Carbon Capture Journal

CCUS in Asia

A roadmap for ASEAN CCS

Deploying Carbon Clean CO2 capture tech in Indian steel

South Korea's green transition hinges on clean power, CCS

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Project Greensand confirms safe CO2 storage in Denmark

- Global Status of CCS 2024 shows significant continued momentum
- Getting big CCS projects moving - report from the CCSA Summit
- We need to apply circular economy principles to accelerate CO2 storage
- Improved technology for MRV at geologic carbon sequestration sites

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Front cover: Project Greensand report confirms Denmark has safe and well-functioning storage for CO2 in the North Sea (pg. 15)

Back cover: The Northern Lights CO2 transport and storage facility has been delivered on time and within budget and is now ready to receive CO2 from Norwegian and European industry (pg. 32)

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Global Status of CCS 2024 shows significant continued momentum

The flagship report from the Global CCS Institute finds strong growth in CCS projects across all stages of development, with a total of 628 projects in the pipeline, an increase of 236 projects compared to the previous year.

The cumulative CO2 capture capacity for all projects is now 416 Mtpa, representing a seven-year CAGR of 32%. Facilities currently in operation have a capacity to capture and store 51 Mtpa of CO2. This figure is on track to double to over 100 Mtpa once facilities currently under construction commence operation.

Regional highlights from the report included:

The Americas continue to lead the world in CCS facility deployment, catalysed by sustained policy support and funding incentives: 27 projects are in operation, and 18 are commencing construction across the US, Brazil and Canada.

Across Asia, storage hubs and cross-border CCS projects are a major focus and dominant trend, as nations with limited geological storage resources explore opportunities with nations that have large storage resources, to store their CO2.

In China, CCUS forges ahead, spurred by climate policy progress, project deployment, and increased international collaboration.

Across Europe and the UK, decarbonisation policies and anticipation of a robust CCS market are driving new projects: 191 projects are at various stages of development in the region, including five in operation and 10 in construction.

Across the Middle East and Africa (MEA), CCS project development has evolved from application in enhanced oil recovery to a focus on industrial decarbonisation and low-carbon fuel development.

As progress continues at pace globally, the business case for CCS is being bolstered with the evolution of new carbon management business models and strong interest in CCS hubs and networks.

The 2024 status report notes 222 transport and storage projects, which currently do not include an associated capture facility. This number has more than doubled over 12 months. This underscores the predominance of new carbon management business models and the anticipated market for these services.

Institute CEO, Mr Jarad Daniels, elaborated further on the role of hubs and networks saying, "Mitigating climate change will require massive infrastructure investments, including new transmission grids for low-carbon electricity generation, as well as pipelines and shipping for both CO2 and low-carbon energy carriers such as hydrogen in various forms. Carbon management hubs and networks can help bring economies of scale to this required new infrastructure."

Against the backdrop of exponential growth in CCS projects, ongoing regional progress and the emergence of new carbon management business models, the 2024 status report calls on all stakeholders to maintain the momentum.

"We are calling on government, industry, communities and all who share our common goal of reaching net-zero as quickly as possible, to work together to continue and improve on our collaborative efforts. Collaboration over decades has taken CCS from early research to where we are today. Although we still face challenges, I am immensely optimistic that these will be overcome by continuing to build and grow key partnerships."

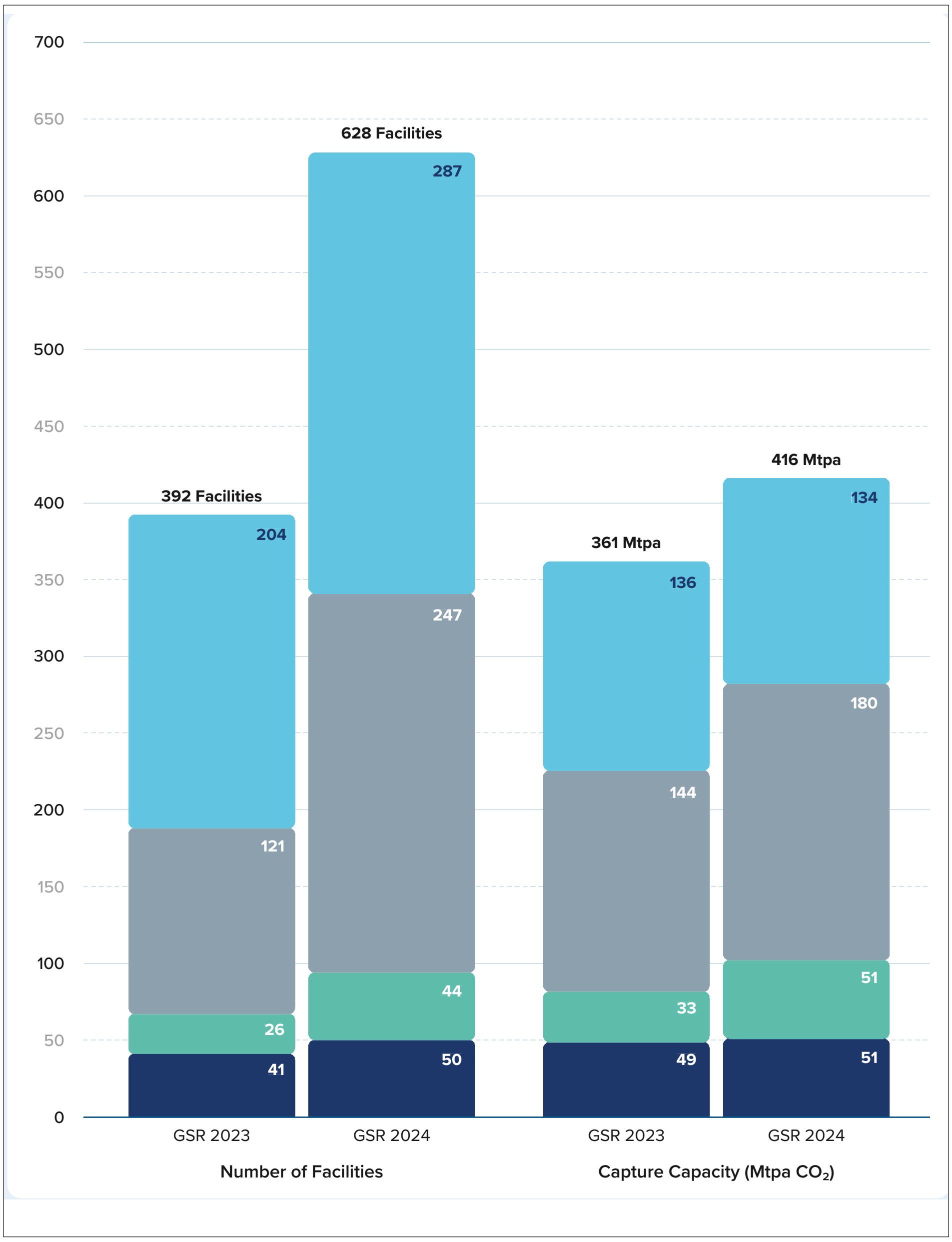
Sectoral trends

A key role for CCS on the road to net zero is its utility in decarbonising hard-to-abate fa-

Key metrics at a glance

- Project development has surged over the past seven years. Operating capture capacity is on track to double as facilities under construction come online. The 2024 CCS project pipeline is at record levels for both facility count and CO_2 capture capacity.
- Collaboration has been crucial. Multilateral government initiatives such as the Clean Energy Ministerial, Mission Innovation and the Carbon Management Challenge and other public-private partnerships are increasing ambition and advancing CCS. Private sector collaboration across industries is accelerating innovation and project development.
- Americas - Federal funding and policy incentives continue to drive investment in CCS in North America, while regulation is being developed in Brazil.
- Europe & UK - European decarbonisation policies are driving the emergence of a robust CCS project pipeline.
- China - CCS is prominent in Chinese climate policy. The Implementation Plan for Green and Low-Carbon Technology Demonstration was launched providing financial support to recognised decarbonisation projects, including CCS. Six of the first 47 selected projects are CCS-related including the world's largest capture plant on a coal-fired power plant currently under construction that will capture 1.5 Mtpa CO_2.
- Asia Pacific (Apac) & India - Hubs and cross-border CCS projects are the dominant CCS trend in Asia.
- Middle East & Africa - The region is increasingly focussing on CCS as part of its decarbonisation strategies.
- Collaboration between governments and the private sector is advancing CCS - Over 50 MOUs or agreements between governments have been executed since 2020 that include CCS within their scope.

cilities including gas processing, chemical, fertiliser, cement, iron and steel. It is essential that these sectors decarbonise, despite the technical and economic challenges. CCS provides the capacity to deliver deep emissions reductions in these industries.



Commercial CCS facilities by number and total capture capacity - from Global Status of CCS 2024

Cement and lime manufacturing

CO2 is unavoidably produced as an inherent byproduct of the process chemistry of cement and lime production. Additionally, significant emissions are produced from fossil fuel combustion in cement and lime kilns, as the process chemistry requires high temperatures. The volumes involved and the unavoidable nature of the CO2 produced make CCS a key technology for cement decarbonisation.

There are presently 30 CCS projects in active development in the cement industry, including one operating facility (Qingzhou Oxy-Fuel Combustion Carbon Capture Project in China) and one under construction (Brevik Cement Plant in Norway). These projects are located across Europe, North America and China and have a combined capture capacity of 29 Mtpa. This demonstrates the strong growth of CCS in the cement sector.

Iron and steel

CCS has two pathways to assist decarbonisation of iron and steel. The first is as a retrofit decarbonisation technology for blast furnaces. Blast furnaces represent a substantial fraction of the world's steel production fleet – particularly in China and India. Steel facilities tend to have long lives and it is unlikely these existing plants will be decommissioned for new technologies – hence post-combustion CO2 capture offers a significant pathway for decarbonisation.

In addition, hydrogen-based ironmaking has been under development. CCS has a pivotal role in the reasonable cost production of hydrogen that could support the operation of these future iron plants. Presently there is one operational capture unit on an iron and steel plant: the Al Reyadah facility operated by ADNOC at EMSTEEL. Six more projects are in development in the iron and steel sector in North America and Asia Pacific.

Direct Air Capture (DAC)

DAC has emerged as an area of intense interest for net zero in recent years. Removing CO2 directly from the atmosphere is a relatively expensive undertaking compared to point-source capture, but early-stage commercial deployments are already growing in scale, helping improve project economics, prove new process concepts, and make the process more competitive.

A dynamic constellation of new technology companies has emerged to develop novel chemical and physical approaches to direct air capture. Three commercial DAC facilities – Climeworks' ORCA and Mammoth plants in Iceland, and Heirloom's DAC California plant – are presently operational, while 16 more facilities are in various stages of development, including two in the construction phase in Oman and the United States.

In the US, two DAC hubs, each with a total capacity of 1 Mtpa, have been selected by the Department of Energy (DOE) for significant financial support from a US$3.5 billion funding pool. Additionally, 29 other DAC hub concepts are also receiving DOE support (under US$10 million each).

DAC projects are showing a wide geographic spread including in Africa, reflecting the location flexibility of DAC technology. DAC tends to be located where low-carbon energy is affordable and geological storage resources are of high quality.

More information

Read the full report at:
www.globalccsinstitute.com

An ASEAN CCS deployment framework and roadmap

A report from the ASEAN Centre for Energy (ACE) aims to assess the current status of CCS in the region and develop a CCS Deployment Roadmap along with policy recommendations, including the establishment of a CCS Working Group to accelerate CCS deployment in the region.

Almost unimaginable amounts of energy are required to fuel the rapid economic growth currently taking place in the Association of Southeast Asia Nations (ASEAN), says the report. Projected to be the fifth largest economy in the world by 2050, ASEAN's total primary energy supply is projected to increase to 1,823 Mtoe by 2050 from 698 Mtoe in 2022.

Fossil fuels have dominated the region's energy mix, accounting for about 82% in 2022. The share of fossil fuels is expected to reach 76% by 2050, even assuming the most aggressive renewable energy and energy efficiency policies and measures. Oil is the largest component, followed by natural gas and coal.

Consequently, ASEAN's energy-related greenhouse gas emissions have been high, amounting to 2,215 million metric tons of CO2 equivalent in 2020, equivalent to 4.3% of the world's total emissions. To date, nine out of ten ASEAN Member States (AMS) have recently updated their Nationally Determined Contributions (NDCs) in adherence to the Paris Agreement. Regionally, ASEAN established its Carbon Neutrality Strategy in 2023, charting strategies to be conducted up to 2050.

However, given that the AMS are mostly developing economies, the balance between energy transition and energy security must be taken into particular consideration. Due to its abundance and affordability, coal has been fundamental in supplying electricity. An abrupt energy transition from fossil fuels to renewable forms of energy could jeopardise the region's energy security, especially given the intermittency issues of renewable energy.

Moreover, ASEAN's coal power plants are relatively young with still many years of economic life ahead. Early retirement of these plants would mean buying out future coal generation based on their contracts with power utility companies that would amount to billions of US dollars. At the same time, governments would need billions of dollars to invest in grid upgrades and battery storage for the variable renewable energy. The heavy industries such as cement, steel and chemical production are extremely energy intensive and hard-to-abate, emitting over 17% of the CO2 emissions.

As energy consumption and CO2 emissions continue to rise, mitigation measures must be applied that do not compromise energy security. This is where carbon capture and storage (CCS) comes in. ASEAN has also acknowledged the crucial role of CCS and has embedded CCS policies into its regional commitment through the 41st ASEAN Ministers on Energy Meeting (AMEM), ASEAN Carbon Neutrality Strategy 2023 and ASEAN Plan of Action for Energy Cooperation (APAEC) Phase II: 2021 – 2025. CCS has been a priority of the ASEAN Chairmanship each year since 2022.

Despite the strong support and significant potential of CCS (particularly in Indonesia, Malaysia, Thailand and Viet Nam), the deployment of CCS in the region is stagnating due to challenges surrounding its economic viability, long lead times, project complexity and innovation gaps.

Therefore, to accelerate the deployment of CCS, the report aims first to assess the current status of three key CCS pillars in ASEAN: (i) policy; (ii) legal and regulatory framework; and (iii) storage. The assessments were based on discussions conducted at the Southeast Asia CCS Accelerator (SEACA) 2023 workshops organised by the Global CCS Institute in collaboration with ACE, desk research, online questionnaires, and closed-door focus group discussions with representatives from all of the AMS. The assessment of the three pillars is the basis of the Framework section of the Report. From the Framework, a CCS Deployment Roadmap is developed, along with policy recommendations.

Under the policy pillar (Chapter 3), it is apparent that the AMS exhibit varying levels of readiness and commitment across the policies enabling CCS deployment. Indonesia and Malaysia (Sarawak) lead in implementing specific legal framework and policies to support CCS projects, which include financial measures such as grants/tax incentives, monetisation and carbon pricing, while Thailand and Viet Nam are still focusing on research and development.

In terms of cost reduction measures, the AMS are employing a mix of grants and tax credits to alleviate the capital-intensive nature of CCS deployment. Indonesia and Malaysia for example, have opted for revenue support through a regulated asset base model to support CCS projects in infrastructure-heavy sectors. The involvement of state-owned enterprises (SOEs) and therefore the regulation of industrial activities are also crucial to reduce the costs of CCS by potentially mitigating the investment risks.

Finally, strategic signalling, the amount of CCS policy integration into national strategies, varies among the AMS, epitomised by the amount of CCS integration into the national strategies. The way forward for the policy pillar involves enhanced policy coordination among stakeholders, as well as increased financial incentives to accelerate the adoption of the CCS technologies.

With regards to the legal and regulatory framework pillar (Chapter 4), Indonesia and Malaysia (Sarawak) are the front runners among the AMS, with the former having established national legal frameworks specifically addressing CCS activities in the upstream oil and gas sector. Examples are the MEMR Regulation No. 2/2023 and Presidential Regulation No. 14/2024. The latter established the 2022 Land Code (Carbon Storage) Rules, which regulate the use of land offshore and onshore for the development of carbon storage sites.

In both countries, the regulation extends to outlining the ownership of CO2 and ownership responsibilities, measures to ensure safe and secure storage throughout the facilities' lifecycles, the long-term liabilities associated with CO2 storage sites, and the obligatory environmental reviews and permitting. Indonesia even goes further by including a framework for transboundary CO2 transport, paving the way for an ASEAN CCS hub.

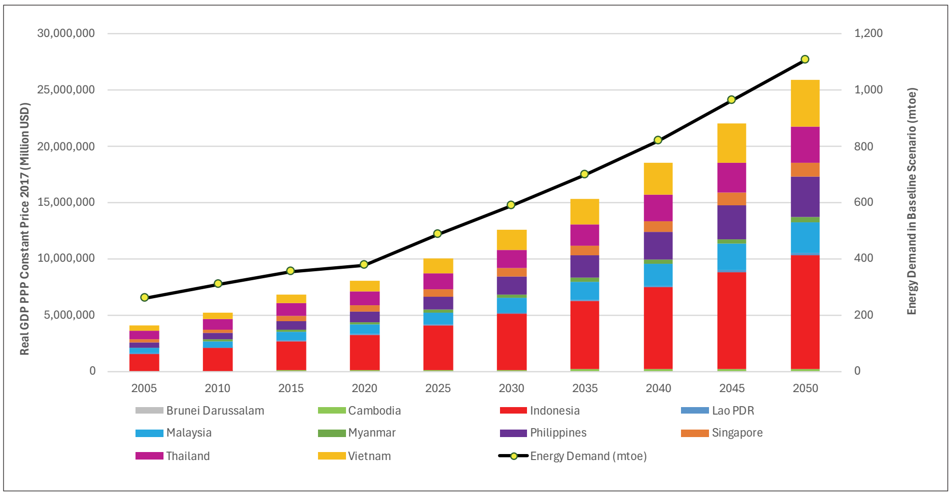
As the formulation of complex regulations for CCS involves effective coordination among multiple stakeholders, a mapping of the tasks that the stakeholders are responsible for is also provided in the report to assist them in developing a coordination plan.

As for the storage pillar (Chapter 5), CO2 storage potential is evaluated primarily in three geological media: saline aquifers, depleted oil and gas reservoirs, and coal beds with three identification phases to be identified: (i) storage location, (ii) storage capacity and (iii) storage suitability. Although all of the AMS are still in the early stages of developing their CO2 storage projects, five countries, namely Indonesia, Malaysia, Philippines, Thailand and Viet Nam have completed all three steps of the identification phase, with seven having at least reached a realistic/effective CO2 storage capacity assessment level which is one level above the theoretical capacity.

To better identify storage capacity, access to storage or geological data must be open. Effective collaboration and the sharing of information and plans among stakeholders would significantly impact the effectiveness and accuracy of CO2 storage characterisation.

As for the key challenges of CCS deployment (Chapter 6) in the region, economic viability is found to be the most difficult one to resolve. Most of AMS representatives believe that the high costs of CCS technologies (especially the upfront costs) are prohibitive, but that financial support could become available from carbon pricing and/or the provision of subsidies, grants and procurement-based contracts. Long lead times and project complexity (including project risk) are other key challenges that need to be addressed. Finally, solving the wide innovation gaps is also crucial if CCS projects in ASEAN are to become viable.

From the above pillar frameworks aligned with the key challenges of CCS deployment, the following recommendations are proposed as part of the ASEAN CCS Roadmap Deployment:



ASEAN Real GDP and Energy Demand, 2005-2050. From "The 7th ASEAN Energy Outlook (2022)" https://aseanenergy.org/the-7th-asean-energy-outlook/

Enhancing the economic viability of CCS development with aim to reduce the high capital costs and improve the competitiveness of CCS compared to other emerging technologies. Key measures include: (i) implementing carbon pricing to support the local CCS ecosystem, (ii) providing financial incentives such as grants and tax credits, and (iii) offering revenue support through contracts and procurement processes. Engaging state-owned utilities in CCS projects during the short and medium terms is also essential.

Shortening the lead times of CCS projects and accelerating the domestic deployment of CCS through fostering close coordination among stakeholders when they formulate the plans, timelines and targets for CCS deployment in ASEAN. These efforts need to be continued through the medium and long terms, especially when it comes to setting clear regulations for the permitting and licensing of CCS projects including transboundary CO2 movements in the region.

Managing project complexity and derisking CCS deployments through a top-down approach which aims to strengthen legislation, public policies and regulations related to CCS projects in the region.

Over the short-term stage (the market creation stage), a robust legal framework is needed to define and classify CO2, including its ownership across the CCS value chain. Long-term post-site closure regulations and financial assurances are also necessary. In the mid-term, the necessary actions include ensuring storage site safety, conducting leakage risk assessments and harmonising regional technical codes and safety standards. By the end of the long-term period, ongoing monitoring and maintenance of CCS projects are recommended. This must involve public engagement with all the relevant stakeholders set by the government.

Narrowing the technology innovation gaps by conducting feasibility studies on technological readiness, socio-economic impacts, and greenhouse gas emissions during the short-term period. In the medium and long terms, the establishment of standards and certifications for CO2 removal (CDR) and their inclusion into the legal and regulatory framework of CCS are essential for reliability, effectiveness and safety.

Facilitating CCS hubs and international transboundary CO2 movements by establishing in the short term a CCS database to map potential source and sink locations, as well as CCS hubs in the region. The regulation regarding access to shared transport and storage infrastructure, cross-border CO2 transportation, and compliance with international law needs to be developed fully during the medium term. To support the smooth implementation of measures for the long term, a close coordination among relevant stakeholders is necessary.

More information

Read the full report at:

www.aseanenergy.org

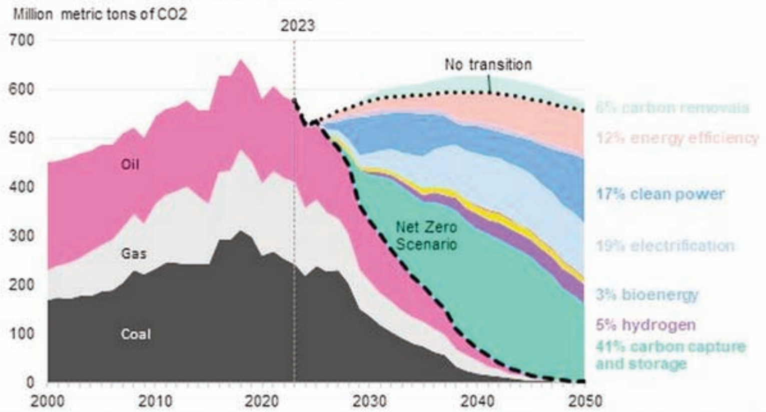
BloombergNEF: South Korea's green transition hinges on clean power, CCS

It's still possible for South Korea to get on track for net-zero emissions by 2050 but a rapid scale-up of clean electricity and carbon capture and storage is required, according to a report published by BloombergNEF.

The power sector is the country's biggest source of emissions. Based on the findings of BloombergNEF's New Energy Outlook: South Korea, in order to be on track with a net-zero-by-2050 pathway, emissions from electricity generation need to drop by more than two-thirds by the end of this decade.

South Korea's Nationally Determined Contribution – its plan to help achieve the goals of the Paris Agreement – aims for emissions to fall by 40% by 2030, relative to 2018 levels. This is less ambitious than the 50% cut envisaged by BNEF's Net Zero Scenario. Should the country's energy transition proceed along an economics-driven trajectory – what BNEF calls its Economic Transition Scenario – there would only be an 18% decline over this period.

Figure 2: South Korea's CO2 emissions reductions from fuel combustion, by measure – Net Zero Scenario versus no-transition scenario



Source: BloombergNEF. Note: The 'no-transition' scenario is a hypothetical counterfactual that models no further improvement in decarbonization and energy efficiency. In power and transport, it assumes the future fuel mix does not evolve from 2023 (2027 for shipping). For all other sectors, the counterfactual to the Net Zero Scenario is the Economic Transition Scenario. 'Clean power' includes renewables and nuclear, and excludes carbon capture and storage, hydrogen and bioenergy, which are allocated to their respective categories. 'Energy efficiency' includes demand-side efficiency gains and more recycling in industry.

"South Korea still has a chance to meet its 2030 emissions reduction target," said David Kang, BNEF's Head of Japan and Korea Research. "In order to do so, the country needs to accelerate the deployment of renewables and electric vehicles, while laying the groundwork to reduce emissions from hard-to-abate sectors over the next five-years."

Carbon capture takes center stage, bucking global picture

Carbon capture and storage does the heavy lifting for emissions reduction in South Korea in the Net Zero Scenario, accounting for 41% of abatement by 2050 versus a 'no transition' pathway. That's much higher than the 14% seen at the global level. Clean power from renewables and nuclear comes in second place, responsible for 17% of the country's emissions savings by mid-century – far below the 45% share in abating global emissions.

"The high share of abatement for carbon capture and storage highlights South Korea's geographical challenges", said Seohee Song, an analyst in BNEF's Energy Economics Team and the lead author of the report. "Finding suitable land for large-scale renewable energy projects is becoming increasingly challenging in the country, putting upward pressure on the cost of solar and wind, thus creating more need for carbon capture and storage to fully decarbonize power and industry."

Reaching net zero would still require South Korea to accelerate deployment of solar and wind to reach 304 gigawatts of capacity by 2050, a 10-fold increase from today. In addition, almost a third of the country's 73 gigawatts of fossil-fuel-driven power plants would need to be equipped with carbon capture by the end of this decade. Right now, no power plants in South Korea are fitted with carbon capture technology.

A multi-trillion-dollar opportunity

The journey to net-zero emissions hinges on $2.7 trillion of investment and spending between now and 2050 to decarbonize South Korea's energy system, 37% higher than in an economics-led transition. On an annual basis, this translates to $102 billion of capital outlay in the Net Zero Scenario, equivalent to 6% of the country's gross domestic product in 2023.

South Korea's investment in the energy transition came in at $25 billion last year. A clear and consistent policy framework is necessary to boost investor confidence and match the spending needs of a net-zero future. ?

"The higher investment requirement for the Net Zero Scenario represents a significant economic opportunity for the country," said Analeigh Suh, BNEF's South Korea analyst and co-author of the report. "Under this pathway, South Korea would reduce emissions and increase its energy security thanks to a reduced need for fossil-fuel imports. The country would also create more demand for technologies such as electric vehicles and batteries, which are the forte of Korean manufacturers."

The research forms part of a series of regional and sector reports diving deeper into results from BloombergNEF's global New Energy Outlook report.

More information

about.bnef.com/new-energy-outlook

BHP, Carbon Clean and JSW Steel implement CCS solution

The companies will begin joint studies to explore the feasibility of Carbon Clean's CycloneCC modular technology to capture up to 100,000 tonnes per year of CO2 emissions, the largest scale deployment to date in steelmaking.

This project is an important step towards supporting the scale-up of carbon capture, including understanding the potential performance, costs, and carbon abatement outcomes. It is anticipated that these joint studies will be completed during 2026, at which time the parties will consider installing CycloneCC at JSW Steel's Vijayanagar site in India's southern state of Karnataka.

BHP's Chief Commercial Officer, Rag Udd, said, "We are actively studying multiple pathways for steel decarbonisation, including through use of hydrogen and renewable power, but we recognise that the blast furnace route will likely remain a pathway for the production of steel, particularly within India. Supporting the development of key abatement technologies such as CCUS is therefore critical. Partnerships and collaboration to accelerate the development and deployment of these technologies is essential, and we are pleased to be working with JSW Steel and Carbon Clean in tackling the challenge of decarbonising steelmaking."

Indian steel producers are collectively the world's second largest, with production potentially doubling by 2030 against 2023 figures, and will likely have a critical role in achieving India's target of net zero by 2070. With the increasing commissioning of blast furnaces in India with decades of life ahead of them, supporting longer term near zero decarbonisation routes is essential.

CCUS technology is anticipated to be a critical abatement tool to support a near zero CO2 emissions intensity route, as well as potentially for other hard-to-abate industrial sectors. There are several challenges with the adoption of carbon capture technology in the steel industry, including capital expenditure and ongoing operating costs, as well as the integration of new equipment into an existing operations site with space limitations.

The CycloneCC rotating packed bed (RPB) technology in combination with Carbon Clean's proprietary APBS-CDRMax solvent aims to address these challenges through reducing total installed cost and the unit footprint by up to 50 per cent, and equipment that is ten times smaller in size than conventional carbon capture technologies.

CycloneCC is a cost-effective, modular and compact carbon capture solution that is easy to scale

Aniruddha Sharma, Chair and CEO, Carbon Clean, said, "The potential impact of carbon capture in decarbonising the steel industry will be huge. First-of-a-kind projects are key to advancing technical innovation, providing valuable learnings that will benefit the entire steelmaking sector, as well as other hard-to-abate industries. Decarbonisation pioneers and early adopters of our modular CycloneCC solution will play a vital role in accelerating progress, with the aim for this technology to be fully commercialised and rolled out at scale."

Utilisation – the 'U' in CCUS – is a key component of the project. If the project is successful, JSW Steel intends to liquefy captured CO2 so that it can be sold locally.

Mr. Jayant Acharya, Joint Managing Director and CEO, JSW Steel, said, "We remain committed to transforming our sustainability vision into reality and have already achieved a reduction of carbon emissions intensity by 30% against our 2005 baseline. At JSW Steel, we aim to further reduce our steelmaking intensity to 1.95 tonnes of CO2 per tonne of steel by 2030 and achieving net neutral carbon emissions by 2050."

More information

www.bhp.com/climate
www.carbonclean.com

Development strategies for carbon-based catalysts in CO2 conversion

A research group at China University of Petroleum (East China) has designed several different effective synthesis strategies using catalysts in the catalytic conversion of CO2.

One of the difficulties of working with CO2 is that it is very thermodynamically stable. To overcome this, additional energy and a strong catalyst are needed to drive the reaction.

"In this review, we summarised the development strategy of catalysts by carbon species assisting method in our research group, which can be applied to CO2 thermochemical and electrochemical hydrogenation," said Mingbo Wu, a professor at the College of New Energy, State Key Laboratory of Heavy Oil Processing at the China University of Petroleum (East China) and lead author of the paper.

“This review aims to inspire new ideas for CO2 hydrogenation through the design of carbon-based catalysts.”

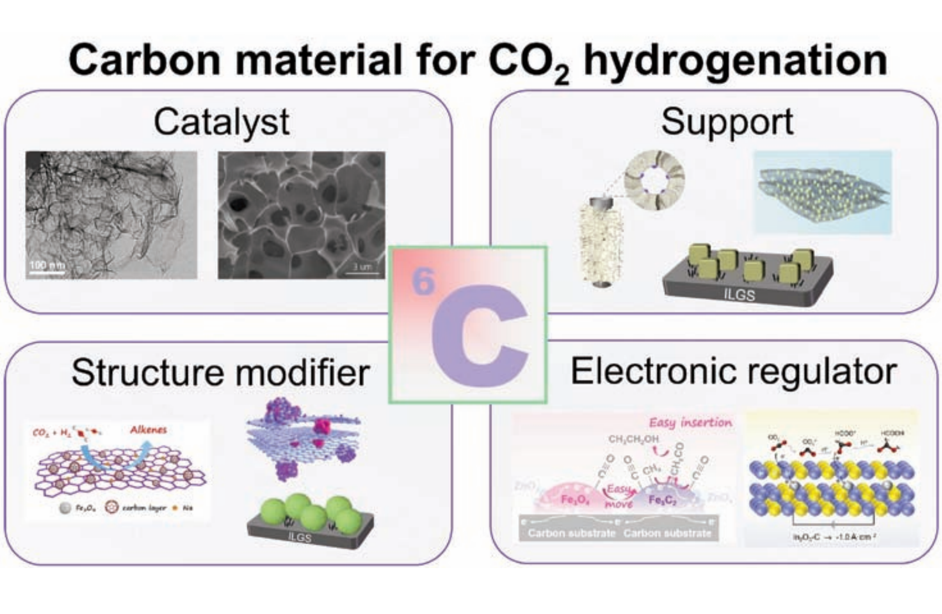
The researchers chose to focus on carbon species because their physical and chemical properties make them good candidates as catalysts, they can be relatively inexpensive and are very stable.

Carbon-based catalysts can also play various roles in the preparation and process of CO2 catalytic conversion. They can be used to modify the structure of catalysts, as supports of catalysts, as electronic regulators of catalysts and as the bulk catalysts.

CO2 conversion occurs via CO2 hydrogenation, the addition of hydrogen atoms to the CO2 and removing its oxygen atoms. This is accomplished using either the energy from electrocatalysis, which uses electricity to drive the process, or thermocatalysis, which uses heat to drive the process.

In order to avoid increasing the amount of pollutants and green-house gases, Wu's team recommends using green renewable energy as the energy source wherever possible.

Wu's team has designed and researched several different catalyst strategies. An example of one of these strategies is the electrocatalysis reduction of CO2 via a carbon-based catalytic material.



Scientists from China University of Petroleum have developed new strategies using carbon-based catalysts in CO2 hydrogenation that make use of the many varied roles that carbon can play in catalytic reactions from material support to structural modification, as electronic regulators of the reaction, to acting as the catalysts themselves. Image: Mingbo Wu, China University of Petroleum (East China)

In essence, CO2 is converted to HCOO, formate, which is a nontoxic, easy to transport and very promising green fuel. The difficulty in designing these strategies lies in building a process that is both efficient and stable, hence the importance of the design of the process and the type of catalyst used.

The researchers carried out the conversion using carburized iridium oxide nanorods, a metallic oxide. The process they designed uses the carbon species' ability to modulate the electronic structure of metals, thus enhancing the activity of catalysts and selectivity of formate, said Wenhang Wang, a researcher from the School of Chemistry and Chemical Engineering at Liaocheng University and first author of the paper.

"We will always be committed to the development and application of carbon-based catalysts. With the development on the design concept of the catalyst and characterization technology, we strongly believe that a clear roadmap of the utilization of carbon materials for catalysts is drawn and the breakthrough in this field will be witnessed in the near future," Wu said.

The work was supported by the National Key Research and Development Program of China, the National Natural Science Foundation of China, and the Taishan Scholar Project (ts201712020).

More information
english.upc.edu.cn

Scientists reveal new design for cells turning carbon dioxide into a green fuel

Researchers from Tokyo Metropolitan University have developed a new electrolyzer for industrial conversion of bicarbonate solution made from captured carbon to a formate solution.

Their new electrochemical cell, with a porous membrane layer in between the electrodes, overcomes major issues suffered in reactive carbon capture (RCC) and achieves performances rivaling gas-fed methods but using less energy. The work could contribute to converting captured CO2 into something more useful for society, such as an environmentally friendly fuel.

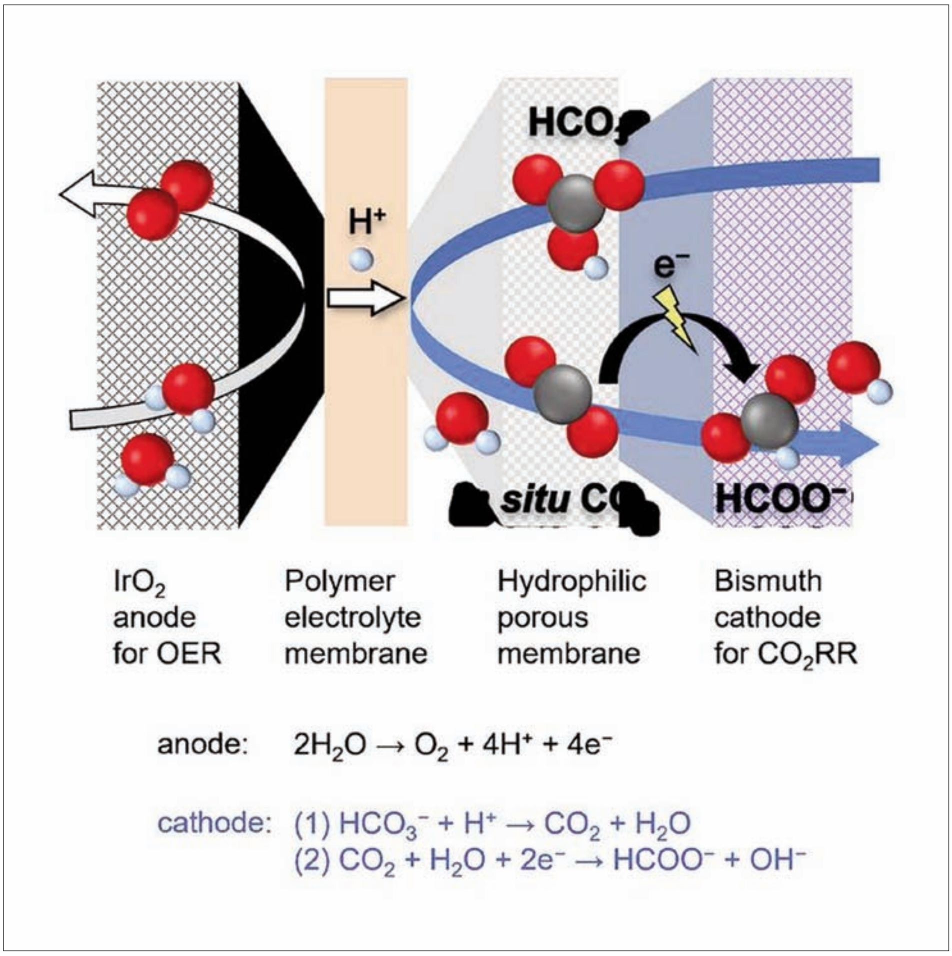
Technology has been developed for using electrochemical cells to reduce the carbon dioxide to a formate compound, which itself can be used in formate fuel cells to generate power. However, a significant roadblock is the need for pure carbon dioxide: pressurising carbon dioxide can be highly energy intensive. The gas is not converted very efficiently, and the cells do not last very long.

Reactive carbon capture, where carbon dioxide dissolved in alkaline solutions, like bicarbonate solutions, can be directly used to create formate ions without the losses associated with providing pure gas. The key challenge facing researchers here is the design of a better electrochemical cell which can selectively produce formate ions from bicarbonate ions without losing out to side reactions, like the production of hydrogen.

Now, a team of researchers led by Professor Fumiaki Amano from Tokyo Metropolitan University have created a new cell with excellent selectivity for the conversion of bicarbonate ions into formate ions. In the new cell, electrodes made of catalytic material are separated from a polymer electrolyte membrane by a porous membrane made of cellulose ester. Hydrogen ions produced at one electrode pass through the electrolyte membrane and make it to the porous layer, where it reacts with bicarbonate ions to efficiently produce carbon dioxide in the pores. The gas is then converted to formate ions at the other electrode, also in contact with the porous membrane.

When they put their cell to work, they found that the faradaic efficiency of their cell, the proportion of electrons converted to formate instead of other compounds, was 85%, even with very high currents. Not only does this outperform existing designs, the cell was found to operate smoothly for over 30 hours and realise nearly complete conversion of bicarbonate to formate. Once the water has been driven off, all that is left is solid, crystalline formate fuel.

Given the demands on climate change technology, improvements like this to the efficient running of electrochemical cells promizes to have a big impact. The team hopes their new bicarbonate electrolyzer can be a viable option for society as it strives towards a green transformation. This work was supported by Tokyo Metropolitan Government.



Bicarbonate conversion to formate is accelerated through in situ CO2 generation and selective CO2 reduction reaction at a gas–liquid–catalyst triple-phase boundary

More information

www.tmu.ac.jp
doi.org/10.1039/D4EY00122B

Asia news

INPEX and Chubu Electric study Japan-Australia CCS value chain

www.inpex.co.jp/english

www.chuden.co.jp/english

They will conduct a joint study to assess the feasibility of establishing a CCS value chain involving the capture of CO2 in Japan and its transportation from the Port of Nagoya to Australia for storage.

INPEX was awarded a greenhouse gas storage assessment permit in the Bonaparte Basin off the northwestern coast of the Northern Territory of Australia with TotalEnergies and Woodside Energy in 2022. This project aims to begin CO2 injection around 2030 and could represent a key component of the Darwin-based CCUS Hub proposed by the Northern Territory Government. INPEX operated Ichthys LNG would be a natural user of this CCS solution as it seeks to reduce its GHG emissions.

Chubu Electric Power aims to achieve net zero CO2 emissions from its operations by 2050 and has been considering the feasibility of CCUS, based in and around the Port of Nagoya for the decarbonisation of the region. By collaborating with Chubu Electric Power, INPEX expects to help build a CCS value chain and contribute to the transition to a decarbonised society.

INPEX said it is working actively to redevelop the energy landscape for the purpose of helping create a net zero carbon society by 2050 while meeting energy demand in Japan and around the world.

Japanese companies to study CCS project development by 2030

www.jogmec.go.jp/english

Three companies agreed a contract with Japan Organization for Metals and Energy Security (JOGMEC) to study engineering design for a CCS value chain in the Tomakomai area.

Japan Petroleum Exploration Co., Ltd. (JAPEX), Idemitsu Kosan Co., Ltd. (Idemitsu), and Hokkaido Electric Power Co., Inc. (HEPCO) were selected through a public Request for Proposal for "Engineering Design Work for Advanced CCS Projects" in the fiscal year 2024.

The three Companies were selected for their application for a CCS project in the Tomakomai area to carry out "basic engineering design for CCS value chain" and "assessment on CO2 storage potential at the planned CO2 storage site", following a feasibility study conducted in FY2023, with the aim to launch of CCS projects by FY2030.

They will conduct specific technical studies on CO2 separation and capture as well as CO2 transport and storage. Specifically, for the CO2 separation and capture, Idemitsu and HEPCO will perform works including basic engineering design for the necessary equipment at each CO2 emission source. For the CO2 transport and storage, JAPEX will conduct works including basic engineering design for the pipelines and equipment connecting each emission source to the candidate storage site.

In addition, JAPEX will carry out assignments including basic engineering design for the equipment necessary for injecting and monitoring deep saline formations of the sea area around Tomakomai to achieve a CO2 storage volume of 1.5 to 2 million tons per year in 2030.

K Line and Sumitomo to study CCS in Alaska with Hilcorp

www.kline.co.jp

www.sumitomocorp.com

A study will investigate the feasibility of building a CCS value chain in which CO2 is aggregated in Japan and transported by large-sized liquefied CO2 vessels to Alaska for storage.

This will be the first time for a Japanese company to conduct a joint study between Japan and the U.S. toward the commercialisation of cross-border CCS, and the three companies aim to commercialise it in cooperation with the Japanese and U.S. governments.

On October 11, 2024, the "4th Japan-U.S. CCUS Working Group", co-hosted by the Ministry of Economy, Trade and Industry (METI) and the U.S. Department of Energy (DOE), was held. Taking advantage of this opportunity, a signing ceremony for the joint study agreement related to this feasibility study was conducted in the presence of both the Japanese and the U.S. governments.

The Japanese government is promoting the improvement of the business environment to initiate CCS projects by 2030. In response to this policy, in April 2024, the fact sheet of the Japan-U.S. Joint Leaders' Statement stated that the two countries would evaluate the potential for cross-border carbon dioxide transport and storage hubs between Japan and Alaska.

Specifically, each company will use its own knowledge and experience to conduct technical research on CO2 storage including storage capacity, research on technical requirements for liquefied CO2 vessels, and review the business environment in order to explore the feasibility of this project.

Chiba University studies cement absorption of CO2

www.chiba-u.ac.jp

Researchers have conducted a comprehensive investigation of carbonation reaction using a new method, revealing the role of structural changes and water transport, paving the way for advanced carbon dioxide-absorbing building materials.

Cement-based materials provide a potential solution for mitigating climate change by trapping and storing atmospheric carbon dioxide as minerals, via a process known as carbonation. Despite extensive studies, however, the exact mechanism of this process is not yet understood.

Previous studies have shown that carbonation is strongly impacted by relative humidity (RH), CO2 solubility, calcium/silicate (Ca/Si) ratio, and concentration and saturation level of water in C–S–H. Moreover, it is also important to understand the influence of ions and water transport through the nanometer-sized pores in C–S–H layers, known as gel-pore water.

"Our study shows that the carbonation process occurs due to a combination of structural modifications and mass transfer, signifying the importance of studying their interplay, rather than just structural changes," said Associate Professor Ohkubo.

Getting big CCS projects moving - report from the CCSA Summit in London

Representatives of Equinor, ExxonMobil, SSE Thermal, Spirit Energy, GE Vernova and Technip shared perspectives on how to get big CCS projects moving, speaking at CCUS 2024, the annual CCSA summit, in London in October. By Karl Jeffery.

Norway's Northern Lights CCS project celebrated being "ready for CO2" in mid-September 2024, said Torbjørg Klara Heskestad, Vice President for CCUS, Equinor.

Equinor sees that governments around the world take different approaches to supporting CCS, such as US offering 'carrots' with 45Q, and the UK providing regulated support. The EU is "a little bit less mature," she said.

A big challenge with carbon capture projects is that the various components all need to take a 'final investment decision' at the same time, so you don't commit to capturing CO2 without knowing there will be storage and vice versa.

In 2015 when the project was first planned, the EU ETS cost was 5 euro a tonne. At the time of the event, it was 64 euros. Project planners need to feel confident prices will increase, she said.

Government funding solutions were found in Norway as they were in the UK. But the real challenge is going to be running projects in future without government funding, she said.

"Striving for simplicity [in policy models] is excellent advice, but easier said than done," she said. "In the US we are struggling with the same challenges. Most important is clarity."

A big challenge with carbon capture projects is that the various components all need to take a 'final investment decision' at the same time - Torbjørg Klara Heskestad, Vice President for CCUS, Equinor

ExxonMobil

A big challenge for UK CCS developments is regulatory uncertainty - Michael Foley, UK Low Carbon Solutions Venture Executive, ExxonMobil

The world needs to store 3bn tonnes CO2 a year by 2050, said Michael Foley, UK Low Carbon Solutions Venture Executive, ExxonMobil. Today's storage figure is about 40m tonnes a year. This means the industry needs to grow 20-30 per cent a year for the next 25 years.

ExxonMobil boosted its US carbon capture activities through the acquisition of Denbury Inc in July 2023, a provider of carbon capture and enhanced oil recovery services. Denbury has 1300 miles of CO2 pipeline and agreements to store 6.7m tonnes CO2 a year, he said.

Big areas of CCS research at ExxonMobil are improving CO2 storage systems (including reservoir modelling) and finding better ways to manage CO2 pipeline integrity.

Shortly before the event in October 2024, ExxonMobil stated that it was not going to proceed "at this time" with its project to transport and store CO2 off the south coast of England, taking CO2 from its Fawley Refinery.

The project involved a CO2 pipeline across the Isle of Wight, and there had been local protests against it. Mr Foley said that local media had published negative articles about the project, which were very unhelpful. But he stressed that this was not the principal reason for the project not going ahead.

The real problem was that there was not enough government support available to make the finances work, he said. ExxonMobil sat together with staff from two government branches (the UK North Sea Transition Authority and DESNZ) and they "tried really hard to find a route forward," but did not manage.

A big challenge for UK CCS developments, in Mr Foley's view, is regulatory uncertainty. The UK requires projects to be selected as part of the government's "track" system, which has, he said, an opaque decision-making process. "The challenges of policy certainty are stopping projects going forward."

It would also be useful to have more government policy which would generate demand for low carbon products, he said.

One general factor inhibiting the UK's competitiveness is its high electricity prices, which are double those of mainland Europe and four times higher than in the US, he said. Another factor inhibiting competitiveness is complex planning requirements. To illustrate, a planned tunnel under the River Thames, the Lower Thames Crossing, required a 360,000-page planning application.

SSE Thermal:

In the 2030s there will be a big need for flexible power generation capacity, said Hannah Bronwin, Director of Business Development, SSE Thermal.

"Flexible" power generation capacity means power that is available on demand (unlike renewables, which is only available when it is sunny or windy). Much of this will need to be provided with gas power.

Yet the UK only has one gas power plus CCS project close to taking a final investment decision today, she said. There may be only 4 GW of power with CCS online by 2030. "Deployment has been slower than planned."

So, it looks likely that there will still be power generation from gas without carbon capture beyond 2030.

To get final investment decisions made for "power with CCS" projects, it is important to expand the Track 1 clusters and launch the Track 2 cluster.

"Our projects are ready, they really are just waiting for government process," she said.

Spirit Energy

Spirit Energy plans to turn gas production fields in Northwest England to gigantic CO2 storage sites. Its project plans are "technically and commercially mature," said Matt Browell-Hook, Energy Transition Director, Spirit Energy. They are not part of the UK government's "track" funding processes.

It has projects to build pipelines connecting CO2 storage with cement and lime manufacturers in Derbyshire and Staffordshire, which includes 40 per cent of the UK's cement manufacturing capability, he said. The project team is also looking at maritime and rail transport.

The infrastructure the company plans to create will enable its own opportunities. For example, a company seeking to build an industrial plant with its CO2 captured and stored might choose to build it in Barrow Energy Park, adjacent to Spirit Energy's project facilities.

Our projects are ready, they really are just waiting for government process - Hannah Bronwin, Director of Business Development, SSE Thermal

21 CO2 storage licenses have been issued in the UK so far. Companies are investing "heavily" in developing them, he said. This is hard to do when you don't know when you will be able to start selling the storage and get a return, he said.

One particularly costly element is seismic surveys over the stores to better understand them, with seismic survey vessels costing £250k a day, he said.

Mr Browell-Hook is a "massive advocate of the full value chain model", where multiple companies work together, he said. For example, we could see emitter companies and storage companies going to their shareholders at the same time to ask for more funding, rather than one group waiting for the other, he said.

I'm a massive advocate of the full value chain model, where multiple companies work together - Matt Browell-Hook, Energy Transition Director, Spirit Energy

GE Vernova

A gas turbine (with carbon capture) together with renewable energy is a "perfect combination of technologies," said Jeremee Wetherby, Carbon Solutions Leader with energy equipment company GE Vernova.

Technologies for carbon capture are much better known than technologies for hydrogen, he said.

For companies investing in carbon capture, it would be helpful to have more clarity about whether the business model will work, he said. "You are investing in an asset that will be there for 20 years. you need to know what the rules of the game are."

"Not understanding what is going to happen 5-10 years in the future is very concerning, incredibly risky.

Within a CCS cluster, power generation companies can have an anchoring role, since their emissions are much larger than those from sectors such as paper, steel and cement, he said.

Technip

The energy cost of carbon capture with amine solvents can be as much as 180 kWh per tonne CO2, said Christophe Malaurie, SVP Decarbonisation Solutions, Technip Energies. CO2 "doesn't react much with anything," he said. This is what makes it so hard to capture.

Another limitation on CCS projects is the capacity of supply chains, equipment and people. To illustrate, France recently "had to take welders from Scotland to work on nuclear plants," he said.

Technology standardisation will help drive the cost down, he said.

More information

See the Jan/Feb 2025 issue for more UK news from the event.

www.ccus.events

Major boost in carbon capture and storage essential to reach 2°C target

A new study led by Chalmers University of Technology in Sweden and University of Bergen in Norway shows that without major efforts, CCS will not expand fast enough to meet the 2°C target.

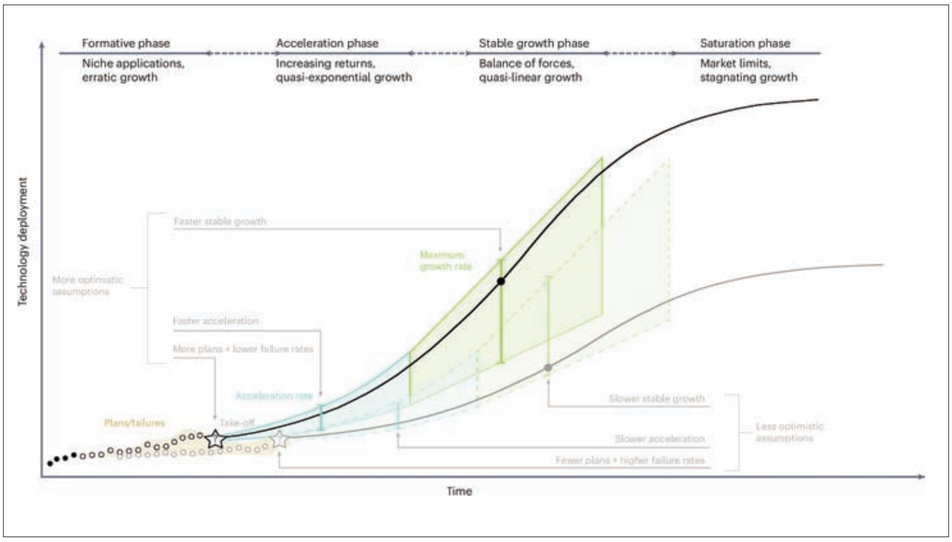
“CCS is an important technology for achieving negative emissions and also essential for reducing carbon emissions from some of the most carbon-intensive industries. Yet our results show that major efforts are needed to bridge the gap between the demonstration projects in place today and the massive deployment we need to mitigate climate change,” said Jessica Jewell, Associate Professor at Chalmers University of Technology in Sweden

A new study published in Nature Climate Change, ‘Feasible deployment of carbon capture and storage and the requirements of climate targets’, conducted a thorough analysis of past and future growth of CCS to forecast whether it can expand fast enough for the Paris Climate Agreement. The study found that over the 21st century, no more than 600 Gigatons (Gt) of carbon dioxide can be sequestered with CCS.

“Our analysis shows that we are unlikely to capture and store more than 600 Gt over the 21st century. This contrasts with many climate mitigation pathways from the Intergovernmental Panel on Climate Change (IPCC) which in some cases require upwards of 1000 Gt of CO2 captured and stored by the end of the century. While this looks at the overall amount, it’s also important to understand when the technology can start operating at a large scale because the later we start using CCS the lower the chances are of keeping temperature rise at 1.5°C or 2°C. This is why most of our research focused on how fast CCS can expand,” said Tsimafei Kazlou, PhD candidate at University of Bergen, Norway, and first author of the study.

Decrease in CCS failure rate required

The study highlights the need to expand the number of CCS projects that realise this technology and cut failure rates to ensure the technology “takes-off” in this decade. Today, the development of CCS is driven by policies like the EU Net-Zero Industry Act and the Inflation Reduction Act in the US. In fact, if all of today’s plans are realised, by 2030, CCS capacity would be eight times what it is today.



“Even though there are ambitious plans for CCS, there are big doubts about whether these are feasible. About 15 years ago, during another wave of interest in CCS, planned projects failed at a rate of almost 90 percent. If historic failure rates continue, capacity in 2030 will be at most twice what it is today which would be insufficient for climate targets,” says Tsimafei Kazlou.

A promising technology with barriers to overcome

Like most technologies, CCS grows non-linearly and there are examples of other technologies to learn from. Even if CCS “takes-off” by 2030, the challenges won’t stop. In the following decade it would need to grow as fast as wind power did in the early 2000’s to keep up with carbon dioxide reductions required for limiting the global temperature rise to 2°C by 2100. Then starting in the 2040s, CCS needs to match the peak growth that nuclear energy experienced in the 1970s and 1980s.

“The good news is that if CCS can grow as fast as other low-carbon technologies have, the 2°C target would be within reach (on tiptoes). The bad news, 1.5°C would likely still be out of reach,” says Jessica Jewell.

The authors say their analysis underlines the need for strong policy support for CCS combined with a rapid expansion of other decarbonisation technologies for climate targets.

“Rapid deployment of CCS needs strong support schemes to make CCS projects financially viable. At the same time, our results show that since we can only count on CCS to deliver 600 Gt of CO2 captured and stored over the 21st century, other low-carbon technologies like solar and wind power need to expand even faster”, says Aleh Cherp, Professor at Central European University in Austria.

By Tsimafei Kazlou of University of Bergen in Norway, Jessica Jewell at Chalmers University of Technology in Sweden and Aleh Cherp at Central European University in Austria.

More information

www.chalmers.se

www.uib.no

doi.org/10.1038/s41558-024-02104-0

Project Greensand releases final pilot project report

The report confirms Denmark has safe and well-functioning storage for CO_2 in the North Sea subsoil, where CO_2 can be permanently stored to mitigate climate change.

The 23 partners behind Project Greensand have now submitted the final report from the pilot project, which has aimed to develop, test and demonstrate safe and efficient storage of CO_2 in the North Sea subsurface.

The thorough technical verification ensures that the stored CO_2 remains safely and permanently in the closed Nini West reservoir 1,800 metres below the North Sea seabed, as expected. This is clear after the results of Project Greensand have been verified by the independent and world-leading provider of risk, verification and standardization services, DNV.

"We now have documentation that we have a well-functioning storage for CO_2 in the North Sea subsoil, where large amounts of CO_2 that would otherwise have been emitted into the atmosphere can be safely and permanently stored. We can see that the stored CO_2 behaves as expected in the reservoir 1,800 metres below the seabed. That confidence gives us a solid foundation to take the next steps that will be crucial for CCS in Denmark," said Mads Gade, Country Manager at INEOS Denmark and Commercial Director at INEOS Energy, the leading partner behind Project Greensand.

"We are very proud that we are the first in the world to succeed in developing, testing and demonstrating a well-functioning value chain for safe and efficient capture, transport and storage of CO_2 across national borders with the aim of mitigating climate change. This is an important step on the way to meeting Denmark's and the EU's climate ambitions, and each of the 23 partners has done an outstanding job. I am impressed by how the task has been solved across many professional groups, which has made this phase of Project Greensand come together," said Gade.

The intensive work in the EUDP-supported project has also meant that a large group of Danish and international companies have gained valuable experience in the work with capture, transport and storage of CO_2, and now have better conditions to play a role in a future CCS market in Europe.

Project Greensand, as the first in the world, has demonstrated that CO_2 can be transported across national borders and stored offshore to mitigate climate change. Image: ©Ineos

With a completed and verified pilot phase, the way has been paved for the development of CCS in Denmark. The lead partner in Project Greensand, INEOS, has already applied for approval on behalf of licence partners Wintershall Dea (now Harbour Energy) and Nordsøfonden for Denmark's first large-scale CO_2 storage facility, and is now working hard to start CO_2 storage in the North Sea by the end of 2025 or the beginning of 2026. The ambition is that up to 400,000 tonnes of CO_2 will be stored per year, while the plan is to store up to 8 million tonnes of CO_2 per year in the area under the North Sea's seabed from 2030.

At the same time, work is also underway to investigate whether it is possible and safe to store CO_2 underground on land in Denmark, and earlier this year, the Minister for Climate, Energy and Utilities awarded INEOS, Wintershall Dea and Nordsøfonden an exploration licence for an area of the Danish subsurface in Jutland in the Gassum reservoir. The experience from Greensand will be included in the work to demonstrate safe storage also on land.

"We emphasised that Denmark has moved to the forefront of CCS in the world when we stored the first CO_2 in the North Sea. Now we are in the process of investigating how to take the next step, and here we stand on the shoulders of the invaluable experience from Project Greensand's pilot. We are keen to continue this momentum with an ambition that Greensand will be the first CO_2 storage facility in operation in the EU, and we are now awaiting the Danish authorities' approval of a permanent storage. This is an important step, because if Denmark takes just 5% of a future CCS market in Europe, it could mean up to 9,000 jobs, with an economic potential of DKK 50 billion. At the same time, we can support the EU's objectives, because we have all the prerequisites to create a new industry that is part of the solution to the challenges of the climate," said Gade.

More information

www.ineos.com

Projects and policy news

Google signs CO2 removal deal with Holocene at $100/ton

https://theholocene.co

Google has agreed a deal to purchase carbon removal credits from direct air capture provider Holocene, at the lowest price on record for this technology: $100 per ton, for delivery by the early 2030s.

Google said it was committed to doing its part to decarbonise the global economy and reach its goal of net zero emissions across its operations and carbon removal technologies were key to that goal. Partnering with Holocene to reach this milestone price will be a meaningful step toward advancing the viability of DAC as a tool to fight climate change.

"We are beyond thrilled to enter this nearly-decade shared commitment with Google, who has a one-of-a-kind track record for building new climate industries on the buy-side through their work in the renewable energy space," said Holocene.

Direct air capture (DAC) is a promising technology because it uses chemical or physical processes to extract carbon dioxide directly from the air, after which it is stored permanently underground or re-used in products. Experts agree we will need to collectively remove billions of tons of CO2 from the atmosphere annually by 2050 to halt climate change, and DAC could be an important part of the solution.

But direct air capture faces a long road to achieving commercial viability and scale. Today, no DAC plant is delivering more than 2,000 tons of carbon removal credits per year. And while the technology is improving, prices remain in the many hundreds of dollars per ton of CO2 removed. For more companies and governments to invest in DAC projects, costs need to fall dramatically.

The partnership with Holocene aims to address one of the key barriers facing DAC technologies: the hefty price tag. While Holocene's technology is still in the early stages of development, it has the potential to bring down costs significantly over time.

A few key factors contributed to the deal with Holocene achieving a substantially lower price than typical DAC deals. First, Holocene takes an innovative approach to DAC, combining elements of both liquid and solid-based systems, which has high potential to reduce costs for this difficult physical challenge over the long term.

Also, Google will provide financial support up front, while making a long-term commitment to accept credits from Holocene's lower-cost facilities, scheduled for delivery in the early 2030s. Finally, Holocene's projects qualify for the U.S. government's 45Q tax credit on top of Google's payment, which incentivises investment in DAC by providing suppliers $180 per ton of carbon removed.

First UK energy from waste CCS pilot operational

https://enfinium.co.uk

enfinium's Ferrybridge-1 energy from waste facility in Yorkshire is capturing one tonne of CO2 emissions from the plant's operations each day.

The technology, a containerised, scaled-down version of the CCS solution that enfinium could deploy across all of its sites, was supplied by global green technology company Hitachi Zosen Inova (HZI).

The trial, which will run for at least 12 months, is being used to demonstrate how the technology can be applied at scale across enfinium's fleet of six energy from waste facilities to remove CO2 from the atmosphere. The pilot is collecting real operational data on performance, such as CO2 capture rate and solvent degradation, and will assess the performance of different amine solvents.

Mike Maudsley, CEO of enfinium, said, "We are proud to have this sector-leading project up and running at our Ferrybridge facility. Carbon capture and storage technology is central to how the UK will be able to decarbonise its unrecyclable waste. CCS is also a critical to generating carbon removals at scale so the UK can achieve Net Zero. Using carbon capture, the energy from waste sector can provide significant levels of carbon removals and enfinium, with the support of HZI, are taking steps now to achieve this."

Earlier this year, enfinium announced its Net Zero Transition Plan, setting out how it will decarbonise its own operations and deliver up to 1.2 million tonnes of carbon removals a year in the 2030s. The plan is underpinned by an investment programme of up to £1.7 billion, with a focus on investing in carbon capture and storage technology across its energy from waste facilities to deliver carbon removals at scale. The carbon capture pilot marks an important milestone in enfinium's pathway to deliver carbon removals, helping to inform the future deployment and operation of CCS technology across its sites.

Deploying CCS at energy from waste facilities generates durable carbon removals, or 'negative emissions.' Around 50% of the unrecyclable waste produced by society is made up of biogenic content including organic material such as waste food, plants and paper, which has already naturally absorbed CO2 from the atmosphere. Installing CCS technology at an energy from waste facility enables this CO2 to be permanently captured and stored rather than released back into the atmosphere, resulting in a net carbon removal from the atmosphere.

U.S. intends to fund CCUS projects up to $1.3 billion

https://oced-exchange.energy.gov

The Oil and Gas Climate Initiative (OGCI) has launched an online tool designed to assess the socio-economic impact of CCUS projects on employment and Gross Value Added (GVA) to the UK economy.

The funding was made under the Bipartisan Infrastructure Law under the Carbon Capture Demonstration Projects Program and the Carbon Capture Large-Scale Pilot Projects Program and will help develop cost-effective emissions reducing technologies needed to decarbonise the nation's electricity generation and hard-to-decarbonise industrial sectors.

The electricity generation and industrial sectors account for a large portion of U.S. carbon emissions. Successfully scaling carbon capture technologies—especially in hard to decarbonise sectors and heavy industries such as steel and cement production—is a key component of President Biden's plan to combat the climate crisis and achieve a carbon-free economy by 2050.

DOE estimates that reaching our nation's climate goals will require capturing and storing 400 million to 1.8 billion tons of carbon dioxide annually by 2050. Commercial demonstration of advanced carbon capture technologies, integrated with reliable transportation and storage infrastructure, is necessary for the widespread deployment of these technologies.

Capturing carbon from the air just got easier with Berkeley tech

A new type of porous material called a covalent organic framework developed at University of California Berkeley quickly sucks up CO2 from ambient air.

Capturing and storing the carbon dioxide humans produce is key to lowering atmospheric greenhouse gases and slowing global warming, but today's carbon capture technologies work well only for concentrated sources of carbon, such as power plant exhaust. The same methods cannot efficiently capture carbon dioxide from ambient air, where concentrations are hundreds of times lower than in flue gases.

Yet direct air capture, or DAC, is being counted on to reverse the rise of CO2 levels, which have reached 426 parts per million (ppm), 50% higher than levels before the Industrial Revolution. Without it, according to the Intergovernmental Panel on Climate Change, we won't reach humanity's goal of limiting warming to 1.5 °C (2.7 °F) above preexisting global averages.

A new type of absorbing material developed by chemists at the University of California, Berkeley, could help get the world to negative emissions. The porous material — a covalent organic framework (COF) — captures CO2 from ambient air without degradation by water or other contaminants, one of the limitations of existing DAC technologies.

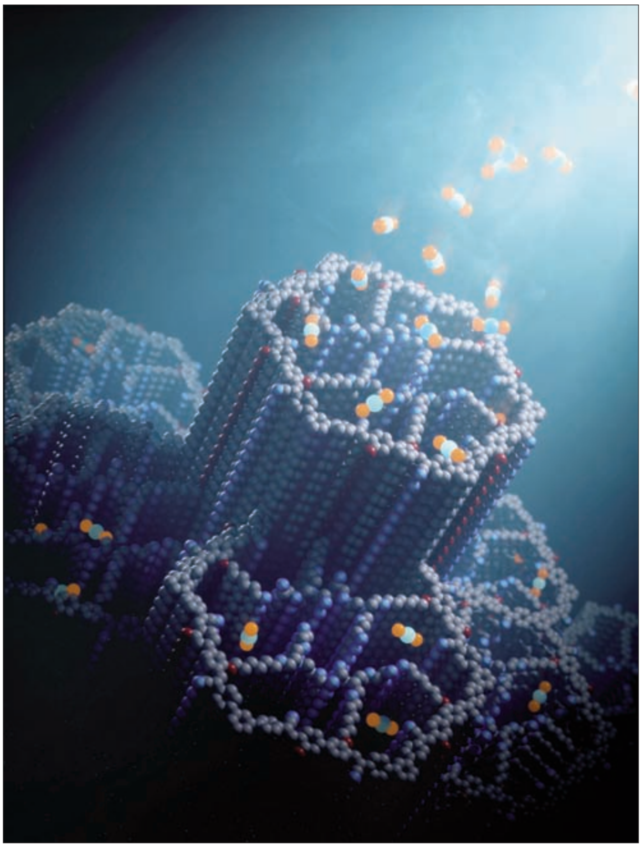
"We took a powder of this material, put it in a tube, and we passed Berkeley air — just outdoor air — into the material to see how it would perform, and it was beautiful. It cleaned the air entirely of CO2. Everything," said Omar Yaghi, the James and Neeltje Tretter Professor of Chemistry at UC Berkeley and senior author of a paper that will appear online Oct. 23 in the journal Nature.

"I am excited about it because there's nothing like it out there in terms of performance. It breaks new ground in our efforts to address the climate problem," he added.

According to Yaghi, the new material could be substituted easily into carbon capture systems already deployed or being piloted to remove CO2 from refinery emissions and capture atmospheric CO2 for storage underground.

UC Berkeley graduate student Zihui Zhou, the paper's first author, said that a mere 200 grams of the material, a bit less than half a pound, can take up as much CO2 in a year — 20 kilograms (44 pounds) — as a tree.

"Flue gas capture is a way to slow down climate change because you are trying not to release CO2 to the air. Direct air capture is a method to take us back to like it was 100 or more years ago," Zhou said. "Currently, the CO2 concentration in the atmosphere is more than 420 ppm, but that will increase to maybe 500 or 550 before we fully develop and employ flue gas capture. So if we want to decrease the concentration and go back to maybe 400 or 300 ppm, we have to use direct air capture."



The new porous material for capturing carbon dioxide, called a covalent organic framework (COF), has hexagonal channels decorated with polyamines that efficiently bind carbon dioxide molecules (blue and orange balls) at concentrations found in ambient air. Image: Chaoyang Zhao

COF vs MOF

Yaghi is the inventor of COFs and MOFs (metal-organic frameworks), both of which are rigid crystalline structures with regularly spaced internal pores that provide a large surface area for gases to stick or adsorb. Some MOFs that he and his lab have developed can adsorb water from the air, even in arid conditions, and when heated, release the water for drinking. He has been working on MOFs to capture carbon since the 1990s, long before DAC was on most people's radar screens, he said.

Two years ago, his lab created a very promising material, MOF-808, that adsorbs CO2, but the researchers found that after hundreds of cycles of adsorption and desorption, the MOFs broke down. These MOFs were decorated inside with amines (NH2 groups), which efficiently bind CO2 and are a common component of carbon capture materials. In fact, the dominant carbon capture method involves bubbling exhaust gases through liquid amines that capture the carbon dioxide. Yaghi noted, however, that the energy intensive regeneration and volatility of liquid amines hinders their further industrialization.

Working with colleagues, Yaghi discovered why some MOFs degrade for DAC applications — they are unstable under basic, as opposed to acidic, conditions, and amines are bases. He and Zhou worked with colleagues in Germany and Chicago to design a stronger material, which they call COF-999. Whereas MOFs are held together by metal atoms, COFs are held together by covalent carbon-carbon and carbon-nitrogen double bonds, among the strongest chemical bonds in nature.

As with MOF-808, the pores of COF-999 are decorated inside with amines, allowing uptake of more CO2 molecules.

"Trapping CO2 from air is a very challenging problem," Yaghi said. "It's energetically demanding, you need a material that has high carbon dioxide capacity, that's highly selective, that's water stable, oxidatively stable, recyclable. It needs to have a low regeneration temperature and needs to be scalable. It's a tall order for a material. And in general, what has been deployed as of today are amine solutions, which are energy intensive because they're based on having amines in water, and water requires a lot of energy to heat up, or solid materials that ultimately degrade with time."

Yaghi and his team have spent the last 20 years developing COFs that have a strong enough backbone to withstand contaminants, ranging from acids and bases to water, sulfur and nitrogen, that degrade other porous solid materials. The COF-999 is assembled from a backbone of olefin polymers with an amine group attached. Once the porous material has formed, it is flushed with more amines that attach to NH2 and form short amine polymers inside the pores. Each amine can capture about one CO2 molecule.

When 400 ppm CO2 air is pumped through the COF at room temperature (25 °C) and 50% humidity, it reaches half capacity in about 18 minutes and is filled in about two hours. However, this depends on the sample form and could be speeded up to a fraction a minute when optimized. Heating to a relatively low temperature — 60 °C, or 140 °F — releases the CO2, and the COF is ready to adsorb CO2 again. It can hold up to 2 millimoles of CO2 per gram, standing out from other solid sorbents.

Yaghi noted that not all the amines in the internal polyamine chains currently capture CO2, so it may be possible to enlarge the pores to bind more than twice as much.

"This COF has a strong chemically and thermally stable backbone, it requires less energy, and we have shown it can withstand 100 cycles with no loss of capacity. No other material has been shown to perform like that," Yaghi said. "It's basically the best material out there for direct air capture."

Yaghi is optimistic that artificial intelligence can help speed up the design of even better COFs and MOFs for carbon capture or other purposes, specifically by identifying the chemical conditions required to synthesize their crystalline structures. He is scientific director of a research center at UC Berkeley, the Bakar Institute of Digital Materials for the Planet (BIDMaP), which employs AI to develop cost-efficient, easily deployable versions of MOFs and COFs to help limit and address the impacts of climate change.

"We're very, very excited about blending AI with the chemistry that we've been doing," he said.

The work was funded by King Abdulaziz City for Science and Technology in Saudi Arabia, Yaghi's carbon capture startup, Atoco Inc., Fifth Generation's Love, Tito's, and BIDMaP. Yaghi's collaborators include Joachim Sauer, a visiting scholar from Humboldt University in Berlin, Germany, and computational scientist Laura Gagliardi from the University of Chicago.

More information
https://yaghi.berkeley.edu

MTR Carbon Capture completes world's biggest membrane CO2 capture plant

The carbon capture plant at the Wyoming Integrated Test Center (ITC) will capture up to 150 tonnes of CO2 per day from Basin Electric's Dry Fork Station (DFS) coal fired power plant. www.mtrccs.com

The plant will produce 99.9%+ pure liquid CO2 with a 90% capture rate and will be the first commercial scale membrane capture plant to be put into operation when it starts later this year.

"This is a very exciting milestone for MTR and an important step in scaling affordable, clean technology for point source carbon capture," said Brett Andrews, President of MTR Carbon Capture. "MTR's Polaris™ membranes have been proven, with over 15 years of development and a series of pilot and demonstration carbon capture plants of increasing scale, culminating in the largest membrane capture plant ever built," said Andrews.

In addition to the 150 tonne per day plant, MTR has been awarded a full scale FEED project for a 3 million tonne per year capture plant at DFS by the U.S. Department of Energy's Office of Clean Energy Demonstrations (OCED).

The MTR Carbon Capture Polaris membrane process uses no chemicals and very little water, making it a much cleaner and environmentally friendly capture technology compared to alternative solvent based capture systems. Polaris also does not require heat or steam input, which generate additional CO2 emissions, as many capture approaches do, resulting in low operating costs.

Capture systems using MTR's membrane technology are highly modular and compact, providing flexibility for limited space applications and reducing capital costs.

The MTR Carbon Capture system at the Wyoming ITC is part of the U.S. Department of Energy's large scale pilot carbon capture program and is funded through grant DE-FE0031587. This program supports the development of key technologies that will significantly improve the economics and environmental performance of point source carbon capture. MTR has been the recipient of over 20 awards from the DOE in support of the development and scale up of the Polaris™ membrane capture technology.

Carbon Clean launches columnless carbon capture system

The CycloneCC C1 series uses rotating Packed Bed (RPB) technology to replace every column used in a conventional plant, reducing the steel required by 35%.

The CycloneCC C1 series is available in concentrations ranging from 3% to 20%, capturing up to 100,000 tonnes of CO2 per year. Each unit is fully modular and columnless, achieving a height reduction of 70% compared to conventional solutions.

The unit footprint is up to 50% smaller than conventional carbon capture plants, with its largest equipment sizes reduced by a factor of 10.

Each unit is prefabricated, skid-mounted and delivered on road truckable modules, cutting the costs associated with transport, logistics, site preparation and installation; the total installed cost is up to 50% less compared to conventional solutions, the company claims.

According to Carbon Clean, more than 50% of industrial emitters lack the space required to deploy conventional carbon capture plants. With its space-efficient design, CycloneCC C1 offers a viable, cost-effective route to decarbonisation, particularly for small-to-mid-size emitters. CycloneCC C1 is also ideal for emitters of all sizes looking to deploy carbon capture units across multiple flue gas emission sources.

The CycloneCC C1 series is available in concentrations ranging from 3% to 20%, capturing up to 100,000 tonnes of CO2 per year.

Prateek Bumb, Co-founder and Chief Technology Officer of Carbon Clean, said, “The launch of the CycloneCC C1 series is a major milestone in the technology’s commercialisation. Repeatability is key to mass adoption, as demonstrated with solar panels and EV batteries. Carbon Clean is leading a similar transformation through eliminating the columns used in conventional carbon capture solutions."

"Delivering fully modular, columnless, replicable units with a substantially smaller footprint is a technological breakthrough. CycloneCC’s ‘Lego-block’, ‘plug and play’ design makes it simple and cost-effective to install, making carbon capture financially and logistically viable to be deployed at scale. First-mover customers and early adopters will have the advantage of tangible decarbonisation results while benefiting from a staggered approach to capital investment due to CycloneCC C1’s modular design.”

At the heart of CycloneCC C1 is the breakthrough combination of two process intensification technologies: rotating packed beds (RPBs) and Carbon Clean’s proprietary APBS-CDRMax solvent. The first-of-a-kind (FOAK) technology application of RPBs to a carbon capture plant is a gamechanger for the sector, the company said. Using RPBs to replace the columns used in conventional carbon capture solutions both reduces the size of the plant and accelerates the mass transfer process, increasing CO2 absorption.

Carbon Clean said its APBS-CDRMax solvent achieves substantial OpEx savings through outperforming the industry standard solvent. APBS-CDRMax lowers energy demand by 10-25%, reduces corrosion by a factor of 20, decreases degradation by a factor of 10, and has a lifespan that is five times longer than conventional solvents.

First-mover customers of the CycloneCC C1 series will have the opportunity to influence the development of the fully commercialised product while experiencing the benefits of tangible decarbonisation results. Early adopters will also be priority customers for the fully commercialised product when it is rolled out at scale.

More information

www.mtrccs.com

Artificial photosynthesis device turns CO2 into ethylene with record efficiency

Scientists at the University of Michigan have developed an artificial photosynthesis device that can turn carbon dioxide and water into ethylene, in a step toward making solar fuels.

A key step toward reusing CO2 to make sustainable fuels is chaining carbon atoms together, and an artificial photosynthesis system developed at the University of Michigan can bind two of them into hydrocarbons with field-leading performance.

The system produces ethylene with efficiency, yield and longevity well above other artificial photosynthesis systems. Ethylene is a hydrocarbon typically used in plastics, so one direct application of the system would be to harvest carbon dioxide that would otherwise be vented into the atmosphere for making plastics.

"The performance, or the activity and stability, is about five to six times better than what is typically reported for solar energy or light-driven carbon dioxide reduction to ethylene," said Zetian Mi, professor of electrical and computer engineering at the University of Michigan and corresponding author of the study in Nature Synthesis.

"Ethylene is actually the most produced organic compound in the world. But it is typically produced with oil and gas, under high temperatures and pressures, all of which emits CO2."

The long-term goal is to string longer chains of carbon and hydrogen atoms together to produce liquid fuels that can be easily transported. Part of the challenge is removing all of the oxygen from the CO2 as the carbon source and water, H2O, as the hydrogen source.

The device absorbs light through two kinds of semiconductors: a forest of gallium nitride nanowires, each just 50 nanometers (a few hundred atoms) wide, and the silicon base on which they were grown. The reaction transforming water and carbon dioxide into ethylene takes place on copper clusters, each with about 30 atoms, that dot the nanowires.

The nanowires are submerged in water enriched with carbon dioxide and exposed to light equivalent to the sun at noon. The energy from the light frees up electrons that split the water near the surface of the gallium nitride nanowires. This creates hydrogen to feed into the ethylene reaction but also oxygen that the gallium nitride absorbs to become gallium nitride oxide.

The experimental setup in Zetian Mi's lab where his team prepared an artificial photosynthesis device that can turn carbon dioxide and water into ethylene, in a step toward making solar fuels. Yuyang Pan shines a light on the device. Image credit: Sylvia Cardarelli and Jero Lopera, Electrical and Computer Engineering, University of Michigan

The copper is good at hanging onto the hydrogen and grabbing onto the carbon of the carbon dioxide, turning it into carbon monoxide. With the hydrogen in the mix and an injection of energy from the light, the team believes two carbon monoxide molecules bond together with the hydrogen. The reaction is believed to be completed at the interface between the copper and the gallium nitride oxide, where the two oxygen atoms are stripped off and replaced with three hydrogen atoms from splitting water.

The team found that 61% of the free electrons that the semiconductors generated with the light contributed to the reaction to produce ethylene. While a different catalyst based on silver and copper achieved a similar efficiency of roughly 50%, it needed to run in a carbon-based fluid, and it could function for only a few hours before it degraded. In contrast, the Michigan team's device ran for 116 hours without slowing down, and the team has run similar devices for 3,000 hours.

The limits of the device's longevity will be explored in future work.

Finally, the device produced ethylene at a rate more than four times higher than the nearest competing systems.

Liquid fuels, which could enable many existing transportation technologies to become sustainable, are Mi's ultimate goal.

More information

mc2.engin.umich.edu

World's first biodegradable plastic produced from CO2 emissions in Finland

Fortum Recycling & Waste has produced a biodegradable plastic from carbon dioxide emissions from waste incineration at its plant in Riihimäki.

Biodegradable plastic sample - it will decompose and does not leave harmful microplastics in the environment

Fortum Recycling & Waste's Carbon2x program piloted carbon capture and utilisation in 2022. The program aims to capture carbon dioxide emissions from the incineration of non-recyclable waste and use them to produce sustainable products, such as biodegradable plastic.

According to Tony Rehn, Head of the Carbon2x program, the production of CO2-based plastic provides a new, sustainable raw material for the plastics industry.

"I am very proud that our team is the first in the world to successfully produce biodegradable plastic entirely from carbon dioxide emissions. This breakthrough is a significant step towards more sustainable plastic production. This kind of development work helps to reduce dependence on fossil-based raw materials and can create new circular economy-based business," Rehn explained.

Similar carbon capture development projects are underway in several industrial sectors in Finland and globally, but the majority of them focus on the production of synthetic fuels and carbon capture and storage.

"Captured carbon dioxide should be utilized as a new raw material instead of storing it underground or releasing it into the atmosphere when using fuel. Utilizing captured CO2 is a much more sustainable option in terms of tackling resource scarcity in the future. Whereas carbon capture and storage is a linear solution that does not address the growing material shortage, carbon capture and utilization promotes circular economy," said Rehn.

Every year, Europe generates nearly 100 million tons of non-recyclable waste that is incinerated and utilized in energy production. According to Rehn, the wider implementation of the Carbon2x program's innovation would mean that up to 90% of the CO2 emissions released into the atmosphere from waste incineration could be captured and bound into products.

According to Rehn, new sustainable solutions are needed for plastic production to complement recycled and bio-based plastics. Biodegradable, CO2-based plastic offers a significant alternative to the market because it has the same qualitative properties as traditional, fossil-based virgin plastics.

"We want to promote the circulation of materials comprehensively. We believe that a whole new category of sustainable plastics is emerging from products such as ours, even though the mechanical recycling of plastics is still needed," said Rehn.

Biodegradable, CO2-based plastic can be recycled just like many other plastics, closing the carbon cycle. An additional advantage of biodegradable plastic is that even if it would end up in nature by accident, it decomposes and does not leave harmful microplastics in the environment.

According to Rehn, the Carbon2x program's innovation is hoped to provide solutions not only for material production for food and cosmetics packaging, but also for other sectors such as toys and home electronics.

Rehn estimates that at this rate of development, the industrial production of biodegradable plastic made from waste incineration's CO2 emissions could start as early as the end of the decade. The new "plastics born from CO2" brand will be introduced to the European market in November 2024.

More information

www.fortum.com

www.plasticsbornfromco2.com

Neustark, Aggregate Industries bring onshore carbon removal tech to the UK

The technology permanently removes carbon from the atmosphere and locks it into recycled concrete. The UK market is ideal due to mature supply chain and infrastructure, and government support for a competitive carbon market – but more focus is needed on carbon removal.

The first site is now in operation in Greenwich, London and will permanently remove CO2 in the coming months and support building projects in the local area. The site will be able to permanently store and remove 1,000 tonnes of CO2 (net) per year.

This is the first venture into the UK market for the Swiss cleantech start-up, which has already established 19 carbon capture and storage sites deployed in Europe to date. The site is one of the first commercially and ecologically viable solutions for permanent, onshore carbon removal in the UK.

Neustark's innovative technology and business model captures CO2 from biomass sites, liquefies it, then injects it into existing mineral waste streams such as demolished materials to be recycled and used in construction. This uses a process of mineralisation that stores the CO2 in the aggregate, permanently removing it from the atmosphere and creating carbonated, recycled building materials such as concrete.

As a leading supplier of materials and solutions to the construction industry, Aggregate Industries, part of the global Holcim Group, has partnered with neustark to accelerate green growth and to provide high-quality, sustainable products to its customers.

The building and construction industry is estimated to account for 37% of global carbon emissions, 7% coming from the production of cement alone, according to a 2023 report by the United Nations Environment Project (UNEP). While there have been efforts from the industry to decarbonise, the UK Green Building Council warned that the UK construction industry was 'significantly off-track' on its net zero goals at the end of last year indicating that decarbonisation rates would need to double in the coming years.

By using the carbon removal process of mineralisation, neustark and Aggregate Industries can support increased decarbonisation in the construction sector by turning demolished concrete, the world's largest waste stream, 1 billion tons per year, into a carbon sink. Each tonne of demolished concrete can store an average of 10 kg of CO2.

The UK government signalled clear support for CCUS by announcing a pledge of £21.7 billion in funding last month, however, the focus of this investment is currently on CCS. The government initiative is also tasked with building out regional technology 'clusters' for the development of the industry.

Valentin Gutknecht, CEO and co-founder, neustark, said, "We have already deployed 19 sites in Central Europe that capture and remove thousands of tons of CO2. By extending our relationship with Holcim and partnering with Aggregate Industries, we are now bringing this revolutionary technology to the UK."

"The UK is an ideal market for us as it has a mature supply chain and the infrastructure we need to remove CO2 at scale. The government is supportive of building a competitive carbon market and shifting the industry away from early-stage developments to a competitive commercial set-up. But there is not enough focus on carbon removal, or consideration of how carbon removal can be embedded into existing supply chains and industries beyond oil and gas rather than always requiring extensive new infrastructure."

"This partnership is proof that collaboration between a cleantech start-up and global leader in building solutions can create tangible climate impact today. The rest of the construction industry should follow suit and we need to look at other applicable industries too."

Unlike other carbon removal technology, neustark is removing CO2 now and has already removed over 2,500 tonnes of CO2 from the earth's atmosphere since it launched commercially in 2023. The business plans to bring online approximately 40 additional sites in the coming months and throughout 2025 in the region.

More information

www.neustark.com

www.holcim.com

Capture & utilisation news

Reactor developed at Rice could make direct air capture more energy efficient

https://wang.rice.edu/research

Rice University researchers have developed an electrochemical reactor that has the potential to drastically reduce energy consumption for direct air capture, the removal of carbon dioxide directly from the atmosphere.

A study in Nature Energy describes the specialized reactor as having a modular, three-chambered structure with a carefully engineered porous solid electrolyte layer at its core. Haotian Wang, a Rice chemical and biomolecular engineer whose lab has been researching industrial decarbonization and energy conversion and storage solutions, said the work "represents a big milestone in carbon capture from the atmosphere."

"Our research findings present an opportunity to make carbon capture more cost-effective and practically viable across a wide range of industries," said Wang, the corresponding author on the study and associate professor of chemical and biomolecular engineering.

The device has achieved industrially relevant rates of carbon dioxide regeneration from carbon-containing solutions. Its performance metrics, including its long-term stability and adaptability to different cathode and anode reactions, showcase its potential for wide-scale industrial use.

"One of the major draws of this technology is its flexibility," said Wang, explaining that it works with different chemistries and can be used to cogenerate hydrogen. "Hydrogen coproduction during direct air capture could translate into dramatically lower capital and operation costs for downstream manufacturing of net-zero fuels or chemicals."

The new technology offers an alternative to the use of high temperatures in direct air capture processes, which often involve running a mixed gas stream through high-pH liquids in order to filter out carbon dioxide, an acidic gas.

This first step of the process ties up the carbon and oxygen atoms in the gas molecules to other compounds in the liquid, forming new bonds of varying degrees of strength depending on the type of chemical used to trap the carbon dioxide. The next major step in the process involves retrieving the carbon dioxide from these solutions, which can be done using either heat, chemical reactions or electrochemical processes.

British Steel starts carbon capture trial with University of Sheffield

https://britishsteel.co.uk

www.sheffield.ac.uk

A trial using technology to capture carbon emissions from the boiler flue of British Steel's Scunthorpe plant has started.

While electrification of the steelmaking process will reduce emissions of carbon dioxide by more than 75 per cent, the company is exploring routes to provide further reductions in CO2e (CO2 equivalent) intensity. This includes the development of technologies for capturing CO2 generated by other parts of its manufacturing operations.

To support this, and the development of the required technology, a mobile carbon capture pilot plant has been installed at British Steel's Central Power Station in Scunthorpe.

The plant has been developed by the University of Sheffield and will be used to extract carbon from the power station's boiler flue.

Dr Andy Trowsdale, British Steel's Head of Research and Development, said, "This project is all about testing the capabilities of the technology. If it works for us, and others, it could be scaled-up and play an important role in carbon capture, utilisation and storage."

"The trial, which has been approved by the Environment Agency, will demonstrate the technology's potential. We're excited to be working with the University of Sheffield and supporting such vital research."

British Steel's involvement is part of a wider project by the University of Sheffield which aims to enable the use of waste gases from manufacturing industries like steel and glass-making to generate an alternative source of carbon for consumer products.

The technology, which is called FluRefin, was developed by Professor Peter Styring and Dr George Dowson from the University of Sheffield in partnership with AESSEAL – the Rotherham-based seal manufacturer.

With the support of SUSTAIN, the future steel manufacturing research hub, the University team have created a carbon capture system that does not use environmentally hazardous chemicals and which is much cheaper and smaller than other carbon capture technologies.

The CO2 captured will be bottled in gas cylinders and transported back to the University of Sheffield where it will be converted into synthetic transport fuels.

GE Vernova-led study shows cost reductions for gas power CCS

www.gevernova.com

A DOE-funded engineering study highlighted how Exhaust Gas Recirculation (EGR) technology can reduce costs of carbon capture at a gas-fired power station by more than 6%.

The front-end engineering design (FEED) study, "Retrofittable Advanced Combined-Cycle Integration for Flexible Decarbonized Generation", evaluated retrofitting Southern Company subsidiary Alabama Power's James M. Barry Electric Generating Plant, located in Bucks, Alabama, with technology capable of capturing up to 95% of the plant's CO2 emissions.

It demonstrated that the integration of GE Vernova's Exhaust Gas Recirculation (EGR) system could lead to a reduction of more than 6% of the total cost of the carbon capture facility, as compared to installing carbon capture without the EGR system.

"GE Vernova is grateful for the Department of Energy's support of this study, the first of its kind to explore EGR technology applied in a gas power carbon capture plant," said Jeremee Wetherby, GE Vernova Carbon Solutions Leader.

The study was completed in collaboration with Southern Company, Linde, BASF, and Kiewit, and explored the benefits of close integration between a natural gas combined-cycle (NGCC) plant and a carbon capture system.

We need to apply circular economy principles to accelerate CO2 storage

Tapping into the potential need for offshore CO2 storage will involve overcoming many hurdles, from cost-effectively and securely locating, sealing and re-abandoning legacy wells against CO2 leaks, to drilling new wells and implementing CO2 injection across storage sites of widely varying sizes and depths. By Stewart Maxwell, Technical Director at Aquaterra Energy.

Amidst an ongoing increase in global emissions, particularly across those generated from hard-to-abate industries, CCS is increasingly recognised as imperative to achieving net zero.

Offshore CCS projects are spreading across Europe with Norway recently offering two blocks in the North Sea for CO2 storage, and the UK announcing its CCUS Vision, meanwhile, there is a growing pipeline of North American projects centred around the Gulf of Mexico. The IEA estimates we will need to scale storage capacity from 40MT-5,000 MT a year to reach net zero and studies have identified some 13,000 gigatons of untapped CO2 storage capacity beneath the seabed.

Operatorsface the challenge of adapting transportation pipes, pressures and flow rates to the unique properties of CO2, not forgetting the need to continuously monitor the integrity and safety of storage sites across their entire lifecycles.

The CO2 storage challenge

Potential CO2 storage sites, such as depleted hydrocarbon reservoirs and saline aquifers, are typically scattered with legacy exploration, appraisal or production wells which could pose a potential leak risk depending on the abandonment approach deployed. For example, if zonal isolation across different formations for future CO2 storage was not considered.

Plugging and re-abandoning previously abandoned legacy wells with methods such as drilling a relief well to intersect and re-abandon the legacy well may be infeasible for some shallow formations, or where the well azimuth and depth are unknown. And while excavation may also seem viable, it quickly presents serious safety and technical difficulties. It does nothing to isolate re-abandonment loading from the compromised legacy well. These approaches can incur costs of over £18-20 million and take up to 95 days per well. Both are prohibitively slow and expensive for large sites with multiple wells and will be unsustainable without more cost-effective alternatives.

Operators also face the cost of drilling injection wells and installing CO2 injection platforms across everything from single wells in shallow waters to multiple wells in deeper waters. And once CO2 has been stored, ensuring it remains under the seabed introduces additional costs and requires the complex task of continually monitoring seismic and other events that could cause gas migration and lead to a CO2 leak.

Addressing all these risks in an economical and efficient way will require a unified, circular economy approach, adapting and sharing solutions across multiple applications from well re-abandonment and injection to CO2 monitoring.

Stewart Maxwell, Technical Director at Aquaterra Energy

A unified, circular approach

Overcoming the many hurdles to CO2 storage entails an unprecedented effort to consolidate and combine resources across all project stages. At the storage stage, it is absolutely vital to eliminate risks and regulatory delays by quickly and efficiently safeguarding storage sites against CO2 leaks.

A recent innovation enables multiple wells to be rapidly, cost-effectively and safely re-abandoned and sealed using a single re-usable and repeatable solution. The technology harnesses seabed surveying, well imaging, marking and tagging technologies to precisely locate wells beneath the seabed with centimeter level accuracy.

A specially designed steel frame can then be positioned precisely over the well to enable safe vertical re-entry while a unique movement mechanism allows the frame to be re-adjusted to account for installation tolerances.

The frame is designed to provide structural support for all equipment required for intervention and keep the weight of this equipment off the well to avoid damaging any corroded well casings. It also enables rapid installation of an environmental barrier to keep out sediment and debris and a pressure-retaining barrier to secure the well for re-plugging.

The ability to rapidly and safely vertically re-enter abandoned wells without excavating or drilling new relief wells could drive 80% cost reductions and over 50% time savings on well abandonment. By redeploying the system across multiple wells, these savings can be replicated without additional investment.

The same system could be re-used to repurpose abandoned wells by installing fibre optics and geophones to transform them into monitoring wells to monitor CO2 plume migration within the formation or detect potential leaks before they breach the seabed.

CCS platforms

Where a new CO2 injection platform is required, applying the modular lightweight principles pioneered in oil and gas, such as Aquaterra Energy's Sea Swift provides significant benefits. The Sea Swift platform can be constructed in a range of configurations, from monopiles or conductor supported platforms for up to nine shallow-water wells to jacketed structures injecting up to 15 wells in deeper waters.

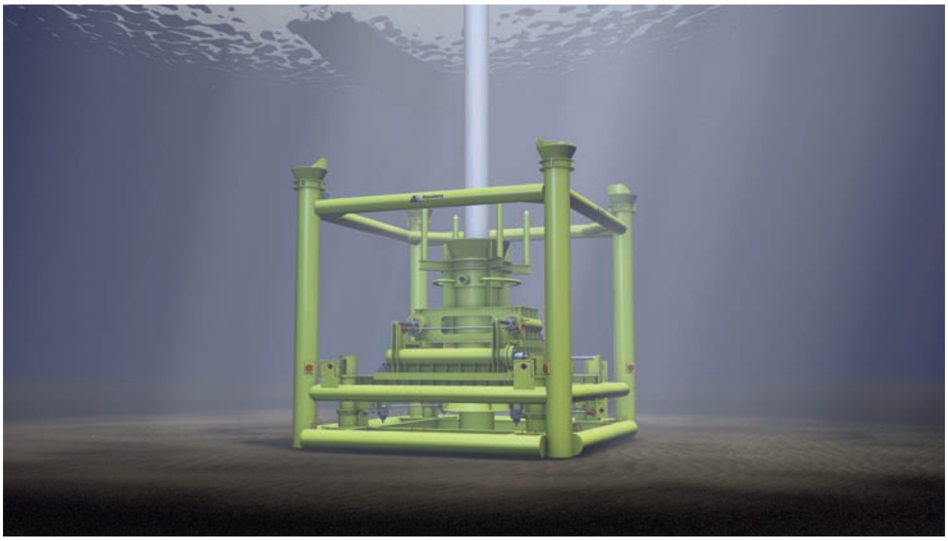
Ultimately, a CCS injection platform works a lot like a production platform, just rather than up and out its in and down so we have the basic principles of platform engineering well worked out.

Just as in offshore production, these lightweight, streamlined designs can be built and transported with existing local infrastructure and even installed with the same jack-up rig used to drill injection wells, significantly reducing costs.

Operational costs are also low as the platforms can be designed to be unmanned and self-powered from renewable sources such as wind and solar. If you're going to the effort and cost of capturing and storing CO2 under the seabed permanently, the significant savings generated from a minimum facilities platform ensures that new emissions are kept to an absolute minimum.

In another scenario, where a developer is in the enviable position of having an existing platform located on a reservoir suitable for CCS, a degree of brownfield engineering may be required to ensure that the platform can be used. This can range from simple changes to the topside equipment configuration to more detailed life extension studies.

Aquaterra Energy is currently applying this life extension approach to the Nini platform, which is part of the broader Project Greensand led by INEOS. Project Greensand is a CCS initiative in the Danish North Sea, with a goal to store up to 1.5 million tonnes of CO2 annually by 2025 and potentially scale up to 8 million tonnes per year by 2030. We are working with INEOS to repurpose the platform for CO2 injection until 2045 confirming the viability of the structure and guiding the implementation of any necessary modifications to support CO2 injection and long-term storage.



Aquaterra Energy's Recoverable Abandonment Frame technology could reduce abandonment costs by £20million per well and cut project timelines by 50%. Image: Aquaterra Energy

Additionally, cutting edge CO2 monitoring technologies can be used in tandem with new and repurposed platforms to monitor and safeguard storage sites against seismic effects or leaks. Monitoring, measurement and verification systems composed of fibre-optics, advanced monitoring systems and other sensors, alongside autonomous power sources can be deployed at CCS sites to provide early warning of hazards during injection.

These sensors can be deployed to monitor wells post injection, enabling remote long-term oversight of potential leaks or tremors across the lifecycle of storage sites, offering end to end assurances against leaks.

Unlocking the potential of CO2 storage

Achieving net zero emissions is a critical global goal, with CCS playing a vital role. Offshore hydrocarbon fields, formerly sources of fossil fuels, now offer significant potential for CO2 storage. However, nobody said tapping into this would be easy, and the industry faces challenges such as safety concerns, regulatory issues, and high costs.

Innovative solutions are essential to overcome these obstacles. Advanced techniques for sealing legacy wells, installing efficient CO2 injection platforms, and deploying state-of-the-art monitoring systems can make large-scale CCS viable.

These innovations combined can reduce costs, enhance safety and speed up project timelines associated with the rollout of CCS at scale.

More information

www.aquaterraenergy.com

Improved technology for MRV at geologic carbon sequestration sites

Updated EPA standards and recently released new fiber optic sensing technology, such as Distributed Strain Sensing Rayleigh Frequency Shift (DSS-RFS), have set a new paradigm for more efficient monitoring, reporting and verification (MRV) in geologic carbon sequestration sites. By Jim McMahon.

According to the United States Environmental Protection Agency (EPA), as of March 2023 a total of two commercial-scale Class VI wells are in operation in the U.S., with 73 projects awaiting permits. Due to the large CO_2 injection volumes occurring and/or planned at these well sites, the relative buoyancy of CO_2, its mobility within subsurface geologic formations, its corrosivity in the presence of water, and the potential presence of impurities in the captured CO_2 stream, the EPA has determined that existing Underground Injection Control (UIC) regulations for Class VI wells are necessary to manage the unique nature of CO_2 injection for GS. A critical component of these regulations encompasses MRV.

Fiber optic data acquisition units on a remote well pad location (Image courtesy Neubrex Ltd)

Monitoring, Reporting and Verification

Monitoring, reporting and verification associated with GS injection projects is an important component of the UIC program. MRV data can be used to verify that the injectate is safely confined in the target formation, minimize costs, maintain the efficiency of the storage operation, and confirm that injection zone pressure changes follow predictions.

The EPA's established MRV requirements for GS projects, including sub-seabed offshore formations, are built upon longstanding programmatic requirements for underground injection in place since the 1980s, with periodic updates including the February 22, 2023 release, Geologic Sequestration of Carbon Dioxide, 40 CFR Part 98 Subpart RR. These requirements are designed to prevent CO_2 movement into Underground Source of Drinking Waters (USDWs) by addressing the potential pathways through which injected CO_2 fluids can migrate into USDWs and cause endangerment to human water usage supplies.

These mandates address the following: a) Site characterization with an assessment of the geologic, hydrogeologic, geochemical and geomechanical properties of the proposed GS site to ensure that wells are located in suitable formations; b) Well construction using materials that can withstand contact with CO_2 over the life of the GS project; c) Computational modeling that accounts for the physical and chemical properties of the injected CO_2 based on available site characterization, monitoring and operational data; and d) Periodic re-evaluation to incorporate monitoring and operational data and verify that the CO_2 plume and the associated area of elevated pressure are moving as predicted within the subsurface.

GS sites are required to develop and implement a site-specific MRV plan which, once approved by EPA, would be used to verify the amount of CO_2 sequestered and to quantify emissions if injected CO_2 leaks to the surface. The GS reports must include information to outline how monitoring will achieve surface detection and quantification of CO_2, and the amount (flow rate) of injected CO_2 for the mass balance equation that will be used to quantify the amount of CO_2 sequestered by a facility.

Robust oversight must be maintained of the CO_2 stream, injection pressures, integrity of the injection well, groundwater quality and geochemistry, and monitoring of the CO_2 plume and position of the pressure front throughout injection. Additionally, comprehensive post-injection monitoring following cessation of injection is required to show the position of the CO_2 plume and the associated area of elevated pressure to demonstrate that neither poses an endangerment to USDWs.

Mechanical Integrity Testing (MIT)

Injection well MIT is a critical component of the EPA's UIC program's requirements designed to ensure USDW protection from endangerment. Testing and monitoring the integrity of an injection well at an appropriate frequency throughout the injection operation, in conjunction with corrosion monitoring of well materials, can verify that the injection system is operating as intended or provide notice that there may be a loss of containment that may lead to endangerment of USDWs.

Routine MITs enable operators to ensure that well integrity is maintained from construction throughout the life of the injection project. UIC regulations require injection well operators to demonstrate both internal and external mechanical integrity.

Internal mechanical integrity is an absence of significant leakage in the injection tubing, casing, or packer. Leakage occurs due to corrosion or mechanical failure of the injection well's tubular and mechanical components. UIC regulations require continuous monitoring to demonstrate well integrity. This is driven by concerns that the potential corrosivity of CO2 in the presence of water and the anticipated high pressures and volumes of injectate could compromise the integrity of the well.

Continuous monitoring is essential because it allows for the immediate identification of corrosion-related mechanical integrity problems or problems due to temperature and pressure effects associated with injection of supercritical CO2.

External well mechanical integrity is demonstrated by establishing the absence of significant fluid movement along the outside of the casing, generally between the cement and the well structure, and between the cement and the well-bore. Failure of an external MIT can indicate improper cementing or degradation of the cement that was replaced to fill and seal the annular space between the outside of the casing and the well-bore.

This type of failure can lead to movement of injected fluids out of intended injection zones and toward USDWs. EPA requires operators of CO2 injection wells to demonstrate external mechanical integrity at least once annually during injection operations using a tracer survey or a temperature or noise log.

Groundwater/Geochemical

Groundwater and geochemical monitoring are important to ensure protection of USDWs from endangerment, preserve water quality, and allow for detection of any leakage of CO2 or displaced formation fluids out of the target formation and/or through the confining layer.

Periodically analyzing groundwater quality – salinity, pH, and aqueous and pure-phase CO2 – above the confining layer can reveal geochemical changes that result from leaching or mobilization of heavy metals and organic compounds, or fluid displacement. EPA requires periodic monitoring of the groundwater quality and geochemical changes above the confining zone, based on a flexible monitoring regime, with the amounts and types of monitoring being site specific.

Fiber optic interrogator units that are connected to fibers that run down the wellbore for thousands of feet. Image courtesy Neubrex Ltd

Pressure Fall-Off Testing

Pressure fall-off tests are designed to determine if reservoir pressures are tracking as predicted. The results of pressure fall-off tests will confirm site characterization information and verify that projects are operating properly, and that the injection zone is responding as predicted.

Pressure fall-off testing provides valuable information, and the EPA specifies that a five-year frequency is appropriate. The EPA believes that this frequency will allow for adequate pressure tracking in the injection formation. It will also help to verify that the operation is responding as modeled and predicted and allow the operator to take appropriate action if the monitoring results do not match expectations.

Monitoring CO2 Plume and Pressure Front

Monitoring the movement of the CO2 and the pressure front are necessary to identify potential risks to USDWs posed by injection activities, verify predictions of plume movement, provide inputs for modeling, identify needed corrective actions, and target other monitoring activities.

UIC regulations require tracking of the plume and pressure front by direct pressure monitoring via monitoring wells in the first formation overlying the confining zone, or by using indirect geophysical techniques such as seismic profiling, electrical, gravity, electromagnetic surveys, or down-hole CO2 detection tools.

The EPA adds that operators may consider performing additional pressure monitoring in wells that are above the confining zone to provide additional verification that no pressure changes are occurring above the confining zone due to CO2 leakage or displacement of native fluids.

Distributed Fiber Optic Sensing in Support of Geologic Sequestration MRV

The deployment of fully distributed fiber optic sensors into deep wells to monitor acoustic vibrations, mechanical strain, reservoir temperature and reservoir pressure distribution, in support of oil and gas down hole applications and CO2 injection, has advanced considerably over the last decade.

Because a fiber optic cable can be installed in harsh environments for long periods of time, the technology holds promise for environmental monitoring of sensitive subsurface operations. Many geofluid systems, including GS, require dynamic acoustic, temperature, strain and pressure monitoring at great pressure, depth and temperature. Sensing systems that employ downhole fiber optic cables serve particularly well for long-term well monitoring and well-integrity monitoring.

Distributed fiber optic sensing provides the critical capability of measuring multiple physical phenomena along the entire length of an internal borehole, as well as monitoring the conditions of the near-well bore region, outside of pipe subsurface rock formations, supporting verification and accounting of geologic carbon sequestration projects.

Distributed fiber optic sensing technologies that support GS include Distributed Acoustic Sensing (DAS), Distributed Temperature Sensing (DTS), Distributed Pressure Sensing (DPS), and Distributed Temperature Strain Sensing (DTSS). While DAS and DTS technologies have achieved success in many GS applications, DTSS provides not only temperature, but also the absolute, differential time lapse and dynamic strain deformation profiles along the full length of optical fiber, over distances reaching up to tens of kilometers. Distributed Pressure Sensing is in development and shows great promise in lab development and testing. It has yet to be proven at field level.

As good as DAS, DTS and DTSS technologies are, the increasing demand for monitoring geofluid systems, like geologic sequestration, has encouraged further development of specialized technologies capable of very high sensitivity and reliability, along with mechanical robustness suitable for harsh operational environments. One of these more recently developed technologies, Distributed Strain Sensing Rayleigh Frequency Shift (DSS-RFS), represents a significant breakthrough for geologic sequestration MRV. It leverages significant advancements in hydrocarbon production operations and has clear cross over applications to GS applications.

Distributed Strain Sensing Rayleigh Frequency Shift (DSS-RFS)

The latest generation of fiber optic sensing systems employed to monitor deep well conditions, Distributed Strain Sensing Rayleigh Frequency Shift (DSS-RFS) is a truly transformative technology for augmenting operational performance in GS. Providing critical data about the downhole well environment from distributed fiber optic sensing, DSS-RFS improves the ability of engineers and scientists to more efficiently and effectively understand strain and temperature dynamics of the subsurface and support engineering operational, monitoring, reporting and verification activities and goals that support GS.

DSS-RFS uses Rayleigh Wavelength, optically sourced backscatter in a nonengineered single mode silica (glass) fiber to measure strain and temperature changes along the fiber. Advanced through research, development and field application by Neubrex Ltd, Kobe, Japan, distributed fiber optic-based strain and temperature sensing measurements are made based on the frequency shift of the Rayleigh optical scattering spectrum, which is linearly dependent on strain and temperature changes applied to the sensing fiber. Strain changes along the wellbore are continuously measured at fine spatial scale during operations of the GS well.

The principle of the DSS-RFS method can be explained accordingly: When an optical fiber is manufactured, random inhomogeneities of the glass density are created in the fiber core. The random density heterogeneities manifest as a variation of refractive index along the fiber. For a certain laser frequency, the constructive and destructive interferences between the Rayleigh backscatters cause irregular but unique amplitude fluctuations in the coherent optical time-domain reflectometer along the fiber length.

For each discrete fiber segment, a unique Rayleigh scattering spectrum (like a fingerprint) is obtained by scanning the fiber with a coherent optical time-domain reflectometer with a range of laser frequencies using a tunable-wavelength laser system. This unique Rayleigh scattering spectrum shifts in frequency space if the temperature and/or mechanical strain on the fiber section changes, which causes the spacing and optical delay to vary between the scatterers. This change is detectable and measurable with Neubrex technology.

DSS-RFS technology permits tens-of-thousands of points down a fiber that is attached to a tubing string or casing string to be measured very quickly every 20 centimeters along the entire fiber length deployed in or along the wellbore. The continuous glass fiber strand inside the cable can sense very small physical length changes at a large range of frequencies. These measurements of thermally or mechanically-driven strain change, as a function of time and depth, are valuable to engineers who use the data to gain an understanding of what is occurring deep down in the well. No other technology provides such insight.

Changes in temperature (degrees), strain (micro-strain unit), acoustics (dB, noise) and pressure (psi) can be made in real-time while CO2 injection is occurring. This helps field engineers understand what is happening in these deep wells much better than with previous discrete sensor-position technologies. Data driven changes or adjustments to operational plans or maintenance plans can then be made when warranted, to optimize the GS operation and make wells with better long-term sequestration performance, efficiency and efficacy.

DSS-RFS is employed in application by Neubrex Energy Services, the U.S. division of Neubrex Ltd. The company's DTSS product line is known as Neubrescope®. It is actively deployed in North America in different operational settings, such as oil and gas, CCS and geothermal operations.

“Neubrescope DSS-RFS is well designed for monitoring geologic sequestration operations," said Dana Jurick, Executive Vice President and General Manager of Neubrex Energy Services. "Nevertheless, companies involved in GS are still in the learning, testing, qualification and acceptance phase of using fiber optics and how they can be reliably, safely and economically installed, and used in a well and long term well operations.”

“Once installed in a well, operators are learning what measurements can be made, and how it differs from competing technologies,” added Jurick. “The value proposition of this technology application is actively being explored by many GS companies, both domestically in the U.S. and internationally in numerous CCS projects."

New Paradigm for Carbon Sequestration Sites

Monitoring, reporting and verification associated with GS injection projects is an important component of the EPA’s UIC regulations. Fiber optic derived data, combined with other data types, can support MRV requirements and can be used to verify that the CO2 injectate is safely confined in the target formation, minimize costs, maintain the efficiency of the storage operation, and confirm that injection zone pressure changes follow predictions.

MRV requirements can now be better realized with the application of Distributed Strain Sensing Rayleigh Frequency Shift (DSS-RFS), which has set a new paradigm for more efficient monitoring, reporting and verification in geologic carbon sequestration sites.

More information

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Ensuring pipeline integrity with advanced ILI technologies

ROSEN, a leader in pipeline integrity solutions, has developed advanced inline inspection (ILI) technologies, including ultrasonic (UT) crack detection and Electro-Magnetic Acoustic Transducer (EMAT) systems, to address the challenges of maintaning CO2 pipeline integrity.

As the world increasingly turns to CCS to mitigate the impacts of climate change, the integrity of CO2 transport pipelines has become a critical focus. The challenge intensifies with the rise of hydrogen and syngas production, where impurities such as hydrogen (H_2), carbon monoxide (CO), and hydrogen sulfide (H_2S) can be introduced in the CO2 streams.

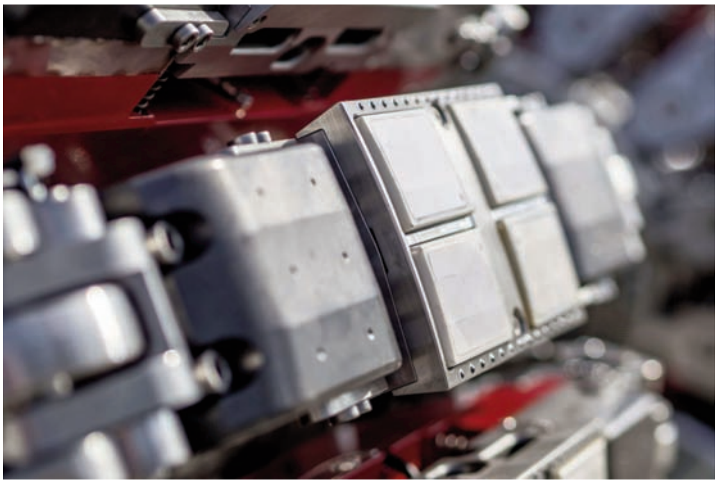
These impurities can induce integrity threats during transportation, and affect the long-term operational safety of the pipelines used for CO2 transport. Internal corrosion is a key concern in dense CO2 transportation. In addition, and for the sake of this paper, H2, CO and H2S can lead to environmentally assisted cracking (EAC) under specific conditions.

This editorial explores how ROSEN's innovations are helping operators manage the complex demands of CCS with hydrogen or syngas production, ensuring safe and efficient transport of CO2 through real-time monitoring, crack detection, and impurity management.

The Challenges of CO2 Pipeline Integrity in CCS

Transporting CO2 through pipelines is widely recognized as the most efficient method for carbon capture and storage applications, particularly when dealing with large volumes of emissions. However, when CO2 contains impurities such as hydrogen, carbon monoxide, or hydrogen sulfide—common byproducts of hydrogen and syngas production—pipeline integrity becomes a significant concern. These impurities can introduce the risk of corrosion and environmentally assisted cracking, which, if left unaddressed, can lead to catastrophic pipeline failures.

The risks posed by these impurities vary based on the specific characteristics of the impurity and the conditions within the pipeline. For example, hydrogen can cause embrittlement in steel, making the pipeline more susceptible to cracking, especially when CO2 is transported in dense-phase conditions at high pressures. In the presence of liquid water, carbon monoxide can lead to stress corrosion cracking (SCC), while hydrogen sulfide, a known cause of sour gas cracking, can cause hydrogen-induced cracking (HIC) and sulphide stress corrosion cracking (SSCC). Industry gaps remain to determine whether these mechanisms are credible under dense phase CO2 operations, and more research is underway.



ROSEN's advanced inline inspection (ILI) technologies

• Hydrogen, for example, can embrittle steel pipelines, making them more prone to cracking. This risk is particularly high in dense-phase CO2 transport, where high pressures exacerbate the embrittlement effects. Studies suggest that limiting hydrogen concentrations to 1% can reduce the likelihood of embrittlement, but more research is needed to determine safe thresholds for higher hydrogen concentrations.

• Carbon monoxide, when combined with water and CO2, can lead to stress corrosion cracking. This occurs when stress, water, and CO levels create an environment conducive to crack formation and growth. Research has shown that CO2-CO-H2O SCC is driven by a "strain-generated active path" model, where a CO film forms on the pipeline's surface and breaks under stress, leading to localised corrosion and crack propagation. In a recent study, X65 pipeline steel was subjected to a 4-point bend test at 50 bar CO2 and 1000 ppm CO, submerged in water, and showed no cracks. However, there is a need for more tests at higher CO2 pressures to simulate conditions of dense CO2.

• Hydrogen sulfide, known for its role in sour cracking, presents additional risks in CO2 pipelines. SSCC and HIC can occur when H_2S is present, especially under high-pressure, dense-phase conditions. Traditional standards for managing SSCC risks in oil and gas pipelines, such as NACE MR0175/ISO 15156, may not apply to dense-phase CO2 transport, where lower pH levels and higher impurity concentrations are common. Ongoing research aims to establish safe H_2S limits for CO2 transport, ensuring the integrity of pipelines operating under these conditions.

A key aspect is the maximum level of impurities (and water in the case of CO and H2S) that can be allowed in specifications to minimise the threats. Nonetheless, over a long-term operational cycle, industry experience shows that process upsets (e.g. dehydration) cannot be discarded especially in offshore environments; the issue of upsets will be compounded in pipeline hub configurations where multiple feeders are involved.

Given the potential for these conditions to develop over time, ongoing monitoring and proactive pipeline management are essential to ensuring safe operations. Advanced inspection techniques, such as ROSEN's ILI technologies, play a crucial role in identifying issues before they evolve into more severe problems, allowing operators to intervene early.

Managing Cracking Threats in CO2 Pipelines

Dense-phase CO2 pipelines, which operate at pressures exceeding 100 bar, present unique challenges when it comes to maintaining integrity. The combination of high-pressure conditions and the presence of impurities like H_2, CO, and H_2S increases the likelihood of cracking. These threats are exacerbated in offshore CCS projects such as Hynet and Acorn, where additional stresses from external factors, such as marine environments and fluctuating temperatures, require even more rigorous pipeline management strategies.

One of the key concerns in CO2 pipelines is determining whether time-dependent crack growth is a credible threat throughout the pipeline's lifecycle, for example to validate further initial specifications or take into account upsets. ROSEN's ILI technologies enable operators to detect cracks early and assess their growth potential, helping them develop tailored intervention strategies to prevent further damage.

In-service crack detection ILI is not possible with UT technology due to the sensitivity of dense-phase CO2 to pressure and temperature fluctuations, which lead to variations in the density, sound velocity and impedance. While a liquid couplant is needed for UT, EMAT technology has no such limitation. UT technology may, however, be used prior to commencement of CO2 service to detect pre-existing cracks.

By applying tools such as UT and EMAT, operators can detect cracks, even those at early stages, and monitor their development over time. EMAT technology allows for real-time monitoring of pipeline conditions, empowering operators to make data-driven decisions about repairs and maintenance.

Case Studies in CO2 Pipeline Inspection

To better understand how advanced ILI technologies are applied in practice, ROSEN has conducted several case studies that showcase the effectiveness of their solutions in managing CO2 pipeline integrity.

In one case, a newly constructed dense-phase CO2 pipeline designed for offshore storage was inspected using EMAT technology. This pipeline, operating at a high pressure of 107 bar, faced significant operational stresses and the risk of cracking due to impurities in the CO2 stream.

The EMAT inspection revealed several anomalies, which were assessed using Engineering Critical Analysis (ECA) techniques to predict potential failure pressures. By identifying cracks early, operators were able to repair the pipeline before any critical failure occurred, ensuring the long-term integrity of the system.

In another case, a vintage onshore pipeline originally used for natural gas transmission was repurposed for gas-phase CO2 transport. This pipeline faced increased stress levels due to its lower wall thickness and lower-grade steel, which made it more vulnerable to cracking in the presence of hydrogen impurities. EMAT technology detected cracks, and further analysis revealed that the pipeline's lower toughness increased its susceptibility to cracking. Proactive measures, such as reducing the Maximum Allowable Operating Pressure (MAOP), helped mitigate the risk of future damage.

These case studies illustrate the value of real-time data in detecting and managing cracking threats in CO2 pipelines. By leveraging advanced ILI tools, operators can ensure the safety and reliability of their pipelines, even when faced with challenging impurities.

The Role of Advanced ILI Technologies in Crack Detection

Traditional methods of pipeline crack management, such as hydrostatic testing and direct assessment, have limitations. Hydrotesting requires pipeline downtime and only identifies leaks after they occur, while direct assessment offers limited insight into the size and location of defects, particularly in offshore applications.

Advanced ILI technologies, such as UT crack detection and EMAT, provide a more proactive approach to crack management. These tools allow operators to detect cracks in real time, assess their severity, and predict their future growth. EMAT, for example, uses electromagnetic waves to detect changes in the material's properties, enabling accurate crack detection without the need for a liquid couplant. This technology is particularly valuable in dense-phase CO2 pipelines, where traditional inspection methods may not be effective.

By combining ILI data with Engineering Critical Analysis (ECA) techniques, operators can gain a comprehensive understanding of pipeline conditions and develop targeted intervention strategies to prevent cracks from reaching critical sizes. This proactive approach ensures the long-term safety and reliability of CO2 pipelines, even in the face of impurities and challenging environmental conditions.

Proactive Pipeline Integrity Management for CCS

As the world moves toward a hydrogen-based energy future, the role of CCS in reducing carbon emissions will only grow. Ensuring the integrity of CO2 pipelines, particularly those transporting hydrogen or syngas-derived CO2, requires a proactive approach that combines advanced inspection technologies with rigorous risk assessments.

ROSEN's ILI technologies, such as UT crack detection and EMAT, are at the forefront of this effort. By providing real-time data and predictive analysis, these tools enable operators to detect and manage cracks before they become critical, ensuring the safety and reliability of CO2 pipelines.

As CCS projects expand, particularly in offshore environments, the ability to manage cracking threats will become increasingly important. With innovative inspection solutions and a commitment to ongoing research, ROSEN is helping operators navigate the complexities of CCS pipeline integrity, paving the way for a more sustainable and secure energy future.

Article by Daniel Sandana PhD EUR ING, NACE SCT, Integrity Consultant in Emerging Fuels and Emily Burrow, Pigging Feasibility Engineer at ROSEN.

More information

www.rosen-group.com

Consortium releases study on potential of onboard carbon capture

The Study found OCCS technology could reduce Stena Impero's existing CO2 emissions by as much as 20% per year, with a fuel consumption penalty of just under 10%.

A project assessing the technical feasibility of onboard carbon capture and storage (OCCS) in the shipping sector, carried out by the Oil and Gas Climate Initiative (OGCI), the Global Centre for Maritime Decarbonisation (GCMD) and Stena Bulk together with a consortium of the world's leading maritime organisations, has concluded that the technology has the potential to help maritime transport significantly reduce its greenhouse gas emissions.

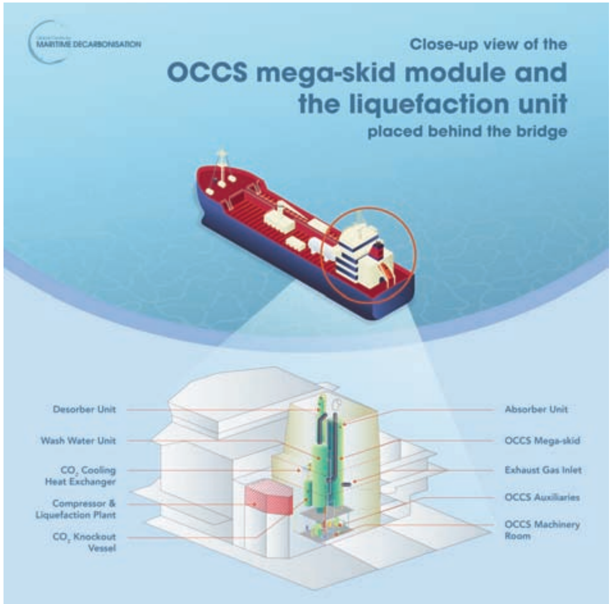
Dr Michael Traver, head of OGCI's Transport Workstream, said, "This study is a major milestone in understanding the potential of using carbon capture technology to decarbonize the shipping industry. The technical feasibility demonstrated in the project is highly encouraging."

The project, Realising Maritime Carbon Capture to Demonstrate the Ability to Lower Emissions (REMARCCABLE), was supported by a consortium comprising American Bureau of Shipping, Alfa Laval, Deltamarin, Lloyd's Register, Seatrium, and TNO. It aimed to assess the viability of deploying carbon capture systems on vessels with minimal impact on operational constraints.

The engineering project analysed the design and cost implications of retrofitting a carbon capture system on the medium-range tanker Stena Impero. It found that the technology could reduce the vessel's carbon dioxide emissions by as much as 20% per year, with a fuel consumption penalty of just under 10%.

The cost of building and installing the full system on the Stena Impero is estimated at US$13.6 million, with an abatement cost of avoided CO2 for the first-of-a-kind prototype evaluated at $769/ton CO2. However, the consortium believes that further research and development will drive down costs, making OCCS increasingly viable for the shipping industry.

The study also looked at incorporating OCCS on newbuild vessels, with the findings that improvements to capture rate and fuel penalty may be achieved using more efficient engines, heat pumps, and alternative solvents.



Professor Lynn Loo, CEO of GCMD, said, "OCCS has gained traction in recent years as a feasible approach to meet the 2023 IMO revised GHG emissions reduction targets. However, its adoption faces numerous hurdles, including the need to balance the tension between maximising CO2 capture rates while maintaining commercially acceptable CapEx and OpEx. This study provides quantitative insights on managing the trade-offs between the actual cost of operating OCCS and its emissions reductions potential."

"For OCCS systems to be practical, the industry needs to manage captured CO2 effectively. To this end, GCMD has previously completed a study to define the operational envelope for offloading onboard captured CO2, contributing to the whole-of-system approach to emissions reduction via carbon capture."

The consortium partners said that many challenges remain to be addressed.

On the regulatory front, the industry awaits guidance from IMO's Correspondence Group tasked with developing a framework for OCCS in MEPC 83.

On the operational front, challenges include recurring additional costs due to fuel penalty, amine solvent replenishment, manpower, maintenance and offloading services.

Offloading captured CO2 is in its nascency, with a lack of national and port policies for accounting captured CO2 and its final deposition. There is also a lack of infrastructure at ports to support offloading and storage.

Therefore, collaboration and support from stakeholders across the value chain will be needed to develop offloading infrastructure and onshore storage. Logistical and policy support for permanent sequestration or utilisation of the offloaded CO2 will also be necessary to encourage the adoption of OCCS solutions. The full project report includes detailed technical specifications, cost projections, and recommendations for further development and implementation of OCCS technology in the shipping sector.

Erik Hånell, President and CEO of Stena Bulk, said, "This may be expensive for first movers, but the consortium believes that further research and development will drive down costs, making OCCS an increasingly viable solution for the shipping industry.

"The results will be instrumental for not only us, but for the whole sector, to evaluate the operational and commercial opportunities, as well as the challenges when capturing CO2 at sea."

More information

www.ogci.com/project-remarccable
www.gcformd.org

Northern Lights storage project set to receive first CO2

The Norwegian Minister of Energy has officially opened the Northern Lights CO2 transport and storage facility, a joint venture between Equinor, Shell and TotalEnergies, in Øygarden, near Bergen.

The onshore and offshore infrastructure has been delivered on time for customers and within budget and is now ready to receive CO2 from Norwegian and European industry. Northern Lights is the first to offer commercial CO2 transport and storage as a service.

The first phase capacity of 1.5 million tons of CO2 per year is fully booked, and the joint venture owners continue to work on plans to increase the transport and storage capacity for the future.

Hundreds of guests from the local community as well as policymakers and industry leaders from across Europe were gathered to celebrate the milestone. Norwegian Minister of Energy, Terje Aasland, did the honour of opening the gates to the facilities.

"Today's ceremony marks a significant milestone—one that fills us with great pride and hope for the future. This is a proud moment not just for Northern Lights as a company, but for Norway and for the advancement of Carbon Capture and Storage (CCS) worldwide", said Terje Aasland, Norwegian Minister of Energy.

CCS will play a key role in the energy transition as it offers a solution for large and hard-to-abate industrial emitters that need to decarbonise their processes.

"Today we achieved an important milestone on our journey to demonstrate CCS as a viable option to help achieve climate goals. The whole world is looking to Norway to learn about CCS. Since construction started, we have welcomed more than 10,000 visitors from more than 50 countries. Today we celebrated the completion of the facilities together with the people of our host municipality Øygarden, the Norwegian Ministry of Energy, and key stakeholders, including policy makers and industry partners in the CCS chain. All are instrumental for the success of Northern Lights and the CCS business in Europe", said Heijn.

The Northern Lights Carbon Capture and Storage facilities. Photo: Torstein Lund Eik / Equinor

Northern Lights is a Joint Venture between Equinor, TotalEnergies and Shell. The partnership began in 2017, and construction of the facilities began in 2021 after the owners finalised their investment decision and the historic approval vote for the Longship project in the Norwegian parliament.

"This is an exciting day for Equinor, Northern Lights Joint Venture and our partners Shell and TotalEnergies. We are proud that Northern Lights, as part of the Longship value chain, has now been completed and is ready to receive CO2. It is an important milestone in the work of establishing a Carbon Capture and Storage value-chain in Europe.", said Grete Tveit, Senior Vice President Low Carbon Solutions at Equinor.

"We are proud to celebrate today the commissioning of the Northern Lights facilities. It has been a long journey since our partnership with the Norwegian State, Equinor and Shell started in 2017. This major milestone signals the readiness of the infrastructure to store CO2 and we look forward to receiving the first volumes from hard-to-abate emitters in 2025. This will bring a strong contribution to the decarbonization of European industry", said Arnaud Le Foll, Senior Vice-President New Business – Carbon Neutrality at TotalEnergies.

"Carbon capture and storage has a vital role to play in helping society achieve the goals of the Paris Agreement. Alongside efforts to avoid and reduce emissions, CCS will be an essential tool in supporting our customers on their decarbonisation journeys, particularly in those industries that are harder to decarbonise."

"I am delighted that the Northern Lights facilities are now ready to receive CO2 from industrial sites across Europe, for Shell this is an important part of our integrated offer to our customers", said Anna Mascolo, Executive Vice President, Shell Low Carbon Solutions.

More information

https://norlights.com

Transport and storage news

EU Innovation Fund's support for CCS projects beyond the North Sea will aid decarbonisation

www.catf.us

The European Commission announced €4.8 billion in grants under the Innovation Fund to 85 important climate and energy projects across 18 countries, including 16 projects involving CCS.

Key takeaways:

First Onshore CO2 Storage in the EU: The Danube Removals project in Hungary marks the first onshore CO2 storage project supported by the Innovation Fund in the EU, as well as Hungary's first commercial-scale CCS project. The project aims to deliver carbon removals through the capture of biogenic CO2 from the fermentation process at the biorefinery. This is a significant milestone in expanding CCS across new geographies and developing potential carbon removal capacity.

Offshore CO2 Storage Innovation: Offshore CO2 storage continues to be a priority with several projects selected, including the innovative StarFish project in Norway, which introduces floating injection and storage technology, helping to clear bottlenecks in Europe's storage capacity.

Expanding Carbon Capture beyond the North Sea: The Innovation Fund is helping to address the geographical imbalance in access to CO2 storage in Europe, with new projects in the Mediterranean. In Italy, two funded capture projects will likely support the development of the Ravenna CCS project by providing CO2. Spain is also particularly interesting, as it marks country's first commercial-scale CO2 storage project, the TarraCO2 project. Spain has vast geological storage potential but has been falling behind in developing CCS until now.

"The Innovation Fund's support for CO2 storage projects beyond the North Sea will greatly aid in decarbonising European industry, helping to address the geographical imbalance in access to storage. The selection of a Spanish project is particularly important, given the country's large cement and lime industries, for which we urgently need CO2 storage solutions," said Codie Rossi, Policy Manage Europe, Carbon Capture Program at CATF.

DOE invests $518M in permanent CO2 storage infrastructure

www.energy.gov/fecm
https://netl.doe.gov

The projects, funded by the Bipartisan Infrastructure Law, will provide for the development and validation of commercial large-scale carbon storage infrastructure.

DOE is also seeking information from stakeholders on carbon storage infrastructure needs prior to opening the next round of this funding opportunity.

"President Biden's Investing in America Agenda is generating record-breaking levels of public and private investment in critical infrastructure across the Nation to achieve historic climate and clean energy goals," said Brad Crabtree, Assistant Secretary of Fossil Energy and Carbon Management.

"The funding announced today will help ensure that carbon storage projects—crucial to slashing harmful carbon pollution—are designed, built, and operated safely and responsibly across all phases of development, to deliver healthier communities as well as high-quality American jobs."

Twenty-three projects were selected for negotiation to support the development of new and expanded commercial large-scale carbon storage projects with the capability to store 50 or more million metric tons of CO2 over a 30-year period.

All projects will support the Carbon Storage Assurance Facility Enterprise (CarbonSAFE) Initiative managed by FECM, and focus on the detailed site characterisation, planning, permitting, and construction stages of project development under CarbonSAFE.

Prior to the next release of this funding opportunity, DOE will evaluate the CarbonSAFE Initiative to ensure that it is supporting the deployment of carbon storage infrastructure in the most responsible, efficient, and effective manner possible.

As part of this evaluation, DOE is releasing a request for information (RFI) that seeks input from multiple stakeholders. The goal is to obtain these individual stakeholders' perspectives.

Industry developing guidelines for impure CO2 handling

www.woodplc.com

Wood is leading a Joint Industry Partnership (JIP) to create industry guidelines for CO2 specifications to accelerate sustainable CCUS projects.

The guidelines are the first of their kind to focus on the impact of impurities in CO2 across the entire CCUS value chain. The findings aim to accelerate the pace and growth of the CCUS industry by creating a CO2 conditioning standard to meet safety, environmental, technical and operational requirements.

Azad Hessamodini, Executive President for Consulting at Wood, said, "We are proud to contribute to the industry by sharing these guidelines for setting CO2 specifications. CCUS will undoubtedly play a crucial role in reducing emissions from hard-to-abate sectors. These guidelines will support the safe and effective design of projects while minimizing operational risks. This collaborative effort made possible through invaluable input from our clients and research partners represents a significant step forward in developing CCUS practices knowledge across our industry."

Wood established the JIP to collate industry research and the experiences of operators currently operating in the CCUS space to determine the effects of impure CO2 in existing carbon capture chains. The findings from this collaboration determined the negative impact impurities from CO2 capture can cause from transportation through to storage and eventual usage.

Identifying this data allowed for the development of guidelines to affirm the CO2 conditioning standards required to meet the safety, environmental and operational necessary for sustainable CCUS production.

The members of the JIP include Wood, Aramco, Equinor, Fluxys, Gassco, Harbour Energy, Mitsubishi Heavy Industries, Net Zero Technology Centre, OMV, Petronas, Shell, and TotalEnergies. The JIP also brought together industry and research experts, DNV, Heriot-Watt University, IFE, NGI, NPL and TÜV SÜD National Engineering Laboratory (NEL), with support from multiple licensors and equipment suppliers.

Northern Lights set to receive first CO2

Image: Jonny Engelsvoll / Equinor