower took that risk, successfully navigating first-of-a-kind challenges to make BD3 CCS a success. Today, SaskPower's Boundary Dam Power Station is the only power facility, and CANSOLV the only post-combustion amine technology, that can speak of a decade of operating experience at scale.

More information

www.shell.com/ct

www.saskpower.com

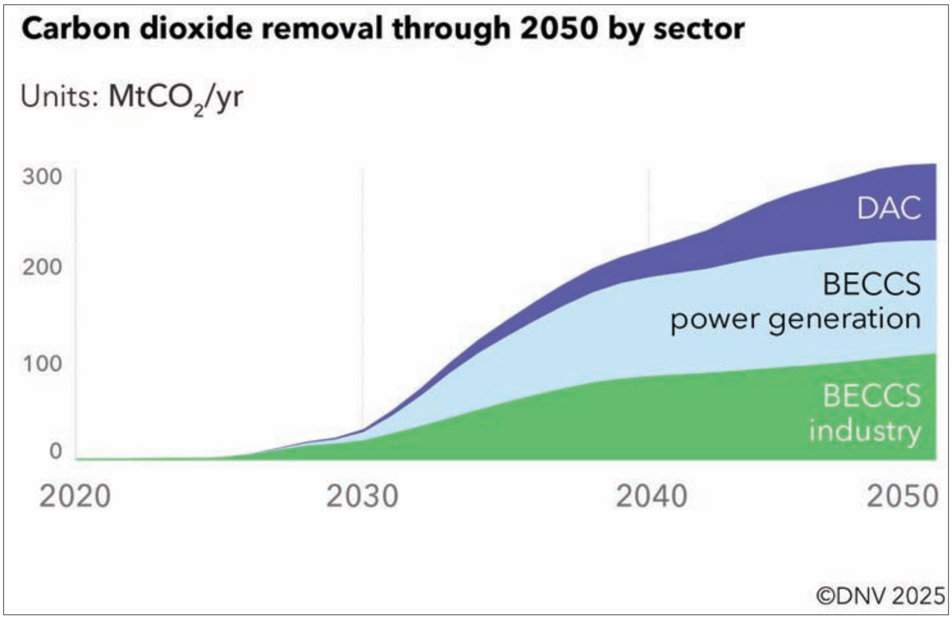
Turning point for CCS is now finds DNV report

Cumulative investment in CCS is expected to reach $80 billion over the next five years and costs will reduce, but capacity still falls short of what's required, according to DNV's new Energy Transition Outlook: CCS to 2050 report. www.dnv.com

DNV forecasts that capture and storage capacity is expected to quadruple by 2030. Up to now, growth has been limited and largely associated with pilot projects but a sharp increase in capacity in the project pipeline indicates that CCS is at a turning point. The immediate rise in capacity is being driven by short-term scale up in North America and Europe, with natural gas processing still the main application for the technology.

In the longer term, CCS is crucial for addressing sectors that are challenging to decarbonise, such as steel and cement production. These hard-to-decarbonise industries are forecast to be the main driver of growth from 2030 onwards, accounting for 41% of annual CO2 captured by mid-century. Maritime onboard capture is expected to scale from the 2040s in parts of the global shipping fleet.

As the technologies mature and scale, the average costs will drop by an average of 40% by 2050 the report finds.



Carbon dioxide removal (CDR) will capture 330 MtCO2 in 2050 — one-quarter of total captured emissions

Ditlev Engel, CEO, Energy Systems at DNV said, "Carbon capture and storage technologies are a necessity for ensuring that CO2 emitted by fossil-fuel combustion is stopped from reaching the atmosphere and for keeping the goals of the Paris Agreement alive. DNV's first Energy Transition Outlook: CCS to 2050 report clearly shows that we are at a turning point in the development of this crucial technology."

"But for all this advancement, the trajectory of CCS deployment remains a long way off where it must be to deliver net zero by 2050. Economic headwinds in recent years have put pressure on this capital-intensive technology and corrective action will need to be taken by government and industry if we are to close the gap between ambition and reality."

CCS will grow from 41 MtCO2/yr captured and stored today to 1,300 MtCO2/yr in 2050, which will be 6% of global emissions. However, CCS will need to scale to six times this level to reach the amount outlined in DNV's Pathway to Net Zero Emissions.

The roll-out of CCS is reliant on policy support and recent political turmoil and shifting budgetary priorities pose a significant risk to future deployment. Europe's strong price incentives will lead it to overtake North America in CCS deployment.

DNV forecasts that carbon dioxide removal (CDR) will capture 330 MtCO2 in 2050 – one-quarter of total captured emissions. Bioenergy with CCS (BECCS) is generally the cheaper CDR option and will be used primarily in renewable biomass for power and manufacturing.

Direct air capture (DAC) costs on the other hand remain high at around USD 350/tCO2 through to 2050, but voluntary and compliance carbon markets still ensure the capture of 32 MtCO2 in 2040 and 84 MtCO2 in 2050.

As the world has been too slow to reduce emissions, CDR will be important to reduce the large carbon budget overshoot. Beyond DNV's forecast period, an enormous amount of CDR, alongside nature-based solutions, will be required to ensure net-negative emissions.

Jamie Burrows, Global Segment Lead CCUS, Energy Systems at DNV said, "CCS is entering a pivotal decade and the scale of ambition and investment must increase dramatically. It remains essential for hard-to-decarbonise sectors like cement, steel, chemicals, and maritime transport. But as DNV's report shows, delays in reducing carbon dioxide emissions will place an even greater burden on carbon dioxide removal technologies. To stay within climate targets, we must accelerate the deployment of all carbon management solutions -from industrial capture to nature-based removal - starting today."

Projects and policy news

Encyclis UK carbon capture pilot goes live

www.encyclis.com

Following installation and commissioning by Kanadevia Inova, the pilot plant at Rookery South Energy Recovery Facility (ERF) in Bedfordshire has now started operations and is capturing around 1 tonne of carbon per day

The pilot plant will be operational for the next 16 months to support the commissioning of the full-scale carbon capture plant which Encyclis is aiming to build at its Protos ERF, in Cheshire. It will enable Encyclis to showcase the technology to key stakeholders and funders who are supporting the project.

The Protos facility was selected as one of the commissioning projects in the industrial decarbonisation programme introduced by the Department for Energy Security and Net Zero (DESNZ).

When delivered, the project is expected to prevent around 370,000 tonnes of CO2 per year from being released into the atmosphere from the treatment of non-recyclable waste at Protos ERF. As part of the Government-backed HyNet North West decarbonisation cluster, CO2 from Protos ERF will be transferred to Liverpool Bay via new pipelines for permanent storage under the seabed.

Owen Michaelson, CEO of Encyclis, said, “Our driving ambition is to deliver on the promise of carbon capture with full, commercial-scale deployment, and the activation of the pilot plant is a significant step towards that. It is a tribute to the expertise of our engineers, and our design, construction and operating partners at Kanadevia Inova, that we have reached this milestone."

The pilot plant will sample ~ 0.1% of flue gases from Rookery South ERF and produce data on process performance before releasing the CO2 back into the facility’s core system.

Encyclis has already launched a financing process to finalise investment in the full-scale facility – confirming the company’s position at the forefront of carbon capture deployment in the UK.

Protos ERF is currently under construction near Ellesmere Port, in Cheshire, North West England. When it becomes operational, the facility will process up to 500,000 tonnes of non-recyclable waste

A one tonne per day pilot will support the commissioning of the full scale Protos facility

Arca's carbon removal methodology successfully validated by DNV

www.arcaclimate.com

This validation marks a significant milestone in the emerging Carbon Dioxide Removal (CDR) industry, as it is the first time a mineralization methodology focusing on enhanced air capture and ex-situ mineralization within ultramafic mine tailings has received such recognition.

Arca's methodology has been validated as compliant with ISO 14064-2, setting a high standard for carbon removal practices at mine sites. This validation serves as an important signal to the mining industry, demonstrating that carbon removal efforts can be unambiguously verified according to ISO standards that carry broad societal legitimacy.

DNV was commissioned by Arca to provide an independent third-party validation of the methodology. The review process included an examination of the presented methodology, project design documentation, and follow-up interviews, which provided DNV with sufficient evidence to determine the fulfillment of the stated criteria. A summary of the methodology can be found on the Arca website.

Lucy Craig, Senior Vice President and Director of Growth, Innovation and Digitalization, Energy Systems at DNV said, “Arca’s validation sets a new benchmark in the Carbon Dioxide Removal industry, proving that innovative methodologies like enhanced air capture and ex-situ mineralization can achieve ISO 14064-2 compliance.”

“To ensure we reduce carbon emissions we need to adopt a variety of methods and this milestone not only underscores the potential for gigatonne-scale CO2 removal but also highlights a major opportunity for the mining industry to contribute to a sustainable future.”

Balfour Beatty wins £833M Net Zero Teesside contract

www.netzeroteesside.co.uk/project/
www.balfourbeatty.com

Technip Energies awarded the contract to act as the construction partner for Net Zero Teesside Power expected to be the world’s first gas-fired power station with carbon capture and storage.

‚Balfour Beatty will work alongside Technip Energies and GE Vernova – with the support of technology partner Shell Catalysts & Technologies – to construct the large-scale combined cycle gas-powered generation plant for Net Zero Teesside Power, a joint venture between bp and Equinor.

In addition, the company will build the post combustion carbon capture system, which is expected to capture up to two million tonnes of CO2 per year, before it is compressed and fed directly into the offshore pipeline to be stored under the North Sea by the Northern Endurance Partnership – a joint venture between bp, Equinor and Total Energies.

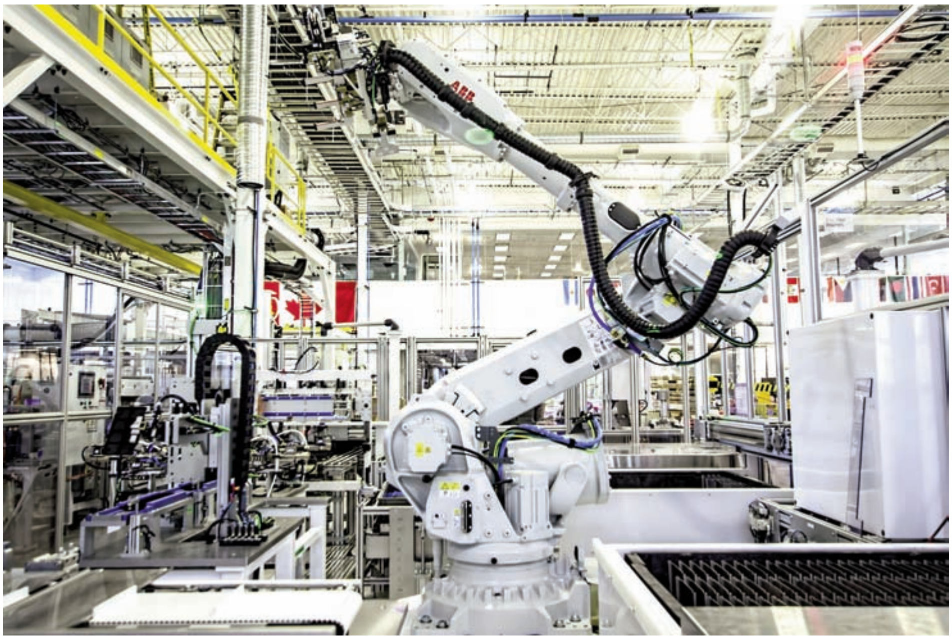
Svante launches 'Gigafactory' for carbon capture & removal filters

Commissioning of its new Centre of Excellence for Carbon Capture and Removal – Redwood manufacturing Facility in Burnaby, British Columbia has been completed.

The world's first gigafactory dedicated to producing commercial-scale carbon capture and removal filters designed to trap CO2 directly from industrial emissions and the atmosphere has opened, with high-volume automation and product standardisation to lower the manufacturing cost.

The Redwood Facility spans 141,000 square feet and is equipped to manufacture enough solid sorbent-based filters to capture up to 10 million tonnes of CO2 annually, equivalent to the emissions of more than 27 million cars. Svante's patented structured sorbent filters, coated with metal-organic framework (MOF), represent a next-generation solution for managing industrial carbon emissions.

"Today, we are making history," said Claude Letourneau, President & CEO of Svante. "This gigafactory is a critical step forward in building the infrastructure necessary to scale up the carbon management industry and to build a marketplace for physical CO2. This first-of-a-kind manufacturing facility is a demonstration of what's possible when technology and climate ambition align to lend nature a hand in managing global CO2 emissions."



At full production, Svante's Redwood 'Gigafactory' will make enough filters each year to capture 10 million tons of CO2, equivalent to the emissions from powering 1.2 million homes

Svante is currently focusing on biogenic carbon dioxide removal (CDR) sectors like pulp and paper, ethanol production, and waste-to-energy, where carbon concentrations in post-combustion flue gas are higher, and capture costs are lower to generate CDR credits.

Capturing the emissions from other industries, such as cement, steel, and fossil fuels, is an essential part of a sustainable energy transition, and the commissioning of Redwood shows that Svante is stepping up to the challenge.

Letourneau added, "We're also proud to launch this transformative manufacturing facility in Canada, which allows us to bring the supply chain to our shores and bring carbon management solutions closer to the needs of emitting industries in North America."

The facility's launch follows a US $145 million capital investment and is supported by a roster of strategic investors, including Chevron New Energies, Temasek, M&G, Canada Growth Fund, United Airlines Ventures, Samsung, GE Vernova, and more.

Svante anticipates the need for additional gigafactories like Redwood in the next decade to keep pace with global carbon management market demand.

Svante's technology is already powering several major carbon capture pilot projects, including installations at Chevron's Kern River asset in the San Joaquin Valley in California. Additionally, its earlier work with Lafarge Holcim on Project CO2MENT continues to demonstrate effective carbon capture at Lafarge's Richmond Cement Plant in British Columbia, Canada. In addition to serving the post-combustion or "point source" carbon capture market, Svante also manufactures filters for the leading direct air capture company, Climeworks, as part of their latest Gen 3 DAC technology, which Climeworks says cuts the cost of regenerative energy in half and doubles the CO2 capture volumetric capacity.

The Redwood model proves that carbon capture doesn't have to be bespoke, expensive, or environmentally risky. Instead, it can be high-volume, reliable, and cost-efficient—more like automotive manufacturing than chemical processing.

More information

www.svanteinc.com

Nuada expands ultra efficient carbon capture to biomass flue gas

Nuada has successfully completed the trial of its second pilot plant, Nuada Scout, at the Energy Innovation Centre (formerly TERC) at the University of Sheffield.

Designed, built and commissioned in under a year, the industrial pilot plant has been capturing carbon dioxide from biomass-derived flue gases at pilot scale, delivering one tonne of CO2 capture per day with high purity and stable performance.

Nuada has developed a solution to capture industrial carbon emissions before they enter the atmosphere, targeting sectors such as cement, lime, and waste-to-energy. Compared to traditional methods, Nuada's technology is more efficient and cost-effective, requiring 90 per cent less energy than conventional approaches.

The system passes industrial emissions through a sponge-like metal-organic framework (MOF) sorbent material, which selectively adsorbs CO2 molecules. A vacuum process is then used to efficiently extract the captured CO2, without the need for large-scale chemical plants or complex infrastructure.

Conventional carbon capture methods rely on energy-intensive processes and require large, capital-heavy installations. Their complexity and infrastructure demands make carbon capture deployment costly and disruptive for industrial emitters/sites.

In contrast, Nuada's approach has the potential to eliminate the need for large chemical processing systems, offering a compact, easy-to-integrate and lower-energy solution suitable for widespread industrial deployment.

The pilot forms part of a project awarded funding via the CCUS Innovation 2.0 programme, as part of the Department for Energy Security and Net Zero's £1 billion Net Zero Innovation Portfolio.

Visitors from the Department for Energy Security and Net Zero, the Carbon Capture and Storage Association, and Nuada's investors recently viewed the pilot plant in operation and heard more about the company's progress.

Nuada co-CEOs Dr Conor Hamill and Dr Jose Casaban in front of the 'Scout' carbon capture pilot at the University of Sheffield Energy Innovation Centre

Key outcomes from the Nuada Scout pilot include:

• Capture of 1 tonne per day of CO2 from energy-from-waste and biomass flue gas

• Stable MOF-VPSA operation demonstrated at pilot scale

• Validation of platform performance across both biomass and cement applications

"With this second successful pilot, Nuada is ready to move from demonstration to commercial-scale deployment. Our low-energy, compact system removes the cost and integration complexity barriers that have long held back industrial carbon capture," said Conor Hamill, co-CEO at Nuada.

"Carbon capture must move from aspiration to implementation. This pilot proves that Nuada's technology is ready to meet that challenge practically, affordably and at scale."

Nuada's MOF-VPSA technology requires up to 90% less energy than conventional carbon capture systems offering a scalable, low-energy, and cost-effective solution that can be installed "end of pipe."

By reducing costs and easing integration, it lowers barriers to CCUS investment, making large-scale industrial decarbonisation more viable and speeding up progress toward net zero.

More information

A video of Nuada Scout in operation is available here:

www.linkedin.com/company/nuadaco2

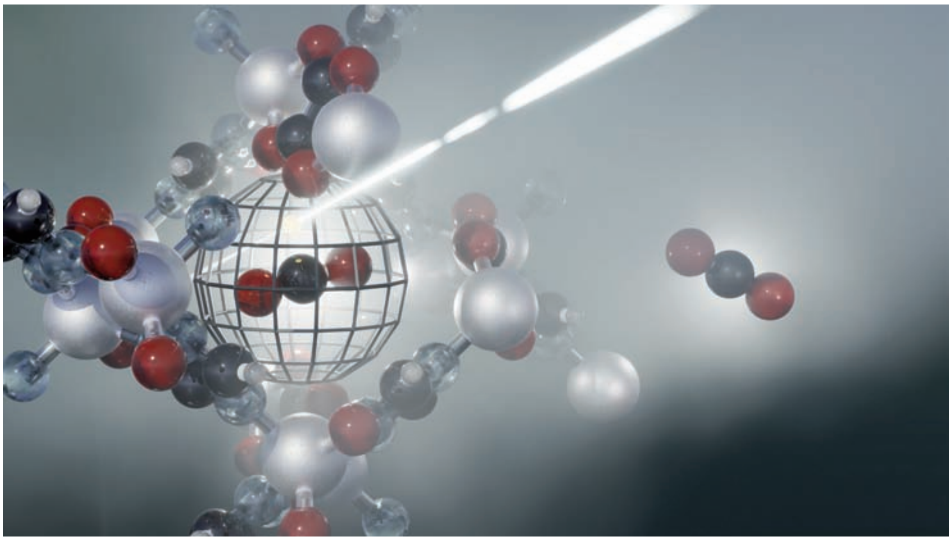
https://nuadaco2.com/technology

Physical probing of a promising material shows exactly how it locks CO2 into place

Research highlights how a Metal Organic Framework (MOF) efficiently captures CO2 while resisting interference from water – a common issue in carbon capture materials.

As industries seek innovative solutions for carbon capture, scientists have turned to advanced materials that efficiently trap and store carbon dioxide from industrial emissions. A recent study of a team from the Helmholtz-Zentrum Dresden-Rossendorf (HZDR), Dresden University of Technology (TUD), and Maria Curie-Sklodowska University in Lublin (Poland) sheds light on the gas adsorption physics of so-called Calgary Framework 20 (CALF-20), a zinc-based metal-organic framework (MOF).

While applying a combination of advanced techniques, the scientists reveal the material's unique adaptability under varying conditions.



Artistic representation of CO2 capture from a moisture-laden gas stream using CALF-20, a zinc-based metal-organic framework. Also shown: The decay of positronium, which is used to probing the void of the MOF. In this process, an electron and a positron annihilate each other to produce characteristic gamma rays which can be detected. Source: B. Schröder/HZDR

CO2 capture technologies rely on materials that can selectively trap the greenhouse gas from gas streams while minimizing energy consumption. Traditional adsorbents, such as activated carbons and zeolites, often suffer from high-energy demands or poor selectivity in humid environments. In contrast, CALF-20 stands out due to its high CO2 uptake and its mild heat of adsorption and regeneration. It maintains a high selectivity by preferentially adsorbing CO2 over water in moderately humid conditions.

CALF-20 captures CO2 more effectively and absorbs less water in such conditions, when compared to other widely studied similar compounds. All those MOFs are highly porous and made of metal-oxygen clusters, which are connected in a structured manner by pillars of organic chemicals. This three-dimensional arrangement leads to networks of cavities reminiscent of the pores of a kitchen sponge

"In this study, we employed a multifaceted approach to investigate CALF-20's CO2 adsorption behavior. Using a combination of positron annihilation lifetime spectroscopy (PALS), in situ powder X-ray diffraction (PXRD), as well as gas adsorption experiments, we were able to visualize the interaction between CO2 molecules and the material's internal structure under different temperatures and humidity levels. These insights provide important information for optimizing CO2 capture technologies in real-world industrial settings", explained Dr. Ahmed Attallah from the Institute of Radiation Physics at HZDR.

The impact of humidity: A key challenge in CO2 capture

In industrial applications, CO2 is rarely captured from dry gas streams – moisture is almost always present. This poses a challenge for many materials, as water molecules often compete with CO2 for adsorption sites, reducing efficiency.

Through in situ humidity-controlled experiments, the team discovered that CALF-20 maintains a robust CO2 adsorption performance even in the presence of water, where the level of relative humidity defines this robustness. At low humidity, water molecules remain isolated within the framework. This network formation alters the material's free volume, but CO2 still finds available adsorption sites, demonstrating CALF-20's resilience under humid conditions. At increasingly higher humidity levels, they form interconnected hydrogen-bonded networks, allowing water uptake to dominate.

By integrating PALS with other characterisation techniques, this study provides a comprehensive understanding of how CALF-20 captures CO2 under diverse environmental conditions. The results suggest that CALF-20 could serve as a scalable and energy-efficient solution for industrial CO2 capture, particularly in settings where humidity poses a challenge. Developed by researchers at the University of Calgary, CALF-20 has already been scaled up to multi-kilogram production, making it a strong candidate for real-world applications

More information

www.helmholtz.de

Mechanochemical approach for low-temperature CO2 conversion

A pioneering approach has been developed at UNIST to convert carbon dioxide into methane at room temperature. Traditionally, this process requires high temperatures above 300°C, making it energy-intensive and costly.

The new method, which involves rotating raw materials with steel balls, was recently published in Nature Nanotechnology, a top journal in nanoscience.

Led by Professor Jong-Beom Baek in the School of Energy and Chemical Engineering and Professor Hankwon Lim of the Graduate School of Carbon Neutrality at UNIST, the research team announced that they have successfully created a mechanochemical process, capable of converting CO2 into CH4 efficiently at just 65°C.

This simpler, low-energy approach could accelerate the shift toward a sustainable, carbon-neutral future.

The process uses a ball mill—a device containing small steel balls of a few millimeters in diameter—filled with catalysts and raw materials. As the mill rotates, collisions and friction activate the catalyst surfaces, enabling CO2 to be captured and react with hydrogen to produce methane.

Remarkably, the team achieved a 99.2% conversion rate of CO2 at this low temperature, with 98.8% of the reacted CO2 turning directly into methane, rather than byproducts.

The process also proved highly effective in continuous operation, maintaining an 81.4% reaction participation rate and 98.8% methane selectivity even at 15°C, below room temperature. This demonstrates its potential for scalable industrial use.

The process uses commercially available zirconium oxide (ZrO2) and nickel catalysts, which are both affordable and widely used in industry. Nickel helps split hydrogen molecules, while zirconium oxide enhances CO2 activation. The mechanical impacts within the ball mill induce oxygen vacancies in zirconium oxide, trapping CO2 molecules and enabling their reaction with hydrogen on the nickel catalyst to produce methane.

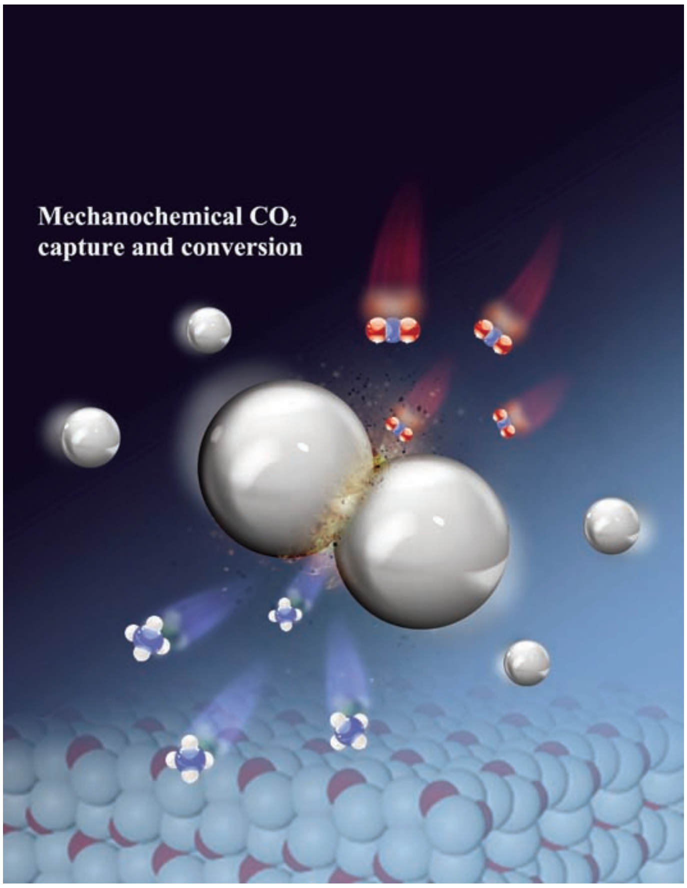
Economic assessments suggest that because the process operates at low temperatures and utilizes readily available catalysts without extensive pre-treatment, it can significantly reduce equipment and operational costs.

Professor Lim explained, "When powered by renewable energy sources, like wind or solar, this method could cut energy consumption in half compared to conventional thermochemical processes."

Professor Baek highlighted the practical significance, "This technology makes it possible to convert CO2 directly into fuel on-site, without the need for high-temperature, high-pressure equipment. It not only reduces carbon emissions but also lowers infrastructure and transportation costs, offering a promising pathway toward carbon neutrality."

This research was conducted in collaboration with Professor Qunxiang Li of the University of Science and Technology of China (USTC), with support from the National Research Foundation (NRF) of Korea and the UNIST Carbon Neutrality Demonstration and Research Center.

The findings have been published in Nature Nanotechnology on June 5, 2025.



Schematic image, illustrating the mechanochemical CO2 capture and conversion

Runnan Guan, Li Sheng, Changqing Li, et al., "Mechanochemical carbon dioxide capture and conversion," Nat. Nanotechnol., (2025).

More information

www.nature.com/articles/s41565-025-01949-6

http://news.unist.ac.kr

Light-activated metal catalyst selectively converts CO2 to industrial chemical

Chemists at the U.S. Department of Energy's (DOE) Brookhaven National Laboratory have designed a new way to convert CO2 into formate (HCO2-), an industrial chemical used as a fuel, as an antibacterial/antifungal agent, and for making pharmaceuticals

The reaction uses a light-activated metal-centered catalyst to facilitate the transfer of electrons and protons needed for the chemical conversion.

"We are taking something cheap and abundant like CO2 and adding electrons and protons to convert it into something useful," said Sai Puneet Desai, the lead author of a paper describing the research just published in the Journal of the American Chemical Society.

In some ways, the process mimics photosynthesis, the series of reactions plants use to convert CO2 and water into sugar, their primary source of fuel. "In both our reaction and photosynthesis, the transfer of protons and electrons is promoted directly or indirectly by light," Desai said.

"You can think of it as storing light energy in the chemical bonds," co-author Andressa Müller added.

Adding ligands adds control

Compared to other attempts to convert CO2 to useful chemicals, the method developed by Desai, Müller, and other members of Brookhaven Lab's Artificial Photosynthesis group has a twist — or rather, an extension.

"Typically, in these types of CO2 conversions, you need to bind CO2 to a metal center on the catalyst," said group leader Javier Concepcion. "That means there are empty spaces for other competing molecules to come in and react with the metal. That can lead to decomposition of the catalyst, and it limits the selectivity over the kind of products you can make."

To control the selectivity and avoid unwanted side reactions, the team surrounded their metal center with ligands.

"The catalyst is like a flower: The metal is the center of the flower and the petals are the ligands," Müller said. "We can tune the properties of the catalyst with these ligands, and all the chemistry takes place at one of the ligands instead of at the metal."

In this new mechanism, all the binding sites on the metal are occupied, so the metal is fully protected from engaging in unwanted side reactions. And by precisely designing the ligands, the scientists can carefully control the product.

"This mechanism is highly selective; only formate is produced," Concepcion said. "Oftentimes, there is competition towards making hydrogen, and/or making carbon monoxide, and sometimes it's difficult to control which of these products you are making. But to make these products, you need open sites at the metal center. In this case, because the mechanism is ligand based, there is no chance for these other products to be generated."

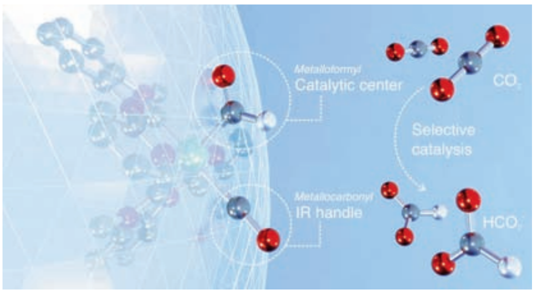
In addition, Müller noted, "Since the chemistry happens on the ligands and not on the metal, this opens the possibility of using other metals at the core of the catalyst."

The current paper reports findings with a ruthenium-centered catalyst. But the scientists have tried a similar approach using inexpensive metals like iron and found that it also works well.

"This paper demonstrates that this ligand-based strategy is generalizable to other metals," Concepcion said. "Our goal is to move toward Earth-abundant metals. It doesn't get more abundant than iron!"

Computation, experiments contribute key insights

The scientists relied heavily on theory and computational chemistry, both in the catalyst design stage and to help them understand their entire reaction mechanism.



A graphic showing how ligands (circled) attached to the metallic (green sphere) center of a catalyst drive the selective conversion of carbon dioxide (CO2) to formate (HCO2-)

"We basically studied the whole mechanism using density functional theory, a computational technique that uses a series of calculations based on electron density to help determine the most likely arrangements and interactions of atoms," added Mehmed Ertem, a principal investigator in the group who specializes in computational chemistry. "The modeling revealed all the steps by which electrons and protons are captured to transform the catalyst into its active form and how the catalyst ultimately delivers these electrons and protons to transform CO2 into formate."

"The mechanism is very straightforward," Desai said. "It starts with a photosensitizer, which absorbs light and acts as a relay for electrons within our catalytic system."

Importantly, once the electrons and protons are delivered to the CO2, all components of the system can revert to their original forms to be used again.

"This recyclability is really important because we want to make this system as efficient as possible and we don't want to introduce waste," Desai said.

More information

www.bnl.gov/chemistry/ap

Capture & utilisation news

MHI starts operation of CO2 capture pilot at KEPCO power plant

www.mhi.com

Mitsubishi Heavy Industries (MHI) has installed a new CO2 capture pilot plant at the Himeji No.2 power plant in Hyogo Prefecture owned by The Kansai Electric Power Co. (KEPCO).

The pilot plant was established to conduct research and development for CO2 capture technologies using flue gas from gas turbines at the power plants. The plant has a capture capacity of approximately five tons per day, and through demonstration of innovative CO2 capture technologies for the next generation, will strengthen the competitiveness of the CCUS business.

MHI has been researching and developing innovative CO2 capture technologies in collaboration with KEPCO since 1990. The operation of this new plant will strengthen that R&D structure, and enable demonstration tests using state-of-the-art equipment.

In 2022, MHI announced an alliance with ExxonMobil, which enables the companies to offer an end-to-end carbon capture and storage solution.The CO2 capture technology currently being developed jointly with ExxonMobil will be demonstrated at this pilot plant, accelerating R&D for reducing environmental loads and costs. MHI will also implement the "ΣSynX Supervision" remote monitoring system, one of its ΣSynX (Sigma Synx) digital innovation brands.

Carbon Clean announces successful factory test of CycloneCC

www.carbonclean.com

Its carbon capture technology has successfully completed an extensive verification programme at Thomas Broadbent and Sons and is now ready for commercial deployment at industrial scale.

Carbon Clean's capture technology uses centrifugal force to enhance CO2 absorption and can capture up to 285 tonnes of CO2 per day. It's modular CycloneCC C1 series, which combines Rotating Packed Beds (RPBs) with the company's proprietary APBS-CDRMax solvent to increase efficiency, is now ready for commercial deployment.

Aniruddha Sharma, Chair and CEO of Carbon Clean, said, "The skills and experience of the teams on the ground, combined with CycloneCC's modular, scalable 'Lego-block' design, have enabled the RPB to exceed acceptance criteria. The CycloneCC C1 RPB is a testament to the UK's outstanding manufacturing capabilities. Producing the first commercial-scale product of this size in the UK is a strong signal that we are ready for large-scale global deployment."

The CycloneCC C1 RPB represents a more than 20-fold RPB scale-up from the first industrial demonstration of CycloneCC, which was designed to capture up to 10 tonnes of CO2 per day

It represents a more than 20-fold RPB scale-up from the first industrial demonstration of CycloneCC, which was designed to capture up to 10 tonnes of CO2 per day.

The CycloneCC C1 series replaces the large columns traditionally used in carbon capture systems with compact, high-efficiency RPBs. Each unit can capture up to 100,000 tonnes of CO2 per year, while reducing equipment height by 70%, cutting steel requirements by 35%, and shrinking the overall footprint by up to 50%. The largest pieces of equipment are also up to 10 times smaller than conventional systems.

Canada Nickel partners with NetCarb to develop carbon capture technology

https://canadanickel.com

https://netcarb.com.au

The new technology has the potential to increase CO2 sequestration capacity of Crawford nickel mineralisation up to approximately 10 times compared to Canada Nickel's proprietary IPT Carbonation.

Canada Nickel has formed a strategic partnership with Australia-based NetCarb to collaborate on the commercialisation of its innovative carbon sequestration technology.

Mark Selby, CEO of Canada Nickel, said, "We are excited by NetCarb's novel technology, which represents the next generation of mineral-based carbon sequestration. While Canada Nickel's proprietary IPT Carbonation process provides a carbon storage capacity facilitating as much as 1.5 million tonnes of annual CO2 storage capacity, the NetCarb process has the potential to increase the CO2 storage capacity of Crawfords tailings by a further magnitude to 10-15 million tonnes of annual carbon storage capacity, representing a magnitude scale leap forward and the third generation of mineral-based carbon sequestration."

Unlike Canada Nickel's IPT Carbonation process, which focuses solely on brucite, the NetCarb technology targets a more complete carbonation of serpentine minerals. This process involves serpentinite activation followed by hydrometallurgical processing of ore through a CO2 activity swing reactor that effectively dissolves and re-precipitates magnesium as solid carbonate minerals for permanent carbon dioxide sequestration.

This technological advance could enhance the carbon sequestration potential of ultramafic mineralisation by more than tenfold. At the Crawford site, this advancement translates to a capacity for sequestering of over 500 million tonnes of carbon dioxide throughout the mine's 40+-year lifespan. Furthermore, with over 20 regional ultramafic exploration properties which host rocks with similar carbon sequestration potential, Timmins could become a multi-gigatonne hub for mineral carbon sequestration.

Why the UK should lead the direct ocean capture revolution

With possibly the world's best natural foundations the UK is uniquely positioned to lead this emerging sector. Captura has already fully demonstrated its DOC technology at a 1000-tonne-per-year pilot facility and is ready to scale. By Steve Oldham, CEO of Captura.

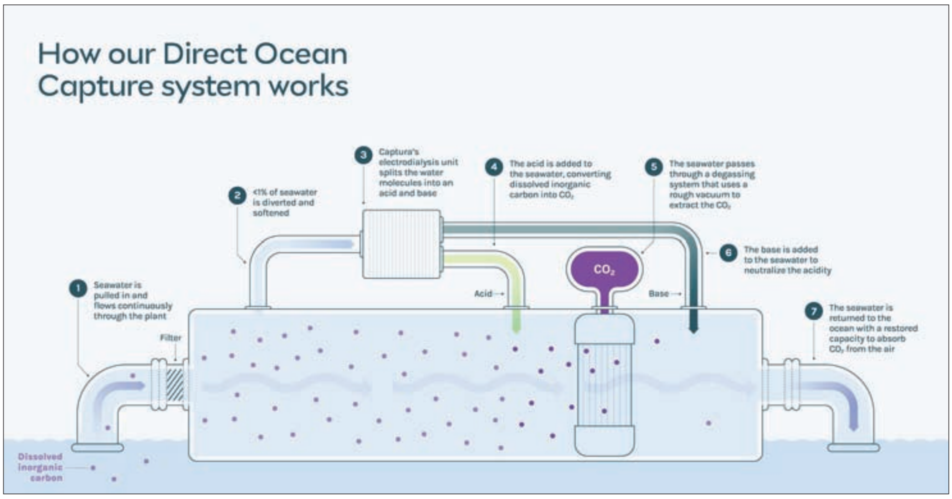
More than 140 countries have set net-zero targets, with the UK among the first to enshrine its commitment into law. Now, as ambition shifts to action, a hard truth is coming into focus: cutting emissions alone won't be enough. Reaching net zero will also require large-scale removal of carbon dioxide that's already in the atmosphere.

Carbon removal is critical for tackling emissions that are too difficult or costly to eliminate at source, such as those from aviation, shipping, and heavy industry. Leading climate assessments agree that carbon dioxide removal must scale to multiple gigatons per year by mid-century to meet Paris Agreement targets.

But for an industry still in its infancy, is this even possible? According to the World Economic Forum, the carbon removal industry must scale by up to 100 times by 2030 to align with net-zero pathways. Other estimates suggest it will need to grow to a level comparable to today's oil and gas sector—an industry that took over a century to build.

A growing number of scientists, academics, and businesses believe the answer lies in leveraging the largest carbon removal device we already have: the ocean. The ocean currently absorbs around 25% of global CO2 emissions—it's huge, natural, and proven. Direct Ocean Capture (DOC) is an emerging technology that amplifies this natural process by removing excess CO2 from the ocean, creating capacity for the ocean to draw more CO2 from the atmosphere.

As global leaders grapple with the scale of the challenge ahead, DOC offers a unique opportunity. It combines the natural scalability and cost advantages of leveraging the ocean, with the measurability and industrial integration benefits of engineered systems. In the UK, this moment is particularly significant. As the country advances CCUS in industrial clusters, including its flagship carbon capture project, there is a timely opportunity to co-locate DOC facilities alongside this infrastructure. Doing so would add a high-integrity carbon removal capability to industrial hubs already aligned with net-zero goals.



When CO2-depleted water is returned to the ocean, it naturally draws in more CO2 from the air to restore the balance

Despite its potential, DOC remains significantly underfunded compared to similar land-based solutions like Direct Air Capture, even though it's equally ready for commercial deployment. The company I lead, Captura, has fully demonstrated our DOC technology at a 1000-tonne-per-year pilot facility and is ready to scale. When it comes to ideal conditions for DOC deployment, the UK is uniquely positioned to lead—if it acts quickly and decisively.

Scaling Nature's Solution

To explain how DOC works, I often use the analogy of a fizzy drink. A soda becomes fizzy when CO_2 is added under pressure. Open the bottle, and the pressure drops causing bubbles to rise, and eventually the drink goes flat. This is a simple demonstration of Henry's Law, a principle of nature that states the amount of gas dissolved in a liquid stays in balance with the pressure of that gas above it. When the pressure decreases, the drink releases CO2 to restore equilibrium.

DOC applies this same principle—just in reverse. By removing CO2 from seawater, the technology reduces the amount of dissolved CO2, disrupting the balance between ocean and atmosphere. When the CO2-depleted water is returned to the ocean, it naturally draws in more CO2 from the air to restore that balance.

This approach is fundamentally different from other ocean-based carbon removal methods. It adds nothing to the ocean—no chemicals, foreign materials, or additional CO2. Instead, DOC removes excess CO2 contributing to ocean acidification and warming, creating space for the ocean to absorb an equivalent amount from the atmosphere. The result is a powerful, nature-aligned solution for removing atmospheric CO2 while protecting ocean health.

What makes DOC particularly compelling is the concentration advantage. CO2 is about 150 times more concentrated volumetrically in seawater than in air, making ocean capture inherently more efficient than air capture. It's not fighting against nature—it's working with it to amplify a process that's already happening.

The Investment Case

The recent drop in global carbon markets—from $1.87 billion in 2023 to $723 million in 2024—reflects growing concerns about the integrity and permanence of existing carbon removal approaches. But these markets are projected to rebound to between $10-40 billion by 2030, creating opportunities for technologies that can deliver credible, measurable carbon removal at scale.

The investment case for DOC is compelling on multiple fronts.

Unlike nature-based solutions, often facing challenges around quantification and permanence, DOC offers a precisely measurable stream of captured CO2 that can be independently verified, both at the point of capture and point of storage. It is fully compatible with a range of safe, durable and regulated storage methods, such as geologic sequestration. This provides the credibility and accountability corporate buyers and compliance markets increasingly demand.

The technology offers a pathway to genuinely climate-relevant scale. Whilst land-based solutions face constraints around land and resource competition, the ocean covers almost three-quarters of our planet's surface and is naturally equipped for massive carbon processing. A modular approach means DOC systems can be scaled from thousands to millions of tonnes of CO2 removal annually.

DOC offers superior economics at scale. It requires no rare earth minerals, fresh water, or significant land use, and its only inputs are seawater and renewable electricity. As a closed-loop system, it produces no waste or by-products requiring disposal, and it doesn't rely on consumable input materials. This operational simplicity translates to lower long-term costs, minimal supply chain risk, and greater scalability.

DOC technology also offers flexible deployment options, both onshore and offshore. It can be integrated with offshore oil and gas infrastructure to transport and store captured CO2, avoiding land use and siting constraints that often limit land-based solutions. Onshore, DOC systems can be co-located with existing facilities already moving seawater, such as desalination plants, power stations, and industrial sites using seawater for cooling. This brownfield deployment approach eliminates the need for dedicated seawater pumping, reducing capital costs.

Unlike many technological approaches, DOC can be configured for highly flexible energy use, taking advantage of off-peak or curtailed renewable energy that would otherwise go unused. In fact, historical analysis from a renewable energy facility suggests a 300-kilotonne Captura DOC plant could source up to 65% of its power from surplus renewable energy, reducing competition with other users and offering a valuable partnership opportunity for clean energy providers.

DOC can also generate multiple revenue streams. The captured CO2 can be permanently stored to deliver carbon credits or utilised in sustainable fuel production, creating multiple value propositions for investors and customers.

Leveraging the UK's Advantage

The UK possesses perhaps the world's best natural foundation for becoming a DOC leader.

Consider the UK's offshore expertise. Decades of North Sea oil and gas operations have created an unparalleled ecosystem of engineering talent, project management capabilities, and offshore infrastructure. The skills required for DOC deployment—managing ocean-based installations, handling high-volume fluid processing, integrating renewable energy systems—are precisely the competencies that already exist within the UK's energy sector.

The infrastructure advantages are equally compelling. The UK has a high concentration of suitable brownfield sites—such as coastal power stations and industrial facilities using seawater—ideal for early DOC co-deployment. It also boasts a world-leading offshore renewables sector capable of supplying clean energy to power DOC operations. Importantly, DOC can seamlessly integrate into the UK's emerging CCUS cluster network, much of which is located on or off the coast, enabling it to tap into the same CO2 transport and sequestration infrastructure. Together, these assets create a uniquely favourable environment for scaling DOC rapidly and efficiently.

Regulatory and policy frameworks also play to UK strengths. The nation's robust environmental standards, established carbon pricing mechanisms, and commitment to transparent climate accounting creates an ideal environment for scaling DOC technologies. The UK's participation in international carbon markets positions it perfectly to capture global demand for high-quality carbon removal credits.

The economic development potential is substantial. Creating a UK DOC hub could generate thousands of skilled jobs, attract international investment, and establish new export industries. As global demand for carbon removal grows, early-mover advantages in DOC could position the UK as the technology provider of choice for coastal nations worldwide.

Seizing the Moment

The convergence of climate urgency, technological maturity, and UK strengths creates a unique window of opportunity. The government's commitment to CCUS demonstrates recognition that industrial-scale carbon management is essential for net-zero. DOC is a natural extension of that vision—bringing the same engineering-led approach to ocean-based carbon removal and leveraging shared infrastructure.

The UK is uniquely positioned to lead this emerging sector. With world-class offshore expertise, abundant renewable energy, and strong regulatory frameworks, the foundations are already in place. What's needed now is the strategic vision to connect these assets, and the investment to scale them.

The ocean has quietly shielded us from climate change for decades. Now it's time we protect it while scaling the solution it offers. The next wave of climate innovation will be blue. The question isn't whether ocean-based carbon removal will scale—but whether the UK will lead or follow. I believe it should lead.

More information

www.capturacorp.com

Wärtsilä launches carbon capture solution to shipping market

According to its tests, the new 'Wärtsilä Carbon capture solution' is proven to reduce vessel CO2 emissions by up to 70 percent, providing ship owners with an immediate solution to meet increasingly stringent environmental regulations.

The ability to capture CO2 from ship exhaust systems will have a major impact on the industry's efforts to reduce GHG emissions, taking into account the International Maritime Organization's (IMO) 2050 reduction target.

Håkan Agnevall, President and CEO of Wärtsilä commented, "CCS is a game-changer for the maritime industry, and we are already seeing huge interest in the market for this solution. Ahead of shipping's net-zero targets, this new technology complements the industry's ongoing efforts to dramatically reduce emissions from vessels and prevent stranded assets."

Wärtsilä also estimates its CCS would have a carbon capture cost of Eur50-Eur70/mtCO2 ($54-$76/mtCO2), inclusive of capital and operating costs

The launch follows the successful installation of the world's first comprehensive, full-scale solution onboard Solvang ASA's Clipper Eris, where the technology captures emissions from all exhaust gas sources. Earlier this year, Wärtsilä installed its CCS technology onboard the 21,000 m3 ethylene carrier for full scale testing and optimisation. The solution, which has been in operation since the Clipper Eris set sail from Singapore in February 2025, will support Solvang ASA's commitment to reducing carbon emissions and promoting sustainable maritime operations.

Solvang's Clipper Eris ship was already equipped with a broad range of Wärtsilä products, including exhaust scrubbers, making it an ideal candidate for the project. Separately, for newbuild vessels currently under construction, Solvang has worked closely with Wärtsilä, and other partners, to ensure these ships are CCS-ready. This includes CCS-ready scrubber systems, as the engines will operate on HFO, as well as necessary space reservation and utility requirements.

"While the shipping sector continues to explore options for lessening its environmental impact, CCS provides a significant shortcut for achieving meaningful sustainability," said Edvin Endresen, CEO of Solvang ASA. "Solvang has been at the forefront of advocating for, and adapting to, new technologies such as CCS for our deep-sea fleet. As one of the more promising solutions for marine decarbonisation, it was important for us to team up with an experienced and trusted partner such as Wärtsilä and we are excited at the potential its CCS offering will bring to our business."

Wärtsilä has been actively developing this technology since 2019 and currently operates a research centre and test facility in Moss, Norway capturing 10 tonnes of CO2 per day from a Wärtsilä marine engine. These tests, which are now supported by the full scale-installation onboard Clipper Eris, have proven that the new CCS has the capability to reduce a vessel's CO2 emissions by up to 70 percent. Wärtsilä also estimates its CCS would have a carbon capture cost of €50-70/mtCO2 ($54-$76/mtCO2), inclusive of capital and operating costs.

"Collaboration has been key here," said Agnevall. "To achieve this significant advance in maritime emissions control it is important to be able to cooperate with like-minded partners such as Solvang ASA. We congratulate them for their vision and support in bringing CCS to their fleet."

Wärtsilä offers different scalable CCS sizes and configurations to suit various vessel types and operator needs, both on newbuildings and retrofits. Wärtsilä's CCS can be applied to the exhaust from any carbon-based fuel – such as HFO, methanol, LNG and MGO – and is designed to work alongside other emission reduction technologies, including SOx scrubbers, NOx reduction systems, and particulate matter filters. As part of Wärtsilä's broader portfolio, CCS can be integrated with other decarbonisation technologies and services.

Wärtsilä said its years of experience in SOx scrubbing and installing technologies that tackle pollutants at the point of exhaust, makes the company uniquely positioned to pioneer maritime applications for CCS, and further unlock decarbonisation benefits for owners and operators.

More information
www.wartsila.com/marine

GCMD demonstrates first end-to-end value chain for onboard captured CO2

The Global Centre for Maritime Decarbonisation has successfully completed the world's first maritime pilot demonstrating the full value chain of onboard captured carbon dioxide in China.

The pilot encompassed two phases. In the first phase, Shanghai Qiyao Environmental Technology Co., Ltd. (SMDERI-QET) conducted a ship-to-ship (STS) transfer of 25.44 metric tons (MT) of captured CO2 from the container vessel MV Ever Top to the receiving vessel Dejin 26. The CO2 was subsequently offloaded from Dejin 26 to a tank truck at a jetty in Zhoushan, Zhejiang Province.

The second phase, led by GCMD, involved transporting the captured CO2 to its end-use destination: a joint venture plant between GreenOre and Baotou Steel in Inner Mongolia. There, the LCO2 was successfully used in the production of low-carbon calcium carbonate, a key component in sustainable construction materials.

This cross-sectoral demonstration highlights how captured CO2 from ships can be repurposed for industrial applications, linking maritime decarbonisation efforts with broader land-based carbon ecosystem.

Professor Lynn Loo, CEO of GCMD, said, "We are proud to leverage our role as a neutral convener to bring together stakeholders from various sectors to address the technical and operational challenges of offloading and utilisation of CO2 captured onboard vessels. This pilot marks a major step in demonstrating how onboard captured CO2 can be integrated into the broader circular economy. With a rigorous life cycle assessment underway, we are quantifying the climate impact across the entire value chain to show how OCCS can serve as a meaningful decarbonisation lever—when applied thoughtfully and transparently."

Significance of the pilot in unlocking the carbon value chain

Advancing maritime decarbonisation at scale requires more than just capturing carbon. It is also essential to address the fate of the captured and offloaded CO2 by establishing a full carbon value chain, including the downstream infrastructure to offload, transport, store and use captured CO2 meaningfully.

Using captured CO2 in concrete production offers one of the higher GHG emissions savings among current utilisation pathways, as it partially displaces the need for carbon-intensive cement production ashore. This finding is based on GCMD's COLOSSUS study, which evaluated life cycle emissions of onboard captured CO2 across various sequestration and utilisation pathways.

As a first-of-its-kind pilot, this project served as a valuable learning experience, helping to uncover real-world challenges that must be addressed to enable the scalable implementation of onboard carbon capture.

A key challenge was the classification of captured CO2. Designated as "hazardous waste" prohibits its reuse and mandates disposal. Through close coordination with the relevant authorities, the captured CO2 in this pilot was redesignated as "hazardous cargo," lifting these restrictions and enabling its use as an industrial feedstock.

For the pilot, GCMD also identified and brought together stakeholders across the value chain—including a like-minded end user willing to evaluate onboard captured CO2 as its feedstock. With its facility located in Inner Mongolia, the captured CO2 was transported over 2,000 km as a first demonstration in its industrial reuse.

The pilot involved close collaboration with multiple stakeholders across the value chain, including vessel owner Evergreen Marine Corp, OCCS provider SMDERI-QET, STS service provider Dejin Shipping, and industrial plant operator GreenOre and its joint venture, Baorong Environmental Co. Ltd. Port authorities and regulators, namely Shanghai Municipal Transportation Commission (SMTC), Shanghai Maritime Safety Administration (SMSA), Shanghai International Port Group (SIPG), Shanghai Customs, and Shanghai Border Inspection also supported the pilot.

Dr. Su Yi, General Manager of SMDERI-QET, said, "As the developer of the world's first complete OCCS process, we are honoured to collaborate with all parties in the successful completion of the world's first ship-to-ship transfer of LCO2. Since the delivery of the first full-process OCCS in early 2024, we have executed two successful ship-to-shore unloading operations and achieved the world's first CII deduction for vessels. From ship-to-shore unloading to ship-to-ship transfer, we are confident that this milestone – coupled with further advancements in OCCS – will not only accelerate the development of a global network for shore-based carbon storage and utilisation facilities, but also advance the decarbonisation of the shipping industry."

GCMD will conduct a comprehensive LCA to quantify GHG emissions for this pilot with CO2 quality and quantity data obtained through sampling activities conducted throughout the pilot. GCMD will work with DNV for third-party verification of emissions reduction claims under recognised accounting frameworks.

Tracy Chen, Senior Vice President of GREENORE, said: "By converting the LCO2 into high-purity, green calcium carbonate, we have helped complete the carbon value chain in this pilot. GREENORE is committed to driving substantial reductions in shipping emissions. In the future, with the launch of GREENORE's coastal mineralisation projects, onboard captured LCO2 can be locally utilised and stored—enabling meaningful emissions abatement and supporting the maritime sector's transition to net-zero."

More information
www.gcformd.org/projects

Transport and storage news

Ecospray launches amine-based carbon capture for marine market

www.ecospray.eu

One of the system's most distinctive advantages is its high energy efficiency: it can reduce energy consumption by up to 50% compared to similar technologies, the company said.

The system is designed for easy integration on existing vessels and will allow the capture of up to 80% of CO_2 emitted during ship operation in specific conditions. An innovative low-temperature regeneration process transforms waste heat from ship engines into a valuable resource.

This approach not only delivers substantial energy savings compared to traditional high-temperature methods, but also simplifies onboard integration and significantly lowers operational costs, said Ecospray.

Over the past 18 months, Ecospray has further refined its solution - already successfully tested onboard in 2023 - through new pilot trials and advanced process modeling. As a result, the system now offers improved performance and a more compact design, making it even more suitable for widespread adoption across the maritime sector.

"We have combined our extensive experience in gas treatment with next-generation chemical capture technologies to offer a concrete, ready-to-go solution," said Maurizio Archetti, President of Ecospray. "Our objective is to make carbon capture not only technically feasible but also economically sustainable for shipowners."

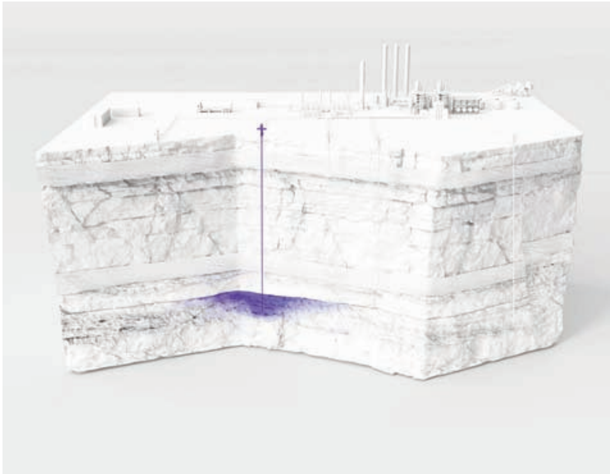
"This technology, now commercially available, is designed to be integrated into a broader decarbonisation strategies and enables existing vessels to significantly reduce their emissions and comply the CO_2 reduction targets set by the IMO. It is also important to underline that, across all decarbonization scenarios, carbon capture remains an essential tool for the next 20 to 30 years to achieve the mandated climate targets."

"For this reason, and to ensure international decarbonization targets are met on time, it is essential that this technology be urgently and fully integrated into regulatory frameworks, enabling large-scale applicability and accelerating its widespread adoption".

SLB launches Sequestri carbon storage solutions

www.slb.com

Sequestri™ is a comprehensive portfolio of technologies and services for accelerating safer and more economic carbon storage projects.



SLB is providing project developers with a full suite of complementary CCS solutions to enable decarbonisation at scale from point of capture to permanent carbon storage

The Sequestri portfolio addresses the unique challenges of long-term carbon storage, providing tailored hardware and digital workflows that improve decision-making across the full carbon storage value chain, from site selection and planning to development, operations and monitoring.

"Advanced technology solutions have a crucial role to play in shifting the economics and safeguarding the integrity of carbon storage projects," said Katherine Rojas, SLB's senior vice president of Industrial Decarbonization. "The Sequestri portfolio offers a comprehensive suite of solutions that provide the precision, reliability and efficiency needed to advance carbon storage projects at every stage of their lifecycle — driving meaningful progress toward industrial decarbonization at scale."

Sequestri includes a network of interconnected digital technologies and services for carbon storage that provide a robust foundation for analysis and prediction. These end-to-end digital technologies harness more than 25 years of CCS project experience to help developers screen, rank, design, model, simulate and analyze every phase of the project lifecycle.

The portfolio also includes a range of technologies which have been specifically engineered and qualified for carbon storage applications, from subsurface safety valves and measurement tools to cementing systems, including SLB's EverCRETE™ CO_2-resistant cement system.

Together with the SLB Capturi standard, modular carbon capture solutions, this provides emitters and project developers with a full suite of complementary CCS solutions to enable decarbonisation at scale from point of capture to permanent carbon storage.

PETRONAS, MISC and MOL form JV to develop LCO2 carriers

www.mol.co.jp
www.petronas.com

Th Jules Nautica JV will lead the development and act as the ultimate owner of Liquefied Carbon Dioxide (LCO2) carriers for transporting CO_2 to designated storage sites.

The three parties have recently completed the Front-End Engineering Design (FEED) for a 62,000 cubic meter LCO2 carrier, which was awarded to Shanghai Merchant Ship Design and Research Institute (SDARI). In December 2024, this jointly developed design received the General Approval for Ship Application (GASA) certification from DNV, establishing it among the most developed Low Pressure Low Temperature LCO2 carrier designs in the industry.

The JV aims to become a leading owner of LCO2 carriers, facilitating the safe and efficient transportation of LCO2 to designated CO_2 storage sites. Focused on supporting future CCS projects across the Asia Pacific region, the JV will also play a key role in completing the CCS value chain.

Through strategic commercial agreements with CO_2-emitting industries and storage companies, this partnership will provide a critical cross-border solution to meet growing environmental and regulatory needs.

Captura: why the UK should lead the direct ocean capture revolution

Image: Captura