Carbon Capture Journal

CCUS in EMEA

Project Bifrost: bridging present and future in Denmark

Rystad: EU falling behind Net Zero targets

EU approves €3 billion Swedish state aid

July / Aug 2024 Issue 100

Climeworks launches next generation DAC technology

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Front cover: Climeworks has launched its Gen 3 DAC technology which promises to double CO2 capture capacity per module, halve energy consumption and cut costs by 50 percent (pg. 25)

Back cover: Climeworks has begun operations of Mammoth, its largest direct air capture and storage plant ten times bigger than Orca (pg. 21)

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Leaders - CCUS in EMEA

Projects and policy

Capture and utilisation

Transport and storage

Project Bifrost: bridging the present and the future in Denmark

Project Bifrost, partly funded by the Danish state through the Energy Technology Development and Demonstration Programme (EUDP), has developed a concept for transporting and storing CO2 offshore in the future depleted Harald gas fields, which have a storage capacity of several million tonnes per year.

The project name "Bifrost" originates from Norse mythology, referring to a rainbow bridge connecting Asgard (the world of Gods) to Midgard (the world of humans). Project Bifrost connects onshore and offshore: CO2 is captured onshore and led offshore to be injected and stored underground in a sustainable way.

This makes Project Bifrost a bridge of transition – a solution that bridges the present-day use of traditional energy forms with the low-carbon energy forms of the future.

Denmark has the potential to become a major provider of CO2 transportation and permanent geological storage services in Europe, benefiting from underground storage potential in current and future depleted hydrocarbon fields and saline aquifer structures.

Further, Denmark is ideal since it has convertible onshore and offshore hydrocarbon facilities, a strategic location near Europe's main CO2 sources, and a competent and experienced offshore workforce.

During the past two and a half years, the focus of Project Bifrost has been to develop a concept for permanently storing CO2 in the underground of the Danish North Sea, turning the nearly depleted Harald fields into a climate solution of the future. With public funding and promising results, Project Bifrost has laid the foundation for Denmark to become a showcase for CCS.

The Harald fields – the perfect destination for the Danish CCS adventure to take off

Project Bifrost has performed the research and groundwork necessary for transporting and storing CO2 offshore in the future depleted Harald gas fields: The process begins with CO2 being captured on land, then transported offshore via specialised shipping or existing pipelines to the Harald platform, which is 250 kilometres off the west coast of Denmark. Finally, the CO2 is injected into the depleted gas reservoirs that are deeply seated in the subsurface.

The Harald fields have been chosen for the project because of the existing infrastructure, the well-known and suitable geology, the shallow sea water depth, and the central location for major national and European CO2 emitters.

The depleted Harald West sandstone reservoir is targeting in the first phase to store 2–3 million tonnes CO2 yearly.

Both a repurposed pipeline and a shipping solution are being explored to transport CO2 to the Harald platform 250km offshore Denmark

By adding the Harald East chalk reservoir as an upside, the injection capacity may be increased significantly. Chalk is the main reservoir type of the oil and gas fields in the Danish North Sea. Accordingly, the success of Harald East could serve as an important stepstone in the efforts to store CO2 in offshore Denmark.

With a storage capacity of several million tonnes per year, the Harald fields are the perfect destination for the Danish CCS-adventure to take off at scale.

Partnering for CCS

With Project Bifrost, the industry and the academic world are on a shared mission: Unlocking the CCS potential in Denmark and advancing state-of-the-art research and development of CCS. The Danish Underground Consortium (TotalEnergies, Nordsøfonden and BlueNord), Ørsted and the Technical University of Denmark (DTU), are all partners in the Project Bifrost and committed to finding CCS solutions in Denmark.

The oil and gas industry's solid offshore experience provides the knowledge necessary to ensure that establishing CCS-solutions in the Danish North Sea is safe for both the environment and people. With DTU as a strong academic force, Project Bifrost gives insights into the technical, operational, and socioeconomic dimensions of implementing CCS development in Denmark.

Pipeline solution

Project Bifrost has investigated the offloading of CO2 from ships to a receiving terminal and intermediate storage in the harbour of Esbjerg, transportation of CO2 to Nybro at the west coast of Jutland through a new onshore pipeline and further transportation to the offshore Harald fields via an existing natural gas pipeline.

The intermediate storage is designed to provide a steady flow towards the Harald fields. The intermediate storage can cover all phases from the startup phase of 3 million tonnes CO2 annually to 16 million tonnes CO2 annually.

The CO2 will be pressurised to 138 bars, heated, and transformed into a liquid phase in the storage tanks prior to transportation through the new onshore pipeline to Nybro where the CO2 will be redirected offshore via an existing natural gas transmission pipeline to the Harald platforms.

The existing offshore pipelines, owned and operated by Ørsted, have been evaluated for CO2 transportation. All pipelines are found suitable for transportation of CO2. The evaluation shows that the maximum transport rate is approximately 25 million tonnes annually for the pipeline from Nybro to the Tyra field and 13 million tonnes annually for the pipeline from Nybro to the Harald fields.

Investigations show that the pipeline from Nybro, connecting to the Harald fields, can be made available in an early stage, meeting the timeline for the first CO2 injection in the depleted hydrocarbon fields.

An assessment of the risk of chemical degradation and corrosion indicates that neither the metallic pipeline nor non-metallic seals or the inner coating of the pipeline will be affected by the CO2 and associated low-concentration contaminants. A fracture assessment indicates that normal pipeline repair methods can be applied in the unlikely event of a fracture formation.

Shipping solution

Project Bifrost has also investigated the transportation of CO2 by ships to the platform at the Harald fields instead of using a pipeline. In the shipping solution, the CO2 is cooled to a cryogenic state (-30°C to -20°C) and loaded onto liquid CO2 tankers. The CO2 is then shipped offshore and loaded onto a Floating Storage & Injection Unit (FSIU) connected to the Harald platform. To allow injection at the target rate of 3 million tonnes CO2 annually, shipping simulations have determined that three liquid CO2 tankers of 12,000 m^3 capacity each are required. The corresponding capacity required for the FSIU is 30,000 m^3.

The CO2 will be imported through a flexible pipeline from the FSIU to the Harald platform. The FSIU will furthermore interface with the Harald platform through a combined power cable and optical fibre connection. The CO2 will be heated and pressurised at the FSIU and will arrive at the Harald platform with a minimum temperature of 0°C and a pressure up to a maximum of 150 bars. At the platform, a set of high-pressure pumps will increase the pressure to 350 bars needed for the injection into the geological reservoirs.

Monitoring for safety

Monitoring of geological storage facilities, from pre-injection baseline surveys to final handover of the facility to authorities, is central to demonstrating safe and permanent containment of the CO2, to prevent and mitigate potential leakage, and to build public acceptance. Identifying the right monitoring technologies is therefore key to the success of any CCS project.

A worldwide review of monitoring, measurement and verification plans for offshore CO2 storage projects was performed. The review maps out the existing and readily available monitoring technologies, with focus on offshore storage in depleted hydrocarbon fields. The review also provides a view on recent advances that could play a key role in future long-term monitoring of storage sites.

Numerical feasibility simulations showed that the combined effects of fluid changes, pressure and temperature changes in the gas cap that will host the CO2 will be detectable using 4D seismic. This requires a seismic baseline survey acquired before the injection starts and another survey acquired after the injection, enabling comparisons of the two surveys.

Should CO2 leak from the sandstone reservoir in Harald West into the chalk at shallower depths, the fluid change will also be detectable using 4D seismic. A micro seismic feasibility study indicated that if rock deformations occur, it will be possible to distinguish deformations in the reservoir (which can be tolerated) from extremely unlikely deformations in the seal (which is not tolerated).

Long-term monitoring of CO2 by physical measurements and deployment of sensing systems at the seabed has been investigated for CO2 seepage detection. A fibre optical technology is under development, where the sensors themselves consist of a micrometre-thin CO2-sensitive coating reacting by contraction and thus affecting the light flux through the fibre optical cable. The plan is to place sensor networks at the seabed across the entire CO2 storage area.

Machine learning may be used to constantly analyse the stream of data that will be provided from monitoring tools. Three machine learning models for monitoring of CO2 plume movements were tested. The tests resulted in promising results supporting further research on the topic.

Forward focus

Project Bifrost is at the appraisal phase – and the start of a journey. Further development is needed to make CCS a commercial and industrial reality, and all participants in EUDP Project Bifrost will continue to engage in this development: DTU continues working on innovative monitoring technologies; Ørsted will launch technical studies for repurposing of the offshore gas pipeline and onshore facilities in Nybro; TotalEnergies and Nordsøfonden continue to work towards storing CO2 in the Harald fields on commercial terms with the storage exploration license, awarded in February 2023; and BlueNord is involved in CO2 storage studies through CarbonCuts.

For Denmark to become the European hub for CO2 storage, additional partnerships are required from the full CCS value chain to develop solutions for transporting the CO2 from emitters to the Harald facilities.

More information

www.bifrost-ccs.com

www.eudp.dk

Rystad: EU falling behind Net Zero targets compared to US and China

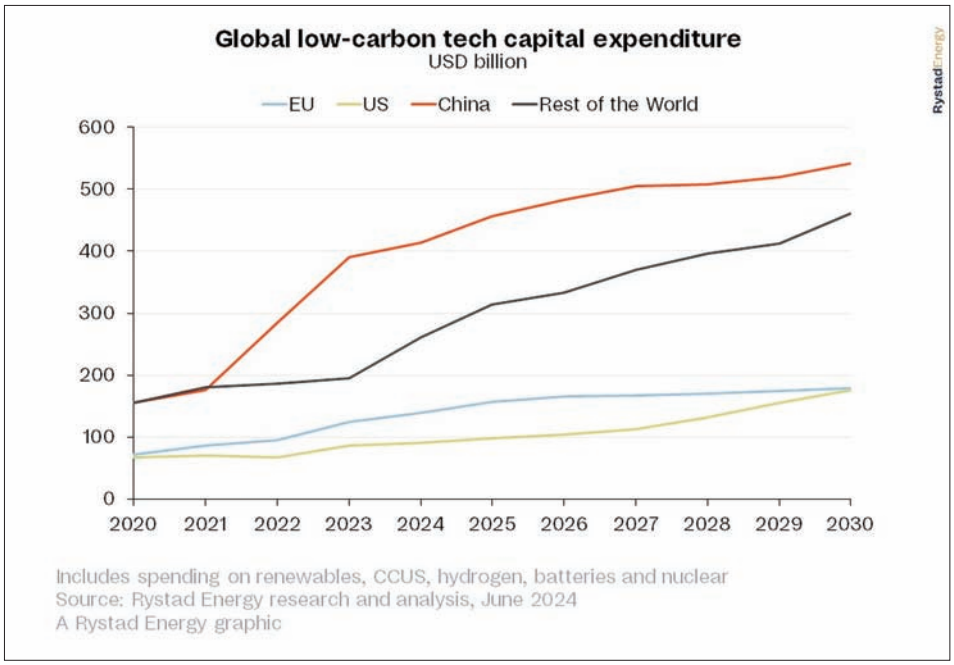
The European Union is set to fall far behind its ambitious energy transition targets for renewable energy, clean technology capacity and domestic supply chain investments, according to Rystad Energy research and modelling.

The EU's capital investments in clean technologies – including renewables, CCUS, hydrogen, batteries and nuclear – totalled $125 billion in 2023, dwarfed by China's spending of $390 billion in the same sectors. The US is currently behind the EU in annual clean-tech spending, investing $86 billion in 2023, but the Inflation Reduction Act is set to spur investments while the EU's spending will plateau in the years to come. The US will all but match the EU in total clean energy spending in 2030, and accelerate past the bloc in the ensuing years.

The Net-Zero Industry Act (NZIA) was passed by the EU earlier this year as a roadmap for the Union to meet its lofty goal of cutting emissions by 92% compared to 1990 levels by 2040 and reaching net zero by 2050. As a direct response to the US' landmark Inflation Reduction Act, the EU has set ambitious targets through the NZIA to support nascent industries, homeshore supply chains and position the bloc as an attractive investment location through supplier incentives. However, the cleantech investment landscape in the EU is a contrasting story of ambition versus reality, and another dose of reality could be coming soon.

The EU elections are right around the corner, and the results are likely to have sweeping impacts on the bloc's policy landscape. Many predict a political shift to the right following similar recent results in national elections, which could usher in a period of heightened Euroscepticism and decreased appetite to tackle climate change and the energy transition from a continental perspective. Next year is a pivotal one for the EU's climate change progress, with reevaluations of its nationally determined contributions (NDC) and emissions goals expected, so significant political upheaval could have a long-lasting impact.

"The stakes are high in the upcoming EU election – as the EU strives to remain competitive in the global clean tech market, the rising right-wing populist wave could critically heighten the EU's risk of falling further behind the US and China. The next few years are critical, and hesitancy or a lack of cohesion could see the bloc lagging its counterparts for decades to come. As things stand, the EU is losing ground and is highly unlikely to reach its lofty goals," said Lars Nitter Havro, senior analyst of energy systems research at Rystad Energy.



The NZIA sets forth ambitious targets and provisions to boost the production and deployment of key clean technologies, including batteries, CCUS and hydrogen electrolyzers, as part of the EU's broader emissions reduction and energy security goals. The Act outlines production targets and regulatory frameworks to accelerate the development and commercialisation of these technologies, but only the battery sector is showing genuine promise. Yet despite the favorable outlook, as with solar manufacturers, some European battery manufacturing companies are favoring the greener pastures across the pond, emphasising the need for competitive developer conditions.

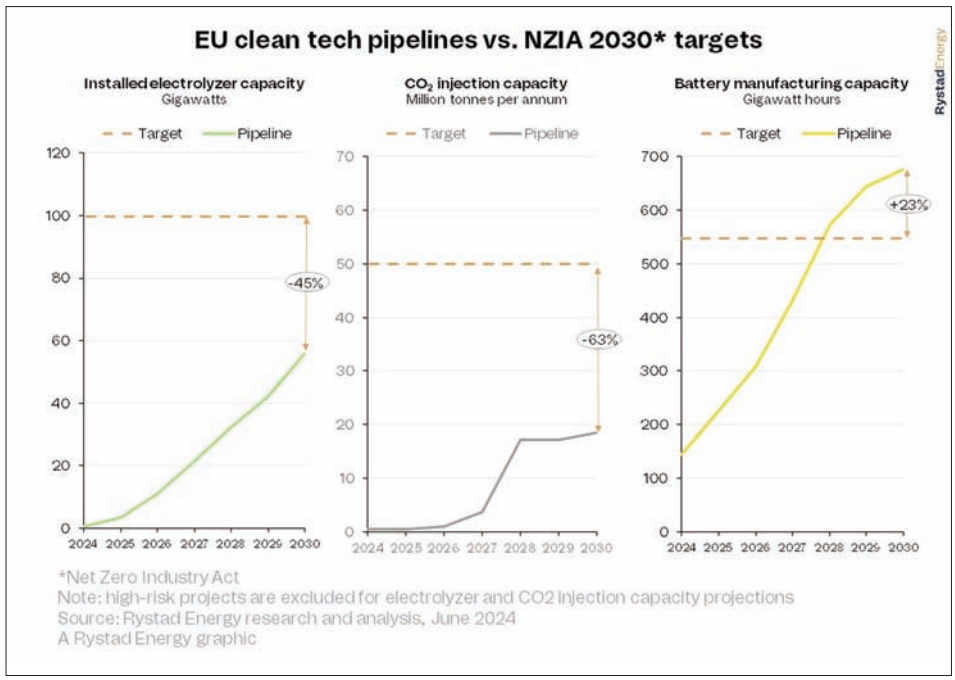
For instance, FREYR Battery, originally based in Norway, has relocated its headquarters to the United States and is setting up a gigafactory in Georgia to benefit from the Inflation Reduction Act's tax incentives. Similarly, Volkswagen, after its initial heavy investment in Northvolt, is now exploring opportunities in Canada to align with the IRA and maximize tax credits, illustrating a broader trend of shifting manufacturing to capitalize on favorable policy environments and sending a clear signal to policymakers. In addition, the Chinese manufacturers are doubling down in the EU, with EVE Energy targeting BWM offtake most recently with their announced Hungary manufacturing plant.

For CCUS, the NZIA focuses on enhancing injection capacity, a critical step for the permanent sequestration of carbon dioxide and lowering atmospheric CO2 levels. While capture technologies at emission sources have matured, the development of injection and storage infrastructure is not advancing at the same pace. The growth in injection capacity, essential for realizing the full potential of CCUS, has been hampered by a slower-than-expected development of storage sites, which remains a significant bottleneck. Recent data indicates the projected CO2 injection capacity will fall short of the NZIA target by about 63% by 2030, re-

flecting a widening gap between ambitious decarbonization goals and the current pace of infrastructure development.

Similarly, despite considerable investment and policy support, including initiatives such as the European Hydrogen Bank auction, hydrogen electrolyzers are not meeting the ambitious goals set by the NZIA. The recent auction results, where a total of 1.5 GW of electrolyzer capacity received support, underline the challenges in scaling up hydrogen production to meet the EU's target of 100 GW by 2030. Currently, the risked pipeline for hydrogen electrolyzers is falling 45% short of this target, highlighting a significant gap in achieving the required installation capacity. This shortfall can be attributed to a variety of factors, including technological challenges, high initial costs, and the slow development of the necessary infrastructure to support a widespread hydrogen economy.

The EU has also laid out specific targets for solar and wind energy capacity build-out in its updated Renewable Energy Directive (RED III), which was passed in October 2023. The bloc aims to generate 42.5% of its total power consumption from renewable sources by 2030 and is not far off that goal. Based on current and expected projects, the EU is expected to have about 975 gigawatts (GW) of combined solar and wind capacity, falling just short of the 1,050 GW required to hit its goal.



The success of this endeavor hinges on continued political and financial support for renewable technologies, which are vulnerable to political shifts and the reliability and availability of adequate manufacturing capacity. The EU has lost much of its manufacturing base to Chinese and US competition, and establishing a resilient supply chain in Europe is proving challenging. Key industry players are departing the bloc and relocating to regions with more attractive incentive structures, such as the US, and the EU simply cannot compete.

The migration of these companies not only erodes the EU's manufacturing capacity but also increases its reliance on non-European sources for essential components, making it dependent on other nations to secure its targets.

More information

www.rystadenergy.com

Njord Carbon secures funding as it aims for multi-million tonnes net negative CCS

Njord Carbon is on track to initially handle close to 1 million tons of biogenic CO2, increasing to around 5 million by 2030 in carbon negative CCS projects. www.verdane.com/njordcarbon

The company's two founding partners Verdane and Södra have fully funded Njord Carbon for the next two years. The funding is based on the commercial traction to date and will allow Njord Carbon to continue to build the necessary organisation and make further technical and commercial progress to be able to start to deliver removal credits in the first half of 2028.

Södra is the largest forest owner association in Sweden, processing forest raw material into renewable products such as pulp, timber, and energy. Verdane is a specialist growth investment firm with funds holding over €6.9 billion in total commitments.

"At Verdane, we committed several years ago to offset all our scope 3 emission through permanent engineered solutions. We look forward to getting access to more cost-effective high-quality removals once Njord Carbon is operational and commend Södra for committing to take a leading role in this important field," said Bjarne Kveim Lie, Founder and Managing Partner at Verdane.

Njord Carbon aims to capture several megatons of biogenic CO2 released from European projects. It is one of the few truly carbon negative CCS initiatives in the world. By separating out and permanently storing CO2 originally captured by growing trees, this venture goes beyond others that simply reduce emissions from existing industrial processes.

These carbon removals generate Carbon Dioxide Removal (CDR) credits that are sold on the Voluntary Carbon Market to customers looking to offset their emissions with the highest-quality technology-based CDR's.

Njord Carbon has now kicked off requests for information work from equipment suppliers, (like capturing technology, liquefaction, interim storage), and will update the business case and commercial discussions with credit customers accordingly.

EU approves €3 billion Swedish state aid scheme to support CCS

The Swedish scheme will support CCS aimed at reducing biogenic carbon dioxide released during the combustion or processing of biomass.

The measure will contribute to the achievement of Sweden's climate targets and the EU's strategic objectives under the European Green Deal, in particular the 2050 climate neutrality goal.

"This €3 billion scheme will enable Sweden to capture and to permanently store a significant amount of carbon dioxide generated by biomass combustion or processing. It will help Sweden and the EU to achieve their ambitious target of climate neutrality by 2050, while ensuring that competition distortions are kept to the minimum," said Margrethe Vestager, Executive Vice-President in charge of competition policy.

Sweden notified to the Commission of its plans to adopt a €3 billion (SEK 36 billion) scheme to support projects removing biogenic CO2 emissions through permanent CCS. The measure aims to enable CCS as a viable and effective tool to mitigate climate change. This is expected to increase investor confidence in CCS-technology, reduce costs for its future applications and thereby facilitate the development of a CCS value chain in the EU.

Under the scheme, the aid will be awarded through a competitive bidding process, with the first auction expected in 2024. Auctions will be open to companies that (i) carry out an activity in Sweden, emitting biogenic CO2, and (ii) implement projects with a capacity to capture and store at least 50,000 tonnes of biogenic CO2 per year.

Under 15-year long contracts, beneficiaries will receive a grant per tonne of biogenic CO2 that is permanently stored. The aid received will be adjusted taking into account possible revenues that might stem from the projects (e.g., thanks to voluntary carbon removal certificates), as well as other public support received for the same project.

The scheme will run until 31 December 2028. By enabling capture and storage of significant amounts of biogenic CO2, the scheme will contribute to Sweden's efforts to reduce its greenhouse gas emissions by 85% by 2045 compared to the 1990 level. It will also help Sweden and the EU to meet the objective of achieving climate neutrality by 2050.

Key findings

The Commission found that:

- The scheme is necessary and appropriate to incentivise investments in projects concerning capture and storage of biogenic CO2 in Sweden and thereby contributes to the national and EU climate targets.
- The scheme has an "incentive effect", as potential beneficiaries would not carry out the investments in biogenic CCS projects without the public support.
- The scheme has a limited impact on competition and trade within the EU. In particular, the aid is proportionate and any negative effect on competition and trade in the EU will be limited in view of the design of the measure, which will notably ensure that the aid amount is kept to the minimum.
- The scheme will be subject to an ex-post evaluation, which will verify, among other things, the effectiveness of the competitive bidding process.

On this basis, the Commission approved the Swedish measure under EU State aid rules.

The Commission assessed the scheme under EU State aid rules, in particular Article 107(3)(c) of the Treaty on the Functioning of the EU, which enables Member States to support the development of certain economic activities subject to certain conditions, and the Guidelines on State aid for climate, environmental protection and energy ('CEEAG'), which allow Member States to support measures reducing or removing CO2 emissions.

"Sweden has a good starting point for implementing BECCS thanks to its large point source pollution of biogenic carbon dioxide and several industries are already investing in the development of this technology," said the Swedish Energy Agency. "However, as BECCS is not economically feasible at present, state aid is needed to continue development."

The level of ambition for the support system is based on the targets stipulated in the Swedish Government Official Report 2020:4 – The road to a carbon neutral future. The goal, according to the governmental report, is to capture and store two million tonnes of biogenic carbon dioxide per year by 2030. However, the feasible potential for BECCS in Sweden amounts to at least 10 million tonnes of biogenic carbon dioxide per year in a 2045 perspective.

Chris Davies, director of Carbon Capture & Storage Europe (CCS Europe), commented, "Sweden now becomes the third country within the EU to provide specific financial support for carbon capture investment, following in the tracks of Denmark and the Netherlands."

"This is an exciting project intended not simply to curb emissions but to reduce the concentration of CO2 already in the atmosphere. It's a powerful demonstration of the essential role that carbon capture technology can play in curbing climate change and helping Europe achieve its net-zero ambition."

More information

ec.europa.eu

www.energimyndigheten.se

www.ccs-europe.eu

Researching synthetic fuels and chemicals from CO2 ten times faster

Empa researchers have developed an automated system, which allows them to research catalysts, electrodes, and reaction conditions for CO2 electrolysis up to ten times faster.

If you mix fossil fuel with a little oxygen and add a spark, three things are produced: water, climate-warming carbon dioxide, and lots of energy. This fundamental chemical reaction takes place in every combustion engine, whether it runs on gasoline, petrol, or kerosene.

In theory, this reaction can be reversed: with the addition of (renewable) energy, previously released CO2 can be converted back into a (synthetic) fuel.

This was the key idea behind the ETH Board funded Joint Initiative SynFuels. Researchers at Empa and the Paul Scherrer Institute (PSI) spent three years working on ways to produce synthetic fuels – known as synfuels – economically and efficiently from CO2.

This reaction, however, comes with challenges: for one, CO2 electrolysis does not just yield the fuel that was previously burned. Rather, more than 20 different products can be simultaneously formed, and they are difficult to separate from each other.

The composition of these products can be controlled in various ways, for example via the reaction conditions, the catalyst used, and the microstructure of the electrodes. The number of possible combinations is enormous and examining each one individually would take too long. How are scientists supposed to find the best one? Empa researchers have now accelerated this process by a factor of 10.

As part of the SynFuels project, researchers led by Corsin Battaglia and Alessandro Senocrate from Empa's Materials for Energy Conversion laboratory have developed a system that can be used to investigate up to ten different reaction conditions as well as catalyst and electrode materials simultaneously.

The researchers have recently published the blueprint for the system and the accompanying software in the journal Nature Catalysis.

The system consists of ten "reactors": small chambers with catalysts and electrodes in which the reaction takes place. Each reactor is connected to multiple gas and liquid in- and outlets and various instruments via hundreds of meters of tubing. Numerous parameters are recorded fully automatically, such as the pressure, the temperature, gas flows, and the liquid and gaseous reaction products – all with high temporal resolution.

Corsin Battaglia examines one of the ten reactors. Image: Marion Nitsch

"As far as we know, this is the first system of its kind for CO2 electrolysis," says Empa postdoctoral researcher Alessandro Senocrate. "It yields a large number of high-quality datasets, which will help us make accelerated discoveries".

When the system was being developed, some of the necessary instruments were not even available on the market. In collaboration with the company Agilent Technologies, Empa researchers co-developed the world's first online liquid chromatography device, which identifies and quantifies the liquid reaction products in real time during CO2 electrolysis.

Sharing research data

Conducting experiments ten times faster also generates ten times as much data. In order to analyze this data, the researchers have developed a software solution that they are making available to scientists at other institutions on an open-source basis. They also want to share the data itself with other researchers.

"Today, research data often disappears in a drawer as soon as the results are published," explains Corsin Battaglia, Head of Empa's Materials for Energy Conversion laboratory. A joint research project between Empa, PSI and ETH Zurich, which bears the name PREMISE, aims to prevent this. "We want to create standardized methods for storing and sharing data," says Battaglia. "Then other researchers can gain new insights from our data – and vice versa."

More information

www.empa.ch

CO2 removal: feasibility study evaluates possible measures for Germany

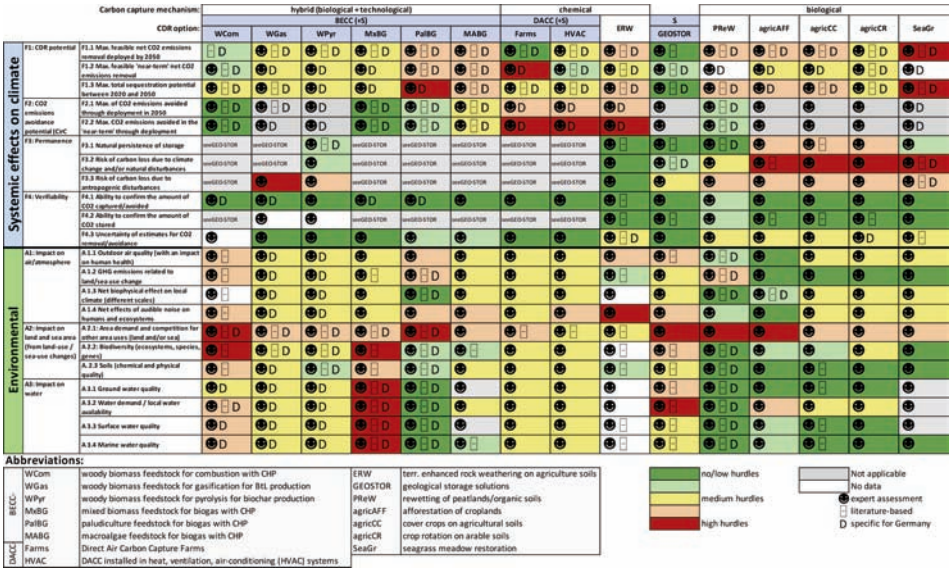
An interdisciplinary research team led by the Helmholtz Centre for Environmental Research has developed a clear evaluation matrix.

Germany aims to be climate neutral by 2045. In order to achieve this goal, greenhouse gas emissions must be greatly reduced and effective measures to remove carbon dioxide from the atmosphere established. But which methods for the removal, binding, and storage of CO2 can be readily implemented in Germany over the next two decades?

An interdisciplinary research team led by the Helmholtz Centre for Environmental Research (UFZ) and the GEOMAR Helmholtz Centre for Ocean Research Kiel has now carried out a feasibility study for 14 different carbon dioxide removal (CDR) options for Germany, taking into account ecological, technological, economic, social, institutional, and systemic aspects. The researchers hope that the results of their study will help to drive forward decision-making processes and strategies in politics, business, and technological development. The study was recently published in the specialist magazine Earth's Future.

In order for Germany to become climate neutral by 2045, CO2 emissions must first be drastically and permanently reduced. However, CDR measures alone cannot remove the large quantities of CO2 that are emitted in Germany. It is assumed that they can offset only approx. 5-15% of the current emissions. But how effective and efficient are the various possible measures? What are the hurdles to implementing them? What are the costs? How environmentally friendly are they? The research team investigated these and other questions in its latest study in which it analysed the feasibility of 14 CDR measures that could be implemented in Germany.

The measures include direct air carbon capture and storage (DACCS) and bioenergy with carbon capture and storage (BECCS) as well as measures to increase carbon uptake by ecosystems. For their investigations, the researchers used an evaluation framework they had jointly developed in a previous study. Six different dimensions are assessed: ecological, technological, economic, social, institutional, and systemic.



Evaluation matrix of systemic and environmental dimensions

"For a good and comparable assessment of the feasibility, taking into account the risks and opportunities of different CDR measures, various aspects must be considered. Because these are not easy to keep track of and compare, we wanted to shed light on them with our study," said Dr Malgorzata Borchers from the UFZ and co-first author of the study together with Dr Johannes Förster and Dr Nadine Mengis.

Within the framework of workshops in multidisciplinary teams of the Helmholtz Climate Initiative, the expertise of 28 co-authors was incorporated into the study. "We thus had an incredibly large pool of expert knowledge at our disposal. This enabled us to assess the current state of knowledge on the CDR methods analysed in our study," said Mengis.

The researchers have presented their results in a clear evaluation matrix using a traffic light colour system. Red means that the hurdles to introducing a CDR measure are high in a certain area (e.g. ecological or economic). Yellow means they are medium, and green means they are low.

For measures with a higher CO2 removal potential such as BECCS, the traffic light colour in the evaluation matrix is red in many areas. "With technological CDR measures, the economic and institutional hurdles in particular are still quite high," said Prof Daniela Thrän, who heads the Department of Bioenergy at the UFZ.

In the evaluation matrix, there are also white spots, which indicate that there are currently no data available. "This is particularly the case with the social assessment aspects of the CDR measures. Further research is urgently needed. For example, on how the costs and disadvantages of CDR measures could be distributed fairly across society and how their implementation would benefit society as a whole," said Mengis.

The scientists hope that their feasibility study for possible CDR measures in Germany can help decision-makers to better understand and categorise the complex information.

More information

www.ufz.de

Danish Energy Agency opens public consultation on multi-billion CCS fund

The competitive bidding process for the new CCS Fund, providing funds for approximately DKK 28 billion over 16 years, is now being opened with the publication of the public consultation material.

The Danish Energy Agency has published public consultation material in connection with the launch of the CCS Fund with a total budget of DKK 28.3 billion (2024 prices). The fund is intended to cover costs for the capture, transport and geological storage of fossil, biogenic, or atmospheric CO2.

DKK 1.770 billion is allocated annually from 2029 to 2044. The funds are tied to a requirement for the commissioning of capture facilities by December 1st 2029, and a minimum requirement for full capture and storage from 2030. Companies that are able to capture and store CO2 from 2029 can also receive subsidy for doing so. The estimated total climate contribution amounts to a reduction of 2.3 million tonnes of CO2 annually from 2030.

The fund is designed to ensure maximum competition for the subsidy in order to achieve as many CO2 reductions as possible at the lowest possible cost. Subsidy is paid per tonne of CO2 stored. The tender will be conducted as a competitive bidding process with negotiation, where market participants bid with a fixed quantity per year that they will capture and store and a price per tonne of CO2. Multiple bidders can be awarded a contract for subsidy.

The CCS Fund will also help promote the long-term use of CO2 (CCU), as the capture and transport infrastructure is largely the same for CCU. At the same time, the contract offers a certain flexibility to opt out of the contract if, for example, the operator sees a better business opportunity in selling CO2 for utilisation purposes.

Contribution to achieving climate goals

The capture and storage of CO2 underground is considered one of the most important tools for meeting both national and international climate goals. The CCS Fund aims to ensure that Denmark meets its 2030 target of a 70 percent reduction in CO2 emissions compared to 1990 levels. The CCS Fund is estimated to contribute 2.3 million tonnes of CO2e annually from 2030. The Danish Ministry of Climate, Energy and Utilities' Climate Status and Outlook 2024 (KF24) estimates a reduction gap of approximately 1.5 million tonnes of CO2e.

The European Commission has recommended that to achieve a 90% reduction by 2040, approximately 50 million tonnes of CO2 should be captured and stored by that year. Similarly, the UN's Intergovernmental Panel on Climate Change (IPCC) estimates that 730 billion tonnes of CO2 must be stored globally by 2100 to meet the Paris Agreement targets. The CCS fund will contribute to achieving these goals.

Broad political coalition behind the fund

In September 2023, a broad coalition of parties in the Danish parliament adopted an agreement on strengthened framework conditions for CCS, Klimahandling – Vejen til fuld fangst og lagring af CO2 i 2030. The agreement allocates funds to the new scheme, which consolidates two previously planned support schemes – the CCUS Fund from Klimaaftale for energi og industri mv (2020) and the GSR Fund from Aftale om grøn skattereform for industri mv. (2022).

The new CCS Fund consists of a single competitive bidding process with negotiation, whereas the previous plan was to allocate funds over two competitive bidding processes in June 2024 and June 2025, respectively. These changes are based on new insights from the Danish Energy Agency's public consultation and experiences from the two previous CCS funds. The most important lesson learned is that the market actors need more time for the commissioning of facilities, the acquisition of storage permits and the establishment of the value chain.

The Danish Energy Agency's consultation will run until August 20, 2024, giving an opportunity for everyone, including potential bidders, to provide feedback on the CCS Fund. The Danish Energy Agency expects to publish the tender material in October 2024 and award contracts in April 2026 following a prequalification and negotiation round.

Additionally, a tender notice will be published on the European Union's electronic tendering platform, Tender Electronic Daily (TED). The materials will be in English.

Facts:

• The CCS fund is the third fund administered by the Danish Energy Agency providing subsidy for CO2 capture and storage.

• The first fund, the CCUS Fund, totalling approximately DKK 8 billion, was awarded to Ørsted, which plans to capture and store 430,000 tonnes of CO2 annually from 2026 and 20 years onwards. Ørsted anticipates capturing and storing the first CO2 by 2025.

• The NECCS fund was concluded in May 2024, with the Danish Energy Agency contracting three companies to ensure the capture and storage of 160,350 tonnes of biogenic CO2 annually from 2026 to 2032.

• According to the Danish Energy Agency's latest point source analysis, the full capture potential from all Danish point sources ranges between 6.9-13.7M tonnes of CO2 by 2030.

• Denmark has six permits for exploration with the aim of CO2 storage.

• Denmark has political agreements with several countries for cross-border transport of CO2 for geological storage beneath the seabed.

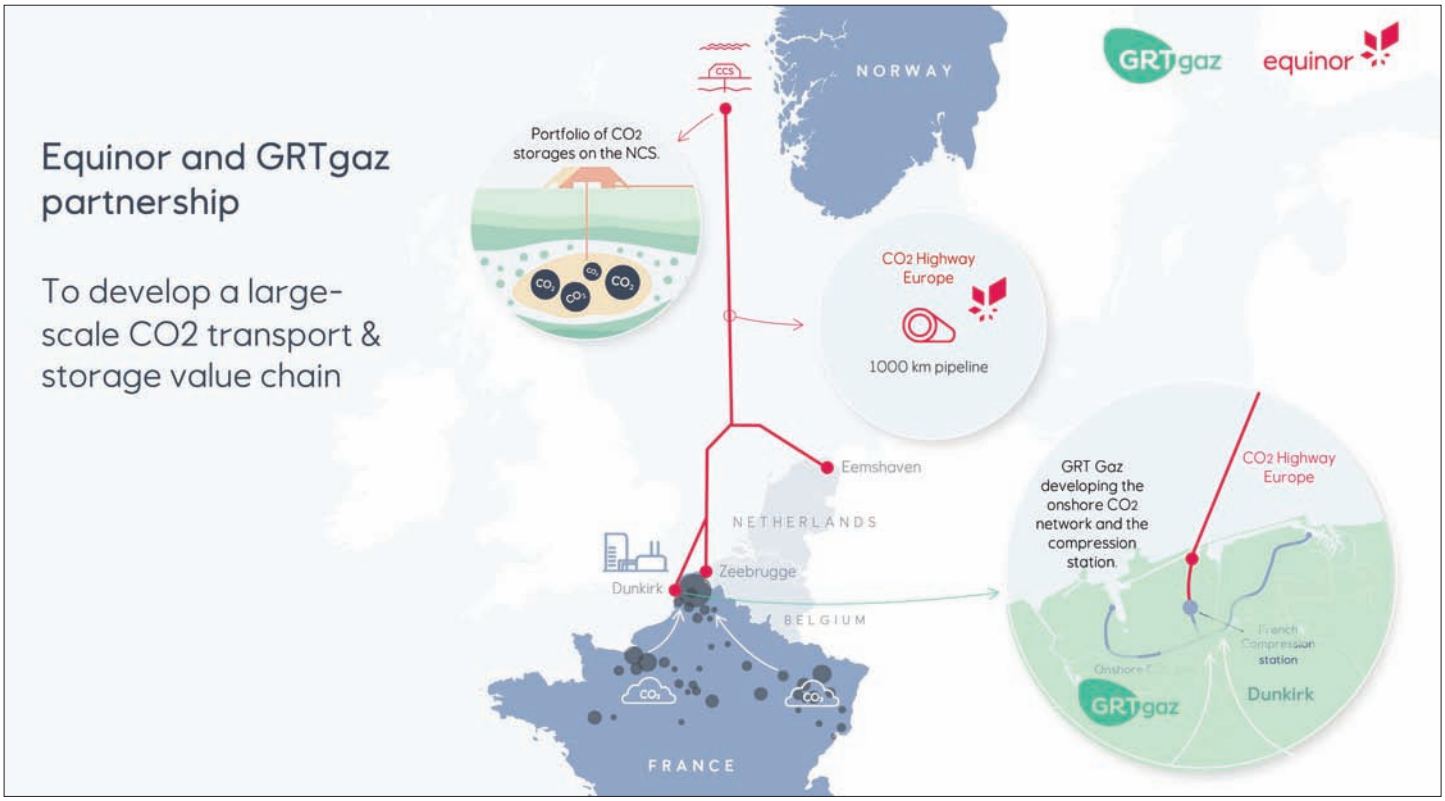
• Implementation of the total CCS fund is contingent upon state aid approval from the European Commission.

More information

www.ens.dk/ccs

Equinor and GRTgaz to develop CO2 transport infrastructure in France

They have signed a project development agreement (PDA) for a CO2 transport system for captured CO2 from industrial emitters in France to permanent storage offshore Norway via the planned CO2 Highway Europe pipeline project.



The development will consist of a network of onshore CO2 pipelines, to be developed by GRTGaz, which will connect France's Dunkirk industrial area to Equinor's CO2 Highway Europe, a large-scale CO 2 pipeline being planned by Equinor also connecting Zeebrugge, Belgium to a portfolio of storage sites under the seabed offshore Norway.

"For industries that cannot decarbonise directly through clean power, CCS offers a viable solution," said Grete Tveit, senior vice president Low carbon solutions, Equinor. "By building CO2 transport and storage solutions at an industrial scale together with GRTgaz we can help carbon-intensive industries in France to continue developing and securing jobs and value creation in a sustainable future. The collaboration also strengthens the viability of the CO2 Highway Europe project as the French connection will further strengthen economies of scale."

The project under the PDA aims to help decarbonise the Dunkirk industrial area which accounts for around 20 percent of France's industrial CO2 emissions. Specifically, GRTgaz will develop a 30 km onshore pipeline network in the Dunkirk region with a compressor station in Dunkirk sending the CO2 into the offshore pipeline connecting to the CO2 Highway Europe.

The capacity in the initial phase will be 3 to 5.5 million tonnes of CO2 per year, and the capacity can be expanded to also accommodate CO2 captured at other industrial clusters in France.

"GRTgaz is developing dedicated transmission networks contributing to transport CO2 from the French industrial sites where it is captured to storage and utilisation sites in France and Europe. Indeed, the capture, storage and utilisation of CO2 will play a major role in decarbonising the national and European economy, and infrastructure is an essential element in this CO2 value chain," said Sandrine Meunier, chief executive officer of GRTgaz.

Equinor and GRTgaz, with their complementary skills, will cooperate in the development of their CO2 transmission and storage infrastructures and associated services: network planning, technical design and industrial safety, interoperability, regulatory aspects and institutional relations. Feasibility studies are currently under way, with the aim of launching basic engineering studies at the end of 2024 and commissioning in 2029.

In France, this project is in line with the proposed government's strategy (France 2030) for the capture, use or permanent geological storage of carbon dioxide.

More information

www.equinor.com/energy/carbon-capture-utilisation-and-storage

www.grtgaz.com

MHI, ArcelorMittal Gent begin blast furnace CO2 capture trial

The pilot carbon capture unit will operate for one to two years at Gent, to test the feasibility of progress to full-scale deployment of the technology, which would be able to capture a sizeable portion of the Gent site emissions.

ArcelorMittal and partners Mitsubishi Heavy Industries, Ltd. (MHI), BHP, along with Mitsubishi Development have successfully started operating a pilot carbon capture unit on the blast furnace off-gas at ArcelorMittal Gent in Belgium. Engineers have been working on site since January to assemble and commission the unit.

Speaking in Gent at the consortium meeting, ArcelorMittal Belgium's CEO, Manfred Van Vlierberghe, said, "ArcelorMittal Belgium's decarbonisation efforts can be summarized in three axes. The first axis focuses on energy efficiency: reuse of waste heat and renewable energy. In our second axis, we are replacing coal with a combination of gas and electrification. And finally, the third axis, is based on circular use of carbon - CCU and CCS. Here, the installation of the carbon capture unit on our Gent blast furnace is a great example. The main ambition is to achieve completely carbon-free processes. A radical change is difficult, so we embrace every step that takes us towards our goal."

In October 2022, the four parties announced their collaboration on a multi-year trial of MHI's carbon capture technology (Advanced KM CDR Process™) at multiple CO2 emission points, starting at the Gent steelmaking site. The pilot carbon capture unit will be testing initially with blast furnace and reheating furnace gas and has the potential to be trialled to capture steelmaking gases such as reformer flue gas from a Direct Reduced Iron (DRI) plant.

The development of the carbon capture solution at Gent could feed into multiple CO2 transport and storage projects under development in the North Sea region and contribute to global technological solutions required for decarbonisation of steel production. The EU has an objective to achieve an annual CO2 storage capacity of 50 million tonnes by 2030, proposed under the Net-Zero Industry Act. Moreover, the International Energy Agency (IEA) estimates CCUS technology needs to apply to more than 37 per cent of primary steel production by 2050, equivalent to 399 Mtpa of CO2, for the Net Zero Emissions scenario (Source: IEA Net Zero Roadmap - 2023 update).

To further understand how MHI's carbon capture technology can be incorporated into existing steel plants, ArcelorMittal is facilitating the trial in Gent, Belgium, with MHI supplying its proprietary carbon capture technology and supporting the engineering studies. BHP and Mitsubishi Development, as key suppliers of high-quality steelmaking raw materials to ArcelorMittal's European operations, are supporting trial funding.

MHI's Senior Vice President (CCUS) of GX (Green Transformation) Solutions, Tatsuto Nagayasu, said, "The launch of this pilot carbon capture unit marks a significant milestone on the iron and steel industry's journey toward net-zero emissions. As a provider of innovative technologies, we are thrilled to witness our solutions in action, helping to decarbonize existing assets. We eagerly anticipate further deploying our technologies to achieve this goal."

The trial at Gent will have two phases. The first phase involves separating and capturing the CO2 from the top gas from the blast furnace at a rate of around 300kg of CO2 a day - a technical challenge due to the differing levels of contaminants in the top gas. The second phase involves testing the separating and capturing of CO2 in the off-gases in the hot strip mill reheating furnace, which burns a mixture of industrial gases including coke gas, blast furnace gases and natural gas.

BHP Group Sales & Marketing Officer Michiel Hovers said, "This represents real progress in proving up the feasibility of carbon capture for steel production, and BHP is delighted to be part of this consortium working on the pilot plant. This work could help develop a technology that may significantly lower CO2 emissions intensity from the blast furnace which remains critical to meet steel demand, and while other pathways are further matured."

More information

www.mhi.com

www.arcelormittal.com

Harnessing the Important Project of Common European Interest for CCUS

Bellona, together with other 29 members of the industrial carbon management community and umbrella organisations, has express its support to the inclusion of an Important Project of Common European Interest (IPCEI) in the area of industrial carbon management and CCUS.

Industrial carbon management is an essential pillar of a sustainable and competitive economy in Europe, which has been legally and politically supported. The Commission's Industrial Carbon Management Strategy (ICMS) stresses the key role of CCS in reaching Europe's climate targets and to decarbonise hard to abate sectors for which CCS might be the only decarbonisation option allowing climate neutrality by 2050.

The Net Zero Industry Act (NZIA) recognises carbon capture and storage as strategic net-zero technologies and supports project deployment with regulatory measures, including accelerated permitting procedures. The Act also includes a target for the EU to achieve 50 million tonnes per year of CO2 storage capacity by 2030.

A key bottleneck in the development of industrial carbon management in Europe is the lack of a viable business case including funding and de-risking mechanisms in order the build-out of CO2 transport and storage infrastructure. Developing infrastructure all over Europe is critical to European industries. Failure to do so could risk undermining the competitiveness of industrial regions without access to transport and storage infrastructure, potentially risking the integrity of the Single Market.

The ICMS acknowledges the difficulties in building a viable business case for CCS and CCU projects, outlining the significant upfront investment capital required and uncertainty of future CO2 prices as a key barrier. Currently, the incentives for private and public investment to provide the business case for industrial carbon management are lacking.

IPCEIs have a demonstrated track record of accelerating industrial production and unlock private investment, as it has been already the case for sectors considered strategic, such as microelectronics, batteries, and hydrogen. For these reasons we believe that the large, cross-border and essential nature of CCUS projects makes the IPCEI instrument appropriately and efficiently suited to overcome the recognized market failure and to support infrastructure investments of unprecedented importance for the EU.

Establishing CCUS at large scale in Europe will allow Member States to reach respective decarbonisation objectives, climate and NZIA target while at the same time supporting the competitiveness of industry, safeguarding jobs and contributing to employment growth.

Therefore, we would positively support the potential initiative of an IPCEI for CCUS infrastructure and stand ready to act decisively in such new public-private partnership cooperation. We would like to call for your support in bringing the CCUS domains high on the agenda during the upcoming JEF-IPCEI Technical meeting. Further, in order to allow the full value chain – from capture to storage – to be swiftly deployed, as needed, we also want to highlight the importance of making the process of IPCEI more efficient, in order to allow for effective and rapid contribution to decarbonisation of hard-to-abate sectors.

Bellona Europa Roadmap for 2024-2029

The upcoming Commission's mandate from 2024 to 2029 is already being hailed as the "mandate of implementation" for climate policy. Bellona Europa has just published its Roadmap for 2024-2029 "Climate infrastructure, science-based policy making and well-functioning markets for a net-zero Europe".

As Europe transitions from planning to action, three key areas should be prioritised by the new Commission to achieve the European Union's climate targets:

• Deployment of Climate Infrastructure: Robust climate infrastructure forms the backbone of the green and just transition, while also rising as a solution to many climate-related challenges. Crucial infrastructure including clean energy networks – especially electricity grids – and CO_2 transport and storage will need to be deployed rapidly and extensively.

• Science-Based Robust Policy Making: Every climate measure implemented today must be compatible with the goal of reaching climate neutrality by 2050 and net-negative thereafter. Policies must be grounded in rigorous scientific research to ensure effectiveness and sustainability.

• A Well-Functioning Market for a Net-Zero World requires strengthening policies that promote low-carbon products, discouraging the production of carbon intensive ones. This is exemplified by the EU's Emission Trading System (ETS) and Carbon Border Adjustment Mechanism (CBAM) whose design should address market failures, properly pricing CO_2, and supporting private investments in sustainable activities, but currently fail to do so sufficiently. The transition must be just and inclusive, with upskilling and reskilling initiatives to support workers moving into green sectors, ensuring that no one is left behind.

"Climate targets must be reached by industries leading this shift by actions rather than words, becoming global leaders and winners of low carbon production," said Jonas Helseth, Director, Bellona. "As the world's biggest single market, Europe can and must contribute to this race to the top, where its transitioning industries can compete in markets for decarbonised products. The EU can accelerate this, leveraging its economic pull to ensure climate impact is key criterion for traded goods and services."

Reaching the European target of being the first climate neutral continent by 2050 is not an ideological choice, but a global necessity.

More information

eu.bellona.org

EMEA news

Nuada starts cement carbon capture trials with Buzzi

www.nuadaco2.com

sustainability.buzzi.com

Nuada's pilot plant has commenced operations, capturing CO2 emissions from the stack of Buzzi Unicem's cement facility in Monselice, Italy.

Buzzi, an Italian cement company with global operations, is trialling UK based Nuada's advanced carbon capture technology as a solution to produce low-carbon cement, leading the way in cement industry decarbonisation.

This pilot project marks a milestone in carbon capture innovation demonstrating the performance of Nuada's next-generation technology within a cement manufacturing setting. Nuada has developed an energy-efficient carbon capture solution by combining advanced solid sorbents named Metal-Organic Frameworks (MOFs) with a mature vacuum pressure swing adsorption (VPSA) process.

The innovative, electrically powered system separates CO2 from industrial flue gases using pressure instead of heat and offers a promising approach to overcoming the energy, cost, and integration challenges associated with deploying traditional carbon capture solutions in industry.

"We are deploying the most energy-efficient carbon capture technology developed to date, a solution that redefines the decarbonisation landscape for hard-to-abate sectors like cement," said Dr. Conor Hamill, Co-CEO of Nuada. Dr. Jose Casaban, Co-CEO of Nuada added, "This plant demonstrates the robustness, scalability and game-changing benefits of our innovative capture system. Together with Buzzi, we are demonstrating the future of carbon capture in cement."

The plant is fully operational now, capturing 1 tonne of CO2 per day from cement flue gas. The project is backed by the Global Concrete and Cement Association (GCCA) and was initiated through GCCA's Innovandi Open Challenge programme, an initiative that fosters collaborations between major cement producers and innovative technology providers to decarbonise cement production. The cement sector currently accounts for 7% of global carbon emissions, and according to the GCCA's Net Zero Roadmap, carbon capture is the main decarbonisation lever.

Nuada has developed an energy-efficient carbon capture solution by combining Metal-Organic Frameworks (MOFs) with a mature vacuum pressure swing adsorption (VPSA) process

"Our company has always been at the forefront of technology and search for innovative solutions" said Luigi Buzzi, CTO at Buzzi. "We are excited to host Nuada's advanced carbon capture technology and start the pilot test campaign in Monselice: we look forward to confirm the high expectations that Nuada technology can play a leading role in the cement industry's decarbonization journey"

Buzzi is aiming to be Net Zero by 2050 with an intermediate goal to reduce by 2030 its specific Scope 1 net emission to less than 500kgCO2/t of cementitious product.

WOOD completes design for CCS hub in Saudi Arabia

www.woodplc.com

Front-end engineering and design (FEED) for the first phase of Aramco's Accelerated Carbon Capture and Sequestration (ACCS) project in Saudi Arabia has been completed.

The project is expected to be the world's largest carbon capture and sequestration hub upon completion. The FEED has been delivered by around 200 engineers from across Wood's global Projects and Consulting business units.

With an ambition to further reduce carbon emissions from its upstream operations, the first phase of the ACCS project intends to capture carbon emissions from Aramco gas plant facilities near Jubail, on the east coast of Saudi Arabia, as well as from third-party emitters.

Wood designed the greenfield dehydration and compression facilities and the large pipeline network, including a 200+ kilometre dense-phase CO2 pipeline for the ACCS project, which aims to transport 9 million tonnes per annum (MTPA) of emissions and sequester it within onshore geological storage by 2027. Aramco plans to store up to 14 MTPA of CO2 equivalent by 2035 – contributing towards the Kingdom reaching its CCUS goal of 44 MTPA by 2035.

Craig Shanaghey, Wood's Executive President of Projects, said, "We are proud to be at the forefront of designing the future of energy by leveraging our 20 years of experience in carbon capture engineering to bring the ACCS project to life, supporting Aramco as our long-term client on its energy security and transition ambitions."

"The United Nations Framework Convention on Climate Change (UNFCCC) has underlined the significant role CCS can potentially play in helping to reach the 2-degree goal set out in the Paris Agreement, and it is investments like this world-leading project that can support that progress and make a tangible difference to reduce the carbon emissions of heavy industries."

CCUS: the viable interim solution to advancing hydrogen production

Ahead of the largest hydrogen congress in North America being held this month, Nadim Chaudhry, CEO of World Hydrogen Leaders, looks at the opportunities for CCUS-enabled low carbon hydrogen and how US policy is accelerating the advancement of this vital fuel of the future.

While its relevance in helping to reach climate goals has long been recognised, deployment of carbon capture, utilisation and storage has been slow and consistently accounting for less than 0.5% of global investment in clean energy technologies.

Although CCUS is not a new technology and there are currently around 41 operational facilities globally, it has typically been deployed at a small scale – mainly for R&D projects and for enhanced oil recovery[1]. In order for CCUS to meaningfully contribute to climate change goals, the amount of CO_2 captured would need to grow four-fold from current levels by 2030)[2].

However, stronger climate targets and investment incentives are now starting to drive increased momentum into CCUS – and one of the key strategies to provide a boost to the technology is the efficient production of hydrogen.

Both CCUS and low-carbon hydrogen are well-tested and the US has shown that they can be rapidly scalable solutions that can deliver decarbonised industries at a lower cost

The role of CCUS in low carbon hydrogen production

Hydrogen is a versatile energy carrier that can help support the decarbonisation of a range of hard-to-abate sectors where electrification from renewable sources cannot deliver the level of energy output required.

These include iron, steel, chemicals and cement production – as well as hydrogen-based fuels for aviation, shipping and long distance haulage.

CCUS can facilitate the production of low carbon hydrogen (sometimes referred to as 'blue' hydrogen) from natural gas and provide an opportunity to bring it into new markets in the near term – and at reasonable cost.

It can help alleviate pressure on already constrained electricity grids, allowing renewable electricity generation and electrolytic hydrogen production to scale at a more manageable pace. This benefit of CCUS-enabled hydrogen over the next decade has been recognised in the Committee on Climate Change's recently published Climate Change Committee's 2023 Progress Report to Parliament.

Today, the cost of CCUS-enabled hydrogen production is likely to be around 50% of hydrogen production via electrolysis powered by renewables-based electricity. While the cost of electrolytic hydrogen is anticipated to reduce over time with the onset of increasingly cheaper electrolysers and renewable electricity, CCUS-equipped hydrogen will most likely remain a competitive option across regions typically associated with low-cost fossil fuels.

Recently there has been a significant increase in the appetite to develop CCUS projects, with a 50% increase in CO2 capture in the 12 months between 2022 to 2023[3]. This has been driven by governments internationally coming under increasing pressure to meet global climate targets, implementing robust legislation and providing clear pricing signals in order to make CCUS commercially viable.

Despite this positive news, there remain three significant issues. From the many announced CCUS projects, only around 5% have taken firm investment decisions due to

1. *Global Status of CCUS Report 2023, CCUS Institute*
2. *Accelerating deployment – CCUS in Clean Energy Transitions – Analysis - IEA*
3. *Global Status of CCUS Report 2023, CCUS Institute*

the uncertainty of demand, a lack of clarity around certification and regulation – and critically important - the lack of infrastructure available to actually deliver the hydrogen to customer sites.

And, according to the IEA, to help deliver a much decarbonised heavy industry by 2030, a third of all hydrogen production will need to be dedicated to those hard to abate sectors - and currently these applications only account for around 0.1% today. So, there is considerably more work to do.

Challenges with deploying CCUS at scale

The fact that CCUS is far from a mature industry, a single stakeholder is typically unable to take on all the expertise, risk and capital expenditure needed across the whole value chain.

As such, the most significant challenges with deploying CCUS at scale are the multiple different, distinct stakeholders that need to be coordinated including: the industrial plants which are the CO2 emitters themselves; the various CCUS technology suppliers which separate and capture the CO2; providers of processing, compression solutions transportation solutions - and, finally, experienced storage providers who can inject and store the CO2 underground.

It is evident that urgent policy action is needed to create demand for low carbon hydrogen and unlocking the necessary investment to accelerate the scale-up of production and the building of delivery infrastructure.

The US leading the way

Currently, different policy approaches are being undertaken by governments to encourage the deployment of CCUS at scale. In particular, the United States has provided a much-needed shot in the arm for the infrastructure required to scale up technologies. Incentives under the Inflation Reduction Act (IRA) provide project developers with a US$50 per metric tonne of CO2 tax reduction where CO_2 is stored in dedicated storage sites. And the Infrastructure Investment and Jobs Act passed in November 2021 provided a combined US$15 billion to support CCUS and low-carbon hydrogen production.

The IRA has had a considerable positive impact on hydrogen, enabling the US to have the largest hydrogen project pipeline of any country. It currently accounts for 18% of total announced capacity, allocating Australia to second place at 14%.

And while the percentage of hydrogen projects in the EU surpass both of those (at 29%), it should be remembered that this figure accounts for the whole of the EU (consisting of 27 countries) and the UK - which ultimately results in relatively minor pipelines per country.

While Europe may be advancing the highest number of projects overall, the US is considerably closer to offering early scale-up, with the generous IRA tax credits, eventually helping a strong flow of US projects towards final investment decision (FID).

The majority of announced projects are for green hydrogen, which is produced using renewable energy and electrolysis and is the cleanest form of hydrogen production. However, it is also expensive, making access to cheaper clean power necessary to achieve the desired economics.

While most of the recently announced projects are for carbon-free hydrogen, the projects that are most advanced are dominated by blue hydrogen, especially in the US. Blue hydrogen is mainly produced from natural gas and creates carbon dioxide as a by-product, so it's a low carbon solution, but not strictly a 'clean' one. However, it enjoys a significant cost advantage over green hydrogen, particularly where natural gas is cheap, as in the US and Canada.

Today, the cost of CCUS-enabled hydrogen production remains around half that of producing hydrogen through electrolysis powered by renewables-based electricity. And while the cost of electrolytic hydrogen will decline over time, with cheaper electrolysers and renewable electricity, CCUS-equipped hydrogen will most likely remain a competitive option in regions with low-cost fossil fuels and CO2 storage resources.

In discussions with Greg Bean, Director, Gutierrez Energy Management Institute at the University of Houston, he commented: "Recent federal government policies affecting low carbon intensity (LCI) hydrogen - specifically the funding of seven hydrogen hubs, along with IRA production tax credits for LCI hydrogen and enhanced CCUS tax credits – should accelerate the initial wave of CCS hydrogen given its current cost advantage over electrolytic hydrogen, especially in the US with low natural gas prices. "

"However, the more favourable tax treatment for electrolytic hydrogen in the IRA and the likely reduction in electrolytic hydrogen cost suggests that it might ultimately have a larger market share in an aggressive decarbonisation scenario."

Hydrogen trading is still at a relatively nascent stage but could see significant growth this decade. Even low carbon hydrogen will be crucial for net importers to reach net-zero targets - and for net exporters like the US to maximise benefits from clean energy deployment. CCUS-based hydrogen is likely to become an internationally traded commodity to help countries meet their hydrogen demand in a more economical way.

However, Greg Bean goes on to note: "With main export markets likely to be in Europe and North Asia, there could be policy actions in these countries that penalise or limit CCS hydrogen imports. A relevant example is the "maximum methane intensity values" and associate penalty structure being discussed for LNG imports into Europe. Time will tell.

Conclusion

We are in a decisive decade and need to scale solutions today if we wish to avoid the worst of climate impacts on our society and global ecosystem. Both CCUS and low-carbon hydrogen are well-tested and the US has shown that they can be rapidly scalable solutions that can deliver decarbonised industries at a lower cost.

The significant opportunities for low carbon hydrogen can only be delivered through coordinated international collaboration. This requires cross-industry partnerships that must work together based on guiding principles of lower costs, speed, and uncompromising quality.

World Hydrogen Leaders hosted the largest hydrogen event in the US, "World Hydrogen North America" in Houston May 21-23, 2024. World Hydrogen Week will be held in Copenhagen Sept 30 - Oct 4. Visit the webpage for more information and to register for futre events.

More information

www.worldhydrogenleaders.com

TCM's pivotal role in advancing solvent technology

At the heart of the endeavor lies the selection of an optimal solvent, a crucial element determining the success of CO2 capture processes. Since it was established in 2012, TCM has supported more than 20 different technologies. Based on more than 4,000 online instruments and 100 manual sample points, TCM has a unique ability to track the CO2 capture process for technology developers.

Since its inception in 2012, TCM has focused on providing technology developers with good and flexible opportunities to test their technology. The facility is equipped with many measurement points, allowing TCM to easily assist with analysis at different stages of the capture process.

TCM serves as the crucible where pioneering solvent technologies undergo meticulous scrutiny and validation. To qualify for testing at TCM's Amine plant, technologies must achieve a Technology Readiness Level (TRL) of 6 or above, signifying readiness for commercial deployment post-TMC testing.

The facility uses two industrial sources of flue gas: Equinor's residue cracker at the Mongstad refinery (13 per cent CO2) and the associated Mongstad Heat Plant (MHP) (8-9 per cent CO2). These two flue gas sources make it possible to simulate emissions from different industries, such as cement production, steel, waste management and oil refining.

TCM can mix different concentrations and compositions from these two sources. This is unique in a global context and means that more companies are able to come and test how their technology works under different conditions.

Through rigorous procedures TCM ensures comprehensive oversight and validation of results. In addition, through collaboration with other market leaders such as SINTEF (video greeting below), TCM can provide third party verification to ensure the quality of the results obtained.

What happens in the absorber?

Aker Carbon Capture constructed the TCM absorber present at the technology center today. During the construction process in 2012, significant emphasis was placed on ensuring the plant's flexibility, a key factor in prolonging the center's operational lifespan.

From initial consultations to campaign execution, TCM collaborates closely with technology vendors, unraveling the intricacies of solvent behavior and offering guidance on solvent management and waste handling

The absorber column has a cross-section 3.55 meters × 2 meters and total height of 60 meters. Three packing beds are installed in the absorber. This absorber column serves as the primary site for both CO2 capture and emission control, effectively addressing environmental concerns in tandem.

Establishing a new absorber constitutes a significant portion, approximately 45%, of the costs associated with a CO2 capture unit. A key insight from one of TCM's cost analyses underscores that absorbents alone represent nearly half of the total material expenses for such a plant.

To mitigate these costs, various strategies can be implemented, including streamlining the scrubbing section, optimizing solvent consumption, enhancing capture rates, reducing steam consumption (thus lowering energy usage), and increasing the CO2 content in the flue gas.

"At TCM, we collaborate closely with technology suppliers to optimize plant performance. Through meticulous testing of different CO2 concentrations ranging from 1% to 20% and strategic positioning of the solvent within the plant, we leverage our team's expertise and extensive operational experience."

"Our rigorous test campaigns provide a robust foundation for comparison and enable us to offer valuable insights to technology suppliers striving to achieve maximum efficiency."

"Ultimately, the shared goal is to advance the development of the most efficient CO2 capture technologies, and we take pride in leveraging our knowledge and resources to support industry partners in realizing this objective."

High flexibility and solvent's path to CO2 capture at TCM

At TCM, the focus is not on determining the superiority of one technology over another, instead they support the technology developers by providing guidance on enhancing the efficiency of their solvent technology. This involves furnishing actionable insights through continuous monitoring of the absorption process. To achieve this various measurements obtained from different sample points are employed, including CO2 inlet, outlet, and water wash sections.

Transitioning to the solvent aspect, the key to the absorber operation efficiency lies in ensuring optimal contact between the solvent and the CO2. At TCM, this is accomplished by introducing the solvent to the packing material within the absorber column. Furthermore, three solvent feed injection levels enable adaptable absorber operation, offering variations with 12 meters, 18 meters, or 24 meters of packing.

As the processed flue gas moves upwards, it passes through the water washes at the top section of the absorber, which helps scrub the flue gas and reduce solvent entrainment, thereby minimizing solvent loss. The amine absorber incorporates two distinct water wash sections, serving dual purposes:

• to maintain a closed water balance in the solvent system by condensing water vapors in the exit flue gas, and

• to reduce the concentration of volatile organic compounds, such as MEA, or amine degradation products (formaldehyde, acetone, acetaldehyde), in the depleted flue gas.

The CO2-depleted flue gas exits the top of the absorber column, and the rich solvent exits the bottom of the absorber column and is heated in the cross-heat exchanger by a countercurrent stream of hot lean solvent.

Owners test campaigns

Beyond vendor testing, the owners of TCM have conducted numerous test campaigns using commercially available solvents, including MEA and CESAR1. These campaigns have scrutinized multiple parameters and operational scenarios to ascertain optimal system performance. These endeavors have yielded invaluable insights that serve as a benchmark for comparison among various technology developers and buyers.

Aker Carbon Capture constructed the TCM absorber present at the technology center today. Photo: Styrk Fjærtoft

The wealth of experience garnered through these endeavors is now available for sharing with other upcoming technology vendors, including Longship; Heidelberg Materials, and Hafslund Oslo Celsio.

"A significant portion of our clientele returns to TCM for solvent re-testing. Whether they have refined their existing solvent based on lab findings or introduced a completely new solvent, we accommodate both scenarios. The feedback we consistently receive from our customers underscores their appreciation for the insightful guidance provided during the testing process."

Focus on knowledge sharing

In a rapidly evolving landscape of CO2 capture technologies, it's imperative to remain ahead of professional advancements. Active participation in collaborative initiatives is a key. TCM is engaged in partnerships with EU projects, to test and demonstrate their CO2 capture technologies.

"By facilitating knowledge exchange, we collectively drive progress in CO2 capture efforts."

TCM encourages everyone who comes to the Technology Centre to share their experiences of testing at the facility. Everyone who comes to us for testing is required to report back weekly on their testing experience. At the end of the test campaign, a separate workshop is organized for those involved and TCM owners are given the opportunity to participate in this learning. Everyone is also encouraged to present papers at international conferences.

To date, TCM has presented over 60 different scientific papers. Sharing the knowledge from the Technology Centre is important. Knowledge will help make CO2 capture technology more efficient and save industry players from uncertainty and unnecessary costs.

More information

www.tcmda.com

Report: Global CCUS investment requires $196Bn through 2034

By 2034, global carbon capture capacity will reach 440 Mtpa and storage capacity will reach 664 Mtpa, requiring US$196 billion in total investment, according to a recent report from Wood Mackenzie.

According to the report "CCUS: 10-year market forecast", nearly half of the investment globally is associated with CO2 capture, with the remaining US$53 billion from transport and US$43 billion from storage. About 70% of the investment will be in North America and Europe across the value chain.

"This is a huge ramp-up from where the industry is today. Government funding plays a critical role in driving the first wave of CCUS investments," said Hetal Gandhi, APAC CCUS lead with Wood Mackenzie. "We see governments offering capex grants, opex subsidies, tax incentives and contracts for differences for CCUS. While no single mechanism has been used predominantly and each country devises novel methods to incentivise investments, nearly US$80 billion is directly committed to CCUS across five key countries."

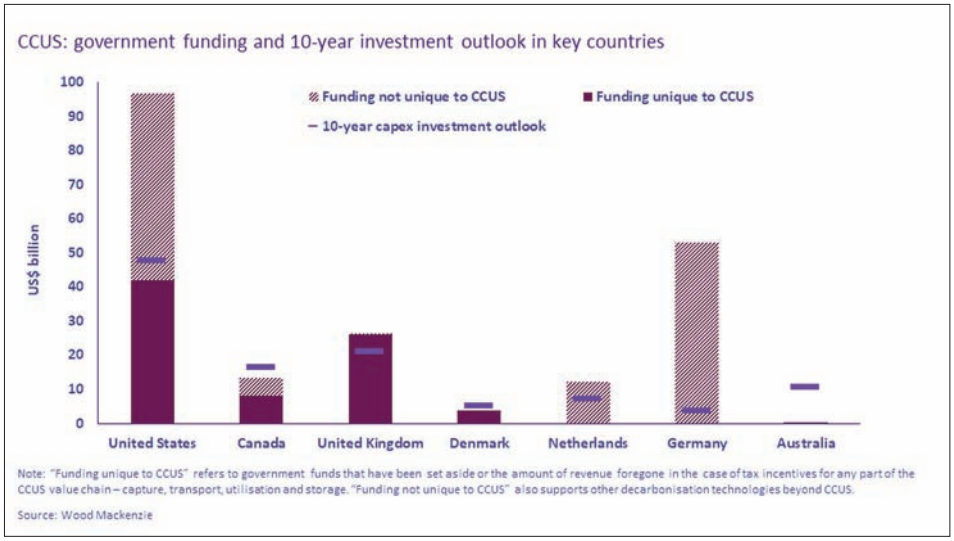
The US leads in funding at 50%, followed by the United Kingdom at 33% and Canada at 10%.

"While we are seeing strong support in countries like the US, government support in APAC lags behind," said Stephanie Chiang, research analyst, CCUS. "Australia, Malaysia and Indonesia have announced some benefits, but they are substantially lower as compared to their investment needs. Australia's direct incentives at US$40 million is less than 1% of the investment needed over the next 10 years."

Capacity not keeping up with demand

Despite the large, forecasted increase in projects, Wood Mackenzie does not expect supply of carbon capture to meet demand. Industries will need up to 640 Mtpa of carbon capture capacity by 2034 as they look to decarbonize, but the projects expected to come into operation fall around 200 Mtpa short of that.

"Of the projects already announced and expected to go ahead in the development pipeline, 71% are in North America and in Europe," said Hetal. "Government incentives such as the US Inflation Reduction Act (IRA), UK business models, Canada's Investment Tax Credit and the Netherlands SDE++ scheme are moving projects towards final investment decision (FID). We also expect a further boost to European projects due to the recently announced EU Industrial Carbon Management Strategy."



"The lack of CCUS announcements in APAC's largest emitting countries – China and India – is causing the region to have substantially lower capacity than needed under Wood Mackenzie's base case. Key sectors like power and chemicals will see a large gap between demand potential and actual supply until 2034. We expect APAC's capture pipeline will mature through additional announcements later in the decade."

Establishing hub infrastructure and ways to handle carbon import are complex. The speed with which these are ironed out for the emerging APAC hubs of Indonesia, Malaysia, and Australia will be crucial over the next two years to galvanise new capacity announcements, project development, and execution to reach the level of decarbonisation needed.

The report also sizes the global storage capacity to reach 664 Mtpa in 2034, with almost 80% of the planned pipeline starting up by 2030. CO2 storage projects will outpace emitter uptake, leaving a global capture-storage gap of more than 200 Mtpa by 2034.

"With storage capacities more concentrated than the spread-out capture capacities, hub-based storage ecosystems will evolve especially in Europe and APAC," said Fauzi Said, senior research analyst.

Policies for transportation of CO2 across borders and bilateral agreements to enable cross-border CCUS, liability risk mapping, insurance obligations and risk definitions are a few crucial modalities to watch out for, as cross-border transport & storage hubs will play a bigger role in Europe and APAC.

The actual buildout of transport infrastructure in Europe and North America – the former characterised by inter-country pipelines and shipping infrastructure and the latter by long and extensive pipeline requirements – will be key for projects of scale to materialise.

More information

www.woodmac.com

7–9 billion tonnes of CO2 must be sustainably removed per year

The 2024 State of Carbon Dioxide Removal report finds that around 7–9 billion tonnes of CO2 per year will need to be removed by mid-century from the atmosphere if the world is to meet the 1.5°C Paris Agreement targets.

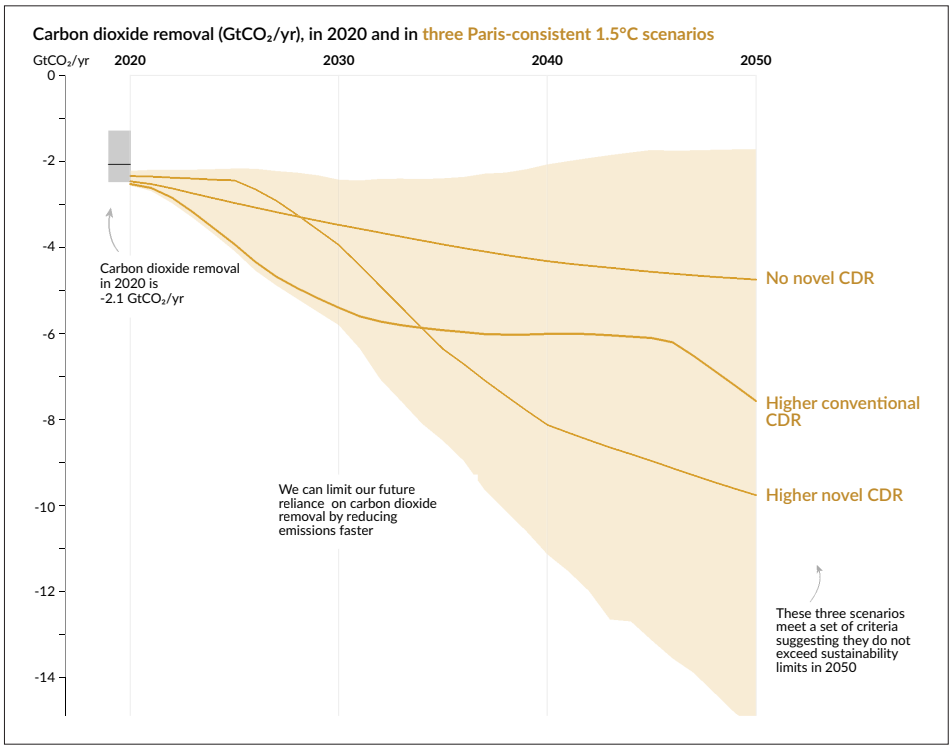
The authors stressed that reducing emissions is the primary way to achieve net-zero, but Carbon Dioxide Removal (CDR) has a critical role to play. This year's report was led by the University of Oxford's Smith School of Enterprise and the Environment.

The authors incorporated sustainability criteria including multiple Sustainable Development Goals into their analysis, and their final figure for a "Paris-consistent" range of CDR was assessed based on these. Currently just 2 billion tons per year are being removed by CDR, mostly through conventional methods like tree planting. Novel CDR methods – like biochar, enhanced rock weathering, direct air carbon capture and storage (DACCS) and bioenergy with carbon capture and storage (BECCS) - contribute 1.3 million tonnes per year, less than 0.1% of the total.

Methods which are effectively permanent account for only 0.6 million tonnes per year – less than 0.05% of the total. A diverse range of CDR methods must be rapidly scaled up to address climate change in line with the Paris Agreement, say the authors. CDR has undergone rapid growth in research, public awareness and start-up companies. Yet there are now signs of a slowdown in development across multiple indicators. While investment in CDR research and start-ups is going to an increasing variety of novel methods, few of these methods are currently targeted in government policies and proposals to scale CDR, which accounts for just 1.1% of investment in climate-tech start-ups.

"Given the world is off track from the decarbonisation required to meet the Paris temperature goal, this shows the need to increase investment in CDR as well as for zero-emission solutions across the board," says Dr Steve Smith of the Smith School of Enterprise and the Environment, University of Oxford.

The report notes that CDR companies have high ambitions which, taken together, would drive CDR to levels consistent with meeting the temperature goal of the Paris Agreement. However, the authors say these ambitions have little ground for credibility at present and depend on a much stronger set of policies than currently exists.



Carbon dioxide removal is a feature of all 1.5°C scenarios that meet the Paris temperature goal, in addition to reducing emissions

The report urges governments to implement policies that will increase demand for carbon removals. These should include the embedding of CDR policies into countries' Nationally Determined Contributions (climate action plans under the UNFCCC) and developing better monitoring, reporting and verification systems for CDR. At present, much of the demand for CDR is coming from voluntary commitments by companies to buy carbon removal credits.

Because CDR methods carry different risks and benefits, and because it is uncertain how much CDR will be needed, deploying a diverse portfolio of methods is a more robust strategy than focusing on just one or two methods. Indicators of research, invention and investment in startup companies show evidence of diversification across CDR methods.

However, current deployment and national proposals for future implementation are more concentrated on a few conventional methods. In addition, many modelled mitigation scenarios still represent only a limited set of CDR methods.

More information

www.stateofcdr.org

CCS from energy-from-waste: a low-hanging fruit?

An Oxford Institute for Energy Studies report evaluates the business case for CCS in the UK EfW sector and assesses the technical feasibility of installing carbon capture technology at the facility level.

Energy-from-waste (EfW) is a waste treatment process that combusts residual waste after re-use, recycling and composting to produce energy in the form of electricity and/or heat. In the UK, the EfW sector contributes around 3% of total national power output, but also 3.5% of overall territorial GHG emissions, making its decarbonisation critical.

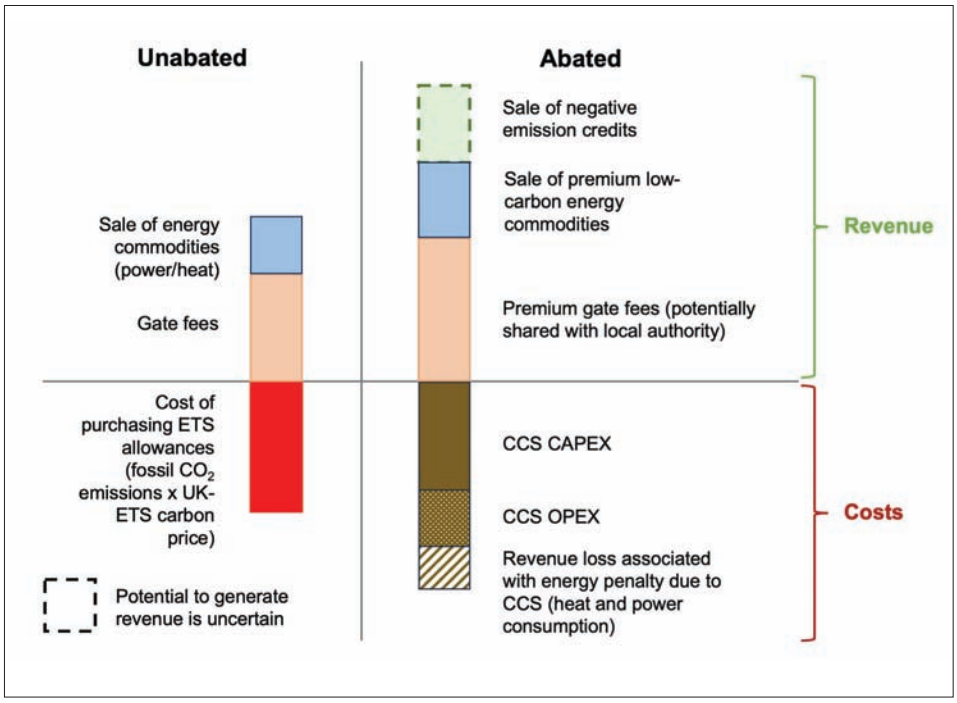
CCS has emerged as a promising decarbonisation solution. As waste is composed of fossil and biogenic content, retrofitting EfW with CCS has the potential to reduce emissions (by capturing fossil CO2) but also generate valuable negative emissions (by capturing biogenic CO2) which can contribute to the UK's negative emissions targets.

This study evaluates the business case for CCS in the UK EfW sector taking the entire UK fleet into account. It also identifies different methods to transport CO2 from EfW facilities to the nearest storage sites, using transport cost and emissions intensity of different transport modes (pipeline, rail, truck, ship) as metrics to evaluate what is economically feasible, and emissions-wise acceptable.

The report highlights how the integration of CCS can help maintain energy from waste facilities as a source of sustainable, low-carbon energy while also meaningfully contributing to the UK's emission reduction targets. enfinium, who contributed to the report, have already announced their intentions to use CCS to decarbonise their operations and deliver carbon removals.

The report found that the potential to generate negative emissions from the UK EfW sector is substantial.

"Under the most conservative scenario in the study, which assumes a low emissions intensity factor of 0.7 tCO2 emitted per tonne of waste combusted, and only considering facilities where there is high certainty of available on-site space for CCS retrofit, we estimate that around 5 Mtpa of negative emissions can be captured from the entire UK fleet," it said.



Costs and revenue streams of unabated (left) vs abated (right) EfW facilities under an ETS (bar sizes are not proportional to respective cost or revenue)

"If a higher emissions intensity factor of 1.18 tCO2/t is assumed, this estimate increases up to 8 Mtpa; that is while excluding facilities where further analysis on space availability is needed, which may increase this estimate even further."

The report concludes that the Efw sector is indeed a low hanging fruit for negative emissions.

"In the UK context specifically, at a time when the UK Government has committed to adopting CCS as a main pathway for national decarbonisation – evident by its now-established CCS business models including the Waste ICC contracts framework – this study makes clear that the EfW sector may well be the low-hanging fruit for CCS deployment and the well-needed generation of negative emissions nationally."

Under current market conditions (low UK-ETS price of around £38/tCO2, and high CCS costs estimated at around 150 £/tCO2 for EfW), an abated facility would expectedly incur higher costs than an unabated one.

However, with additional revenue in the form of premium gate fees (the fees charged to users to treat the waste) and sale of premium low-carbon energy commodities such as zero emission electricity, in addition to potential sales of (high-value) negative emission credits, an abated facility is likely to be profitable if the additional benefits outweigh the costs of CCS (see Figure).

More information

www.oxfordenergy.org

Projects and policy news

Shell to build two carbon capture and storage projects in Canada

www.shell.ca
www.atco.com

Shell Canada Products will proceed with the Polaris project in Alberta and the Atlas Carbon Storage Hub in partnership with ATCO EnPower.

The company announced the Final Investment Decision (FID) for Polaris, a carbon capture project at the Shell Energy and Chemicals Park in Alberta, designed to capture approximately 650,000 tonnes of CO2 annually from the Shell-owned Scotford refinery and chemicals complex.

Shell also announced FID to proceed with the Atlas Carbon Storage Hub. The first phase of Atlas will provide permanent underground storage for CO2 captured by the Polaris project.

Both projects are expected to begin operations toward the end of 2028.

"Carbon capture and storage is a key technology to achieve the Paris Agreement climate goals," said Huibert Vigeveno, Shell's Downstream, Renewable and Energy Solutions Director. "The Polaris and Atlas projects are important steps in reducing emissions from our own operations."

Polaris and Atlas will build on the success of the Quest CCS facility at Scotford, which has safely captured and stored more than nine million tonnes of CO2 since 2015 that would otherwise have been released into the atmosphere.

CO2 emissions captured by Polaris will be sent to the Atlas Hub via an approximately 22-kilometre pipeline to two storage wells. CO2 will be stored there approximately two kilometres underground in the Basal Cambrian Sands, the same formation used to successfully store CO2 from the Quest CCS facility.

Future development of Atlas, which is subject to a future investment decision, will be aimed at meeting both ATCO EnPower and Shell's carbon storage needs, with remaining capacity available for third-party emitters through open access.

Shell plans to invest $10-$15 billion across 2023-2025 to support the development of low-carbon energy solutions.

"World's largest" carbon capture pilot begins operations in Illinois

prairie.illinois.edu

The Prairie Research Institute (PRI) and U.S. Department of Energy (DOE) have launched testing and operations at City Water, Light and Power's Dallman 4 coal-fired power plant in Springfield.

The $80 million Phase III pilot, funded by DOE, Linde/BASF and the state of Illinois, retrofits Dallman 4 and is the largest of its kind globally.

"As someone who has researched carbon capture for over twenty years, it is gratifying to see carbon capture achieve this milestone. It is especially exciting to see how state and local support has enabled the construction of a facility that is globally recognized. It demonstrates Illinois' leadership in carbon capture," said Kevin O'Brien, director of the Illinois Sustainable Technology Center (ISTC) and the Net-Zero Center of Excellence at the Prairie Research Institute (PRI).

PRI projects that the construction and operation of the Dallman Unit 4 carbon capture facility will have a baseline regional economic impact on construction and jobs of at least $47.1 million, and it will generate tax revenue of more than $5.6 million.

"This phase is the last step in the development process to de-risk technologies before they go to commercial operation or commercial demonstration," said Ronald Munson, point source carbon capture technology manager, NETL, DOE.

"To see the progression of the technology and to see the application of the approach the Department of Energy has adopted is really gratifying."

"It is essential we have solutions to meet environmental goals through carbon capture to power our nation's infrastructure, power our homes and businesses, and support the operations of our manufacturers," said City Water, Light and Power Chief Utility Engineer Doug Brown.

"Just as power plants require sustainable solutions, so will manufacturers need to rely on low-carbon processes to meet these goals."

Climeworks' Mammoth plant in Iceland begins capturing CO2

www.climeworks.com

Climeworks has begun operations of its largest direct air capture and storage (DAC+S) plant, which is about ten times bigger than its predecessor plant Orca.

The plant is designed for a capture capacity of up to 36,000 tons of CO2 per year once in full swing by filtering CO2 from the air and storing it permanently underground. The plant has successfully started to capture its first CO2, with twelve of its total 72 collector containers installed onsite.

Mammoth, the world's largest direct air capture and storage plant, is designed for a nameplate capture capacity of up to 36,000 tons of CO2 per year.

Mammoth, the world's largest direct air capture and storage plant, is designed for a nameplate capture capacity of up to 36,000 tons of CO2 per year

Climeworks broke ground on Mammoth in June 2022. The plant is built in a modular design, with twelve of its total 72 collector containers currently installed onsite. The plant will be completed throughout 2024. It is designed for a nameplate capture capacity of up to 36,000 tons of CO2 per year.

Mammoth has successfully started to capture its first CO2. Climeworks uses renewable energy to power its direct air capture process, which requires low-temperature heat like boiling water. The geothermal energy partner ON Power in Iceland provides the energy necessary for this process.

Once the CO2 is released from the filters, storage partner Carbfix transports the CO2 underground, where it reacts with basaltic rock through a natural process, which transforms into stone, and remains permanently stored. Climeworks verifies and certifies the whole process by independent third parties.

The design is based on seven years of field experience which increases plant performance, efficiency, recovery and ensures better availability to maximise CO2 capture through the year. Climeworks will gain further operational field experience and will continue large-scale testing and development.

A clean approach to carbon capture: MTR's Membrane Technology

MTR has developed a point source carbon capture process built on its proven Polaris™ polymeric membrane, using no chemicals and less water than conventional methods. Polaris is modular and scalable, and commercially ready today. By Tim Merkel, VP of Technology, MTR.

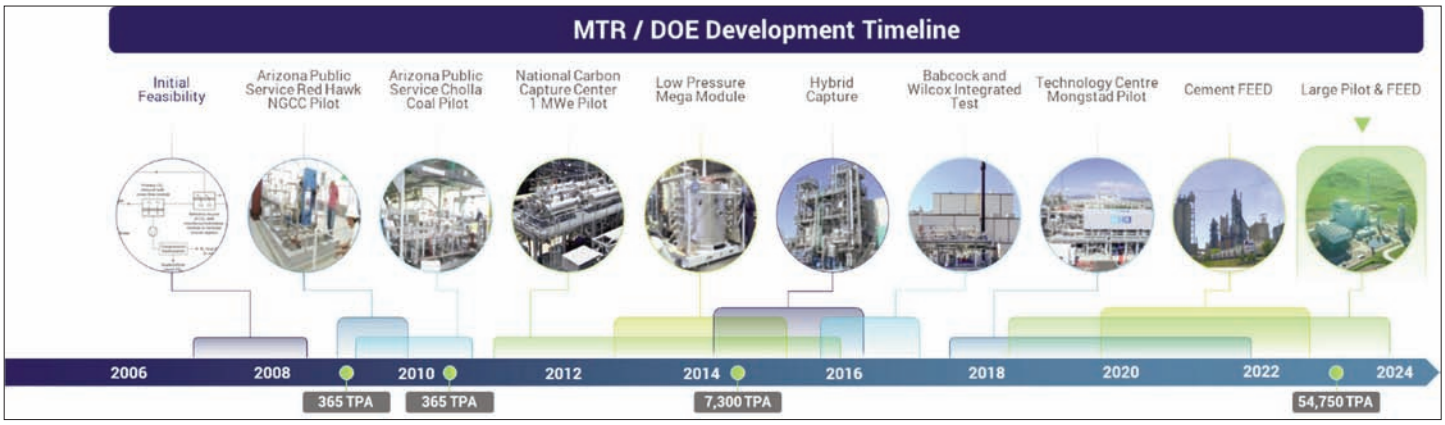


Fig 1 - MTR CO2 capture development timeline.

Membrane Technology and Research, Inc. (MTR) is a privately-owned developer, manufacturer, and supplier of customized membrane process solutions for separations in the natural gas, refining, and petrochemical industries. The company's principal non-CO2 capture membrane products are VaporSep® membrane systems to remove organic vapors from air and nitrogen in the petrochemical industry, and fuel gas conditioning membrane units for upgrading natural gas; more than 450 commercial membrane units have been installed by MTR worldwide since the company's founding in 1982. Through this commercialisation history, MTR has developed extensive experience designing, building, and operating industrial separation systems.

For the past 15 years, MTR has worked with the U.S. Department of Energy (DOE) to develop an innovative, cost-effective membrane-based CO2 capture solution. This effort will culminate with the commissioning of a Large Pilot capture plant at the Wyoming Integrated Test Center (WITC) located in Gillette, WY in late 2024.

The Large Pilot system is an integrated demonstration of the total MTR carbon capture process – a fully featured, albeit small, commercial capture plant.

MTR CO2 Capture Technology Development

The most common technology for post-combustion CO2 capture is amine absorption. However, this approach has inherent challenges, including high water demand, a requirement for thermal (steam) input, chemical handling needs and the creation of new secondary air emissions. In recognition of these issues, the DOE has funded development of a suite of second-generation tech-

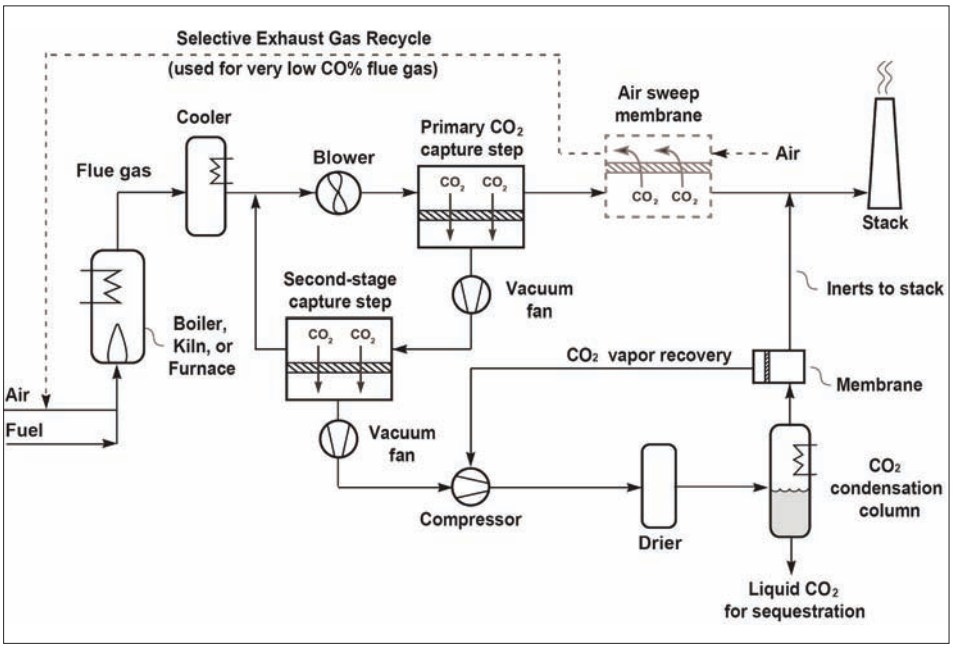


Fig 2 - Simplified flow diagram for the MTR capture process

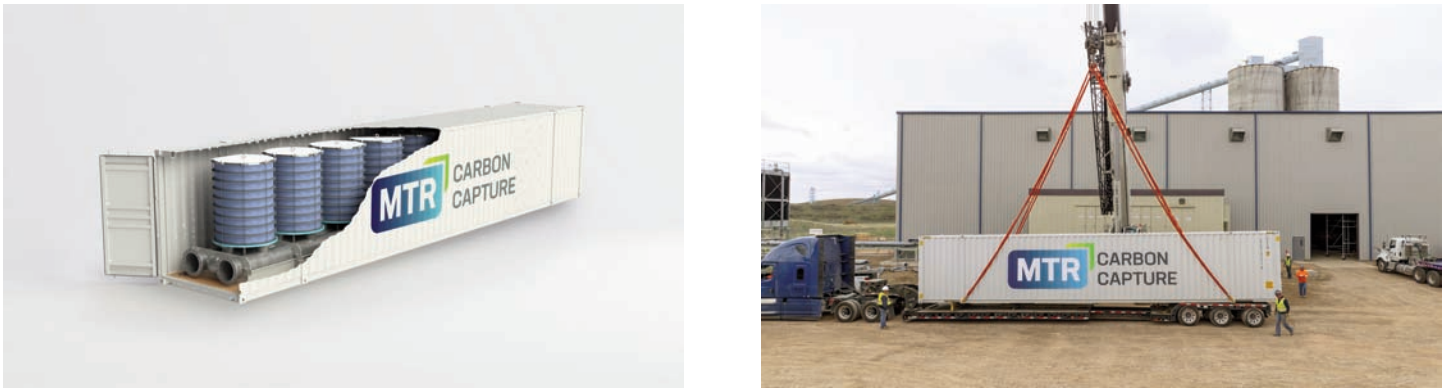


Fig 3 - Schematic and picture of an MTR membrane container

nologies including advanced solvents, sorbents and membranes, with the goal of delivering reliable, robust and affordable capture options that provide environmental benefits to society.

Among the new capture technologies being developed are CO2-selective membranes. Membranes have emerged over the past 50 years as an environmentally friendly, low energy separation technique, and they are widely used today for water purification and separation of industrial gases. Membrane processes offer significant advantages for CO2 capture, including no hazardous chemical handling, storage, disposal or emissions issues, a simple all-electric process, a flexible plant footprint, and low water demand compared to alternatives.

A challenge for membranes is the low CO2 partial pressure in flue gases, which can result in large membrane area, and hence, high capital cost. Working with DOE, MTR has made three key innovations to address this challenge:

1. A new class of membranes called Polaris™ that has at least ten times the CO2 permeance of conventional gas separation membranes was developed. The higher permeance reduces the required membrane area, and thus, the capital cost and footprint of a capture system.

2. A membrane selective-recycle process has been developed. This patented process uses combustion air as a sweep to strip CO2 from the flue gas and recycle it to the combustion process. This design is particularly useful for achieving high capture rates affordably.

3. A low-pressure-drop membrane module was designed specifically for post-combustion capture conditions. The pressure differentials, and therefore the energy required, to circulate gas through this new module is a fraction of that measured in conventional membrane modules.

As shown in Figure 1, MTR has worked with DOE to advance these innovations from concept through small pilot testing and FEED studies. This development included validation tests at the National Carbon Capture Center (NCCC), where commercial-sized Polaris membrane modules accumulated >11,000 hours of operation on coal-derived flue gas.

In subsequent work, the MTR carbon capture process was scaled-up 20-fold to the small pilot stage (1 MWe or 20 TPD) and verified in slipstream tests at NCCC, and later in a fully-integrated coal boiler test at a Babcock and Wilcox (B&W) research facility. In these same tests, Gen-2 Polaris membrane and advanced low-pressure-drop modules were validated. In a recently completed field test, the performance of MTR's Gen-2 Polaris membrane packaged in low-pressure-drop modules was demonstrated at Technology Centre Mongstad (TCM) in Norway. These activities have progressed the MTR membrane carbon capture technology toward commercial readiness.

Figure 2 shows a simplified flow diagram for the MTR membrane capture process. Flue gas is first cooled in a direct contact cooler (DCC) to <40°C, and then sent to a feed blower that increases the gas pressure to ~1.1 bara to overcome pressure drop through the membrane system. The boosted gas enters the first stage membrane module where a partial vacuum on the permeate-side provides the driving force for CO2 capture.

The membrane partitions the gas into a CO2-enriched permeate (~50 mol% CO2) and a CO2-depleted residue gas. The residue is discharged to the atmosphere via a stack, or as shown in Figure 2, it can be sent first to a selective recycle membrane for additional CO2 removal. This optional selective exhaust gas recycle (SEGR) step is particularly useful for high capture rates (>90%) from dilute sources.

The permeate gas from the first membrane is sent to a second stage membrane where it is further enriched to 85-95 mol% CO2. This second stage membrane is much smaller than the first stage and also uses a vacuum pump to provide driving force. The twice-enriched permeate from the second membrane stage is compressed, dried, and liquefied to produce high purity CO2. The liquid CO2 is then pumped to high pressure as required for pipeline or storage specifications (often ~150 bar).

The Polaris membrane that is used in the Figure 2 design has been tailored for low pressure carbon capture operation. This development includes packaging of the membrane into the containerized modular units shown in Figure 3. Here, the cylindrical membrane stacks are housed in a standard shipping container that includes built-in conduits for moving gases to and from the membranes.

These containerized membrane repeat units are fabricated in a shop and allow for easy, low-cost shipping and assembly at site.

Large Pilot Project at WITC

The WITC is a new, dedicated CO2 capture facility located adjacent to Dry Fork Station (DFS), a 445 MWe coal-fired power plant owned by Basin Electric Power Cooperative that supplies the flue gas slipstream to the test

center. The overall objective of MTR's project at WITC is to demonstrate the Polaris membrane CO2 capture process in its commercial form through steady state operation on coal-derived flue gas.

Sized to capture 150 tonnes CO2/day from a slipstream of flue gas from Dry Fork Station, the Large Pilot will demonstrate a range of CO2 capture rates including greater than 90%. As shown in Figure 4, the system has all of the features of a full-scale capture plant including flue gas pretreatment, membrane CO2 capture, and purification to produce pipeline quality CO2.

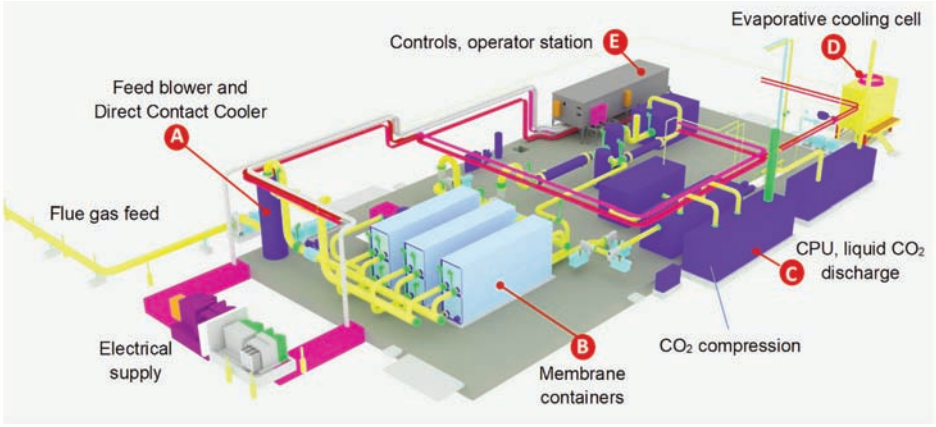


Fig 4 - A schematic drawing of the MTR Large Pilot that will operate at WITC

Roughly an order of magnitude larger than prior MTR field testing systems, the Large Pilot will demonstrate the final membrane module form factor, with future larger systems simply using multiples of these unit membrane building blocks. For this reason, the information obtained from this program will help reduce risks associated with scale-up to full-scale implementation.

The groundbreaking ceremony for the Large Pilot occurred at WITC in May 2023 with key stakeholders in attendance as shown in Figure 5. Construction and commissioning activities are ongoing and the Large Pilot is on schedule to be fully operational in Q4 2024. Once on-line, the Large Pilot will be the largest membrane carbon capture plant in the world.

The year-long Large Pilot test will focus on optimizing process conditions to minimize the cost of capture. Completion of this project will be an inflection point for the MTR capture technology and will set the stage for future commercial-scale projects already in development. In spring 2024, MTR began a Demonstration project funded by the DOE Office of Clean Energy Demonstrations (OCED) to produce a Front End Engineering Design (FEED) study with commercial quality budgets, and all necessary supporting studies (Demonstration Phase I) to execute an integrated, full-scale carbon capture and storage project at DFS (Demonstration Phase II).

This is a joint project between MTR and the University of Wyoming's School of Energy Resources (SER), who has been developing CO2 storage options and drilling storage wells through the DOE supported Wyoming CarbonSAFE program. The Phase I FEED study will update the capture plant design from previous studies incorporating relevant performance data and lessons learned from the Large Pilot project.

The DOE Large Pilot project at WITC and OCED Integrated FEED project at DFS are important steps toward commercialization of the MTR technology. Phase II of the OCED program offers the potential for federal cost share for construction of a full-scale MTR capture plant at DFS. Successful execution of the OCED Demonstration project would complete the commercialization of an environmentally-friendly membrane capture technology that MTR and DOE have developed over 15 years.

It would also deliver community and stakeholder benefits by positioning DFS to be a low-carbon emitting, base-loaded generation asset for the Basin Electric Power Cooperative members for many decades to come, and would establish the proposed DFS storage complex to store carbon oxides from this project and from other future capture projects.

Fig 5 - Large Pilot groundbreaking

Summary

Many carbon capture approaches are technically feasible, but achieving widespread public acceptance for this approach will require an environmentally friendly solution. Membrane capture technology offers numerous advantages in this regard including no secondary emissions, no use of hazardous chemicals, and recovery of flue gas water.

The MTR Large Pilot system being installed at WITC will be the largest membrane capture system in the world when it goes online later this year. This project will be a key step toward providing a full-scale clean carbon management solution with clear benefits to Wyoming and beyond.

More information

www.mtrccs.com

Climeworks introduces next generation Direct Air Capture system

Climeworks said it is future-proofing its technology for scaling globally to gigaton carbon removals by using the latest research and development findings in its filter materials and plant design for its Generation 3 Direct Air Capture system.

The Generation 3 direct air capture technology is based on novel structured sorbent materials housed in modular cubes (Image: ©Climeworks)

At its annual Carbon Removal Summit in Zurich, Climeworks has showcased its Generation 3 direct air capture (DAC) technology: doubling CO2 capture capacity per module, halving energy consumption, increasing material lifetime, and cutting costs by 50 percent.

Generation 3 technology and design have been developed and validated over the past five years and implemented at full scale for the first time in June 2024 at its largest direct air capture testing facility in Switzerland.

The Generation 3 technology uses novel structured sorbent materials replacing the packed filter beds used in previous technology generations. The new structures increase surface contact with CO2, reducing the time to capture and release CO2 by a factor of at least two, thus capturing more than twice as much CO2 as previous filters. The new filter materials consume half the energy and are designed to last three times longer than prior materials.

Climeworks said its Generation 3 technology represents a major milestone in its cost reduction strategy, which aims to achieve costs of 250-350 USD per ton captured and total costs of 400-600 USD per ton net removal by 2030. This represents an overall cost reduction of up to 50 percent compared to today.

"Climeworks has always been committed to technology leadership. We were pioneers in the development of direct air capture technology and launched our first commercial facility in 2017," said Jan Wurzbacher, Co-founder and Co-CEO.

"We operate the world's largest commercial direct air capture plant, Orca, in Iceland, and have inaugurated a larger plant, Mammoth, ten times the size. In parallel, we have, over the past five years, been developing our Generation 3 technology. This development is based on real field data, enabling the scale-up to megaton removal capacities."

The first plant using this new technology generation, including new cube design, will be built in Louisiana as part of the megaton-scale "Project Cypress DAC Hub" funded by the U.S. Department of Energy. Construction is set to begin in 2026 and would mark another tenfold scale-up step towards megaton capacity. In addition, Climeworks is part of two further megaton hub proposals in the U.S. and is actively developing projects in Norway, Kenya, and Canada, as well as exploring further sites on its journey towards gigaton capacity.

More information

www.climeworks.com

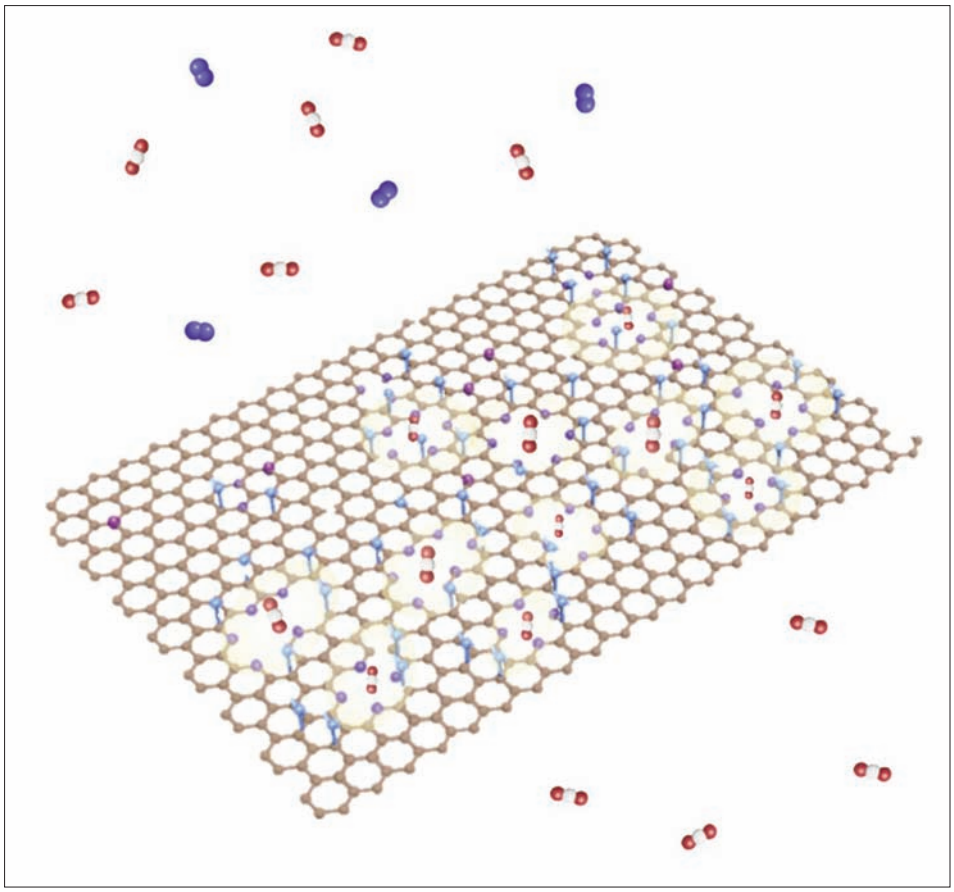
Atom-thin graphene membranes make carbon capture more efficient

Scientists at EPFL have developed atom-thin graphene membranes with pyridinic-nitrogen at pore edges which show unprecedented performance in CO2 capture.

Current capture methods rely on energy-intensive processes, which makes them costly and unsustainable. Research now aims to develop membranes that can selectively capture CO2 with high efficiency, thereby reducing the energy and financial costs associated with CCS. But even state-of-the-art membranes, such as polymer thin films, are limited in terms of CO2 permeance and selectivity, which limits their scalability.

So the challenge is to create membranes that can simultaneously offer high CO2 permeance and selectivity, crucial for effective carbon capture.

A team of scientists led by Kumar Varoon Agrawal at EPFL has now made a breakthrough in this area by developing membranes that show exceptional CO2 capture performance by incorporating pyridinic nitrogen at the edges of graphene pores. The membranes strike a remarkable balance of high CO2 permeance and selectivity, making them highly promising for various industrial applications. The work is published in Nature Energy.



A schematic of porous graphene hosting pyridinic N (shown as purple spheres) at the pore edges. The resulting membrane is highly selective to CO2. Credit: Kuang-Jung Hsu (EPFL

The researchers began by synthesizing single-layer graphene films using chemical vapor deposition on copper foil. They introduced pores into the graphene through controlled oxidation with ozone, which formed oxygen-atom functionalized pores. They then developed a method to incorporate nitrogen atoms at the pore edge in the form of pyridinic N by reacting the oxidized graphene with ammonia at room temperature.

The researchers confirmed the successful incorporation of pyridinic nitrogen and the formation of CO2 complexes at the pore edges by using various techniques, such as X-ray photoelectron spectroscopy and scanning tunneling microscopy. The incorporation of pyridinic N remarkably improved the binding of CO2 on graphene pores.

The resulting membranes showed a high CO2/N2 separation factor, with an average of 53 for a gas stream containing 20% CO2. Remarkably, streams with about 1% CO2, achieved separation factors above 1000 because of the competitive and reversible binding of CO2 at the pore edges, facilitated by the pyridinic nitrogen.

The scientists also showed that the membrane preparation process is scalable, producing high-performance membranes on a centimeter scale. This is crucial for practical applications, meaning that the membranes can be deployed in large-scale industrial settings.

The high performance of these graphene membranes in capturing CO2, even from dilute gas streams, can significantly reduce the costs and energy requirements of carbon capture processes. This innovation opens new avenues in the field of membrane science, potentially leading to more sustainable and economical CCUS solutions.

The uniform and scalable chemistry used in creating the membranes means that they can be scaled-up soon. The team is now looking to produce these membranes by a continuous roll-to-roll process. The versatility and efficiency of these membranes could transform how industries manage their emissions.

More information

www.epfl.ch

CarbonCapture Inc. unveils first U.S. DAC system designed for mass production

Designed for mass production and ease of global transport, each new Leo Series module is the size of a standard shipping container and can capture over 500 tons of CO2 from the atmosphere per year.

CarbonCapture will demonstrate a fully commissioned 12-reactor Leo Series module today at an unveiling event outside of Los Angeles. Guests include a wide range of industry stakeholders and speakers.

Adrian Corless, CEO of CarbonCapture Inc., said, "The Leo Series represents a major achievement for CarbonCapture. We've now developed a manufacturable product, built a full commercial supply chain, and established a facility for mass production—the combination of which allows us to introduce cost-saving improvements very quickly while also scaling up production. We're seeing robust demand for our modules from both our company-owned projects fueled by carbon removal credit sales and external project developers."

The Leo Series incorporates structured sorbents that enable each module to capture over 500 tons of atmospheric carbon dioxide per year. Due to its open systems architecture, modules can be upgraded throughout their life with higher capacity sorbents as they are released, minimising obsolescence risk and driving down costs over time.

"What CarbonCapture Inc. is doing with its modular approach to direct air capture, and efforts to ramp up production of the technology and bring down costs, underscores the indispensable role of the private sector in developing and deploying carbon management at a scale needed to achieve a clean energy and industrial future," said Brad Crabtree, the U.S. Department of Energy's (DOE) Assistant Secretary for Fossil Energy and Carbon Management. "Achieving our climate goals will require a domestic industrial renaissance, and CarbonCapture Inc. is a great example of the kind of homegrown, U.S.-based manufacturing that is central to President Biden's Investing in America agenda."

Designed for mass production

By developing and mass-producing modular DAC systems that can be strung together in large arrays, CarbonCapture aims to rapidly drive down the cost of atmospheric carbon removal. The solar industry provides a clear precedent for how economies of scale can lead to substantial cost reductions; over the past two decades, the cost of solar photovoltaic modules has plummeted by over 90% primarily due to advancements in high-volume manufacturing, increased production volumes, and enhanced efficiencies.

Nick Ellis, a Principal at Amazon's Climate Pledge Fund, commented, "As co-founders of The Climate Pledge—with a goal to reach net-zero carbon emissions by 2040—Amazon's first priority is to implement decarbonization strategies through real business changes and innovations, including efficiency improvements, renewable energy, materials reductions, and other emission elimination strategies. We also invest in companies like CarbonCapture, who aim to accelerate the removal of carbon dioxide from the atmosphere. We look forward to continuing to work with CarbonCapture to navigate the challenges ahead of managing rapid growth, navigating complex supply chains, and adapting to a fast-changing landscape—all areas where Amazon can share our expertise."

By producing DAC modules at scale, CarbonCapture intends to use cost-savings such as bulk purchasing of raw materials, streamlined manufacturing processes, and the amortization of R&D costs over large numbers of units. This approach is expected to significantly reduce the per-unit cost of the company's DAC modules and make them more accessible for widespread deployment.

CarbonCapture's 83,000-square-foot manufacturing facility in Mesa, Arizona, was chosen after an exhaustive nationwide search due to its central location, availability of clean energy, and workforce readiness. In addition to supplying DAC modules to third-party carbon removal developers around the world, the high-volume facility will have the production capacity needed to supply Project Bison, the company's megaton-scale carbon removal project in Wyoming, as well as the Southwest Regional Direct Air Capture Hub, both of which are supported by grants under the DOE's $3.5 billion Regional Direct Air Capture Hubs program.

More information

www.carboncapture.com

Capture & utilisation news

Simple new process stores CO2 in concrete without compromising strength

www.northwestern.edu

By using a carbonated — rather than a still — water-based solution during the concrete manufacturing process, a Northwestern University-led team of engineers has discovered a new way to store carbon dioxide in the ubiquitous construction material.

Not only could the new process help store CO2 from the ever-warming atmosphere, it also results in concrete with uncompromised strength and durability.

In laboratory experiments, the process achieved a CO2 sequestration efficiency of up to 45%, meaning that nearly half of the CO2 injected during concrete manufacturing was captured and stored. The researchers hope their new process could help offset CO2 emissions from the cement and concrete industries, which are responsible for 8% of global greenhouse gas emissions.

"The cement and concrete industries significantly contribute to human-caused CO2 emissions," said Northwestern's Alessandro Rotta Loria, who led the study.

"We are trying to develop approaches that lower CO2 emissions associated with those industries and, eventually, could turn cement and concrete into massive 'carbon sinks.' We are not there yet, but we now have a new method to reuse some of the CO2 emitted as a result of concrete manufacturing in this very same material. And our solution is so simple technologically that it should be relatively easy for industry to implement."

"More interestingly, this approach to accelerate and accentuate the carbonation of cement-based materials provides an opportunity to engineer new clinker-based products where CO2 becomes a key ingredient," said study coauthor Davide Zampini, vice president of global research and development at CEMEX.

Rotta Loria is the Louis Berger Assistant Professor of Civil and Environmental Engineering at Northwestern's McCormick School of Engineering. The study was a collaboration between Rotta Loria's laboratory and CEMEX, a global building materials company dedicated to sustainable construction.

"The idea is that cement already reacts with CO2," Rotta Loria explained. "That's why concrete structures naturally absorb CO2. But, of course, the absorbed CO2 is a small fraction of the CO2 emitted from producing the cement needed to create concrete."

Processes to store CO2 fall into one of two categories: hardened concrete carbonation or fresh concrete carbonation. In the hardened approach, solid concrete blocks are placed into chambers where CO2 gas is injected at high pressures. In the fresh version, workers inject CO2 gas into the mixture of water, cement and aggregates while concrete is being produced.

In Northwestern's new approach, the researchers used the fresh concrete carbonation process. But, instead of injecting CO2 while mixing all the ingredients together, they first injected CO2 gas into water mixed with a small amount of cement powder. After mixing this carbonated suspension with the rest of the cement and aggregates, they achieved a concrete that actually absorbed CO2 during its manufacturing.

O.C.O Technology signs landmark deal with Petronor

www.oco.co.uk
www.petronor.com

O.C.O Technology has announced a joint venture with Petronor to develop a €20 million facility in the Port of Bilbao.

It will be the first facility in continental Europe to produce carbon negative manufactured limestone aggregate using O.C.O's patented Accelerated Carbonation Technology (ACT). The process will use CO2 captured from the Petronor refinery to treat municipal waste that would otherwise have been sent to landfill.

Work is due to begin later this year with the plant due to be commissioned in early 2026.

O.C.O CEO Steve Greig believes the partnership is a major step forward in helping the European Energy from Waste (EfW) sector manage its waste materials. European Union (EU) regulations already demand that by 2035, only 10% of municipal waste should be sent to landfill.

"This is a hugely important milestone for O.C.O Technology and we are delighted to be working closely with our European partner Petronor. This development marks a number of firsts for us," said Steve Greig.

"Our innovative processes and products are making a significant difference by contributing to the low-carbon circular economy. We firmly believe that this is just the first of many opportunities to demonstrate how our technology can transform the way the European Energy from Waste sector manages its waste materials."

The project has already won several awards in Spain, including an Innovation Fund Small scale award in 2021, beating over 200 other entries to receive a €3.2m investment.

Ocean GeoLoop: 200 kWh per tonne carbon capture

www.oceangeoloop.com

Energy data based on flue gas conditions for the quicklime and cement industries has validated the company's carbon capture technology.

GeoLoop CC technology captures CO2 from point source emissions using natural and harmless processes, the company said.

"Based on a thorough test program including flue gases with 25% CO2 concentration, recent calculations conclude an electricity consumption for carbon capture in the size order of 200 kWh per tonne (approx. 0,7 GJ per tonne). These energy data position Ocean GeoLoop in the front line of technology providers for carbon capture worldwide.

We continue to develop disruptive solutions for further reduction of the electricity consumption for our next generation carbon capture," said Odd-Geir Lademo, Chief Executive Officer of Ocean GeoLoop.

The quicklime and cement industries account for more than 8% of the world´s CO2 emissions and CO2 capture is necessary to achieve these industries' climate goals.

"The results confirm the attractiveness of our carbon capture offering and provide significant commercial opportunities to the global quicklime and cement industries," said Anders Onarheim, Chairman of the Board in Ocean GeoLoop.

Will CO2 shipping be ready to service CO2 storage projects? Place your bets.

A recent report by CCSA-ZEP estimates that up to 40 CO2 vessels will be needed to service North Sea CCS projects by 2030. Even if not all these projects come on stream within this timeframe, 2030 is now less than six years off. So while this requirement may not be impossible to meet, it does represent a challenge. By Elwin Taylor, Clarksons.

By way of comparison, it took ten years, from 1951, to get 45 very small LPG carriers on the water in Europe at the same time.

But while the LPG fleet grew incrementally in line with a steady growth in LPG production and demand, liquefied CO2 shipping is expected to start at something much closer to scale – at least so far as industrial and power emissions are concerned. No need to wait for the emitting plants to be constructed – they already exist. Which is why the start-up of so much projected CCS activity is congested into the 2027-2030 period.

Ignoring issues of potential shipyard bottlenecks (a factor that did not apply in the 1950s with a substantial European shipbuilding base and quicker construction times), the question is: where are these ships are going to come from?

There are two basic supply scenarios. The first sees ships built for long-term charter (say 15 years) against specific projects. In this set-up, the ships could be built for one or more of the project partners, or they could be built for the account of a third-party shipowner and time chartered to the project. In the second scenario, ships would be built on speculation by shipowners anticipating future demand.

Today we see examples of both these models. On the one hand, four 7,500 cbm medium-pressure ships have been ordered as components of the Northern Lights project. At the same time, Capital Maritime has ordered four 22,000 cbm low pressure ships on speculation. Assuming that the Capital ships are employed in the North Sea, these orders go some way to addressing anticipated vessel demand. However, a significant theoretical delta remains.

Will this shortfall be made up by further speculative orders? If not, CCS projects will not be able to pick up ships off the market as and when they need them. And in that case, projects will have to take a much more proactive approach to securing tonnage ahead of start-up.

Risk is always easier to manage in an established market, especially if new vessels are as future-proofed as possible. Where there are well-forecast patterns of supply growth (today's Very Large Gas Carrier market would be a good example), speculative building decisions are more easily taken. Construction and financing costs loom large in the equation, as will analyses of the order book and growth in LPG supply. There is an underlying assumption that supply growth will be absorbed. This is important because demand is less easy to forecast and involves assumptions about GDP.

When comparing CO2 to a normal traded commodity, everything is back to front. The suppliers pay the receivers. Consequently, the equivalent to an analysis of supply would be an analysis of sink capacity. These projects are well known. An analysis of the volume of emissions seeking storage is less straightforward. Will it materialise, or will the underlying industrial activity be shut down? Or relocated? How far will volumes need to be transported? That will depend not only on the distance to the possible sink locations, but also on the cost of storage, which is today a largely unknown factor.

When it comes to waste grade LCO2 shipping, an actual market does not yet exist. As such, it is worth looking at the past experiences of gas shipowners ordering vessels speculatively for projected markets. There are several examples to choose from, and one seems particularly instructive. In the mid-1970s, an idea took hold that gripped the imagination of traders and shipowners alike: significant LPG import demand would develop in the USA, sometime around 1980. Everyone agreed. Consultants, brokers, in-house studies, all projections intersected in a pot of gold at the end of the rainbow. There were seemingly good reasons behind this belief. The US energy shortage was brought into focus by the 1973-74 oil embargo and price shock. At the same time, the global supply of LPG was growing and US demand for peak-shaving, synthetic natural gas and petrochemical feedstock usage was taken for granted. All that was missing was adequate terminal and storage infrastructure – and the ships. The owners duly obliged, with a major construction programme of large and very large fully-refrigerated units. But the producers and consumers let them down.

The LPG producers were, of course, the same as the oil producers. They did not see a compelling need to undercut their core business with what they viewed as a valuable product in its own right. Volatile and eccentric pricing policies made things worse. And for their part, the consumers saw no compelling reason to pay premium prices for an unpredictable new energy source/feedstock. Then recession struck, demand remained static, Canadian pipeline volumes picked up, and terminal projects were cancelled. Deregulation of natural gas delivered the coup de grâce. Even for those ships which did fit into the existing terminals, seaborne imports into the US were far less than forecast.

What about the speculatively ordered ships? Well, they didn't do nothing, although some experienced periods of layup. A level of alternative LPG employment was found, but Japan was already well served by Japanese tonnage. Low paying clean petroleum products were an option. And for the smaller ships there was ammonia, then as now, at a freight discount to LPG.

On the positive side, some of these ships also found work in higher-paying petrochemical gases, but in fierce competition with even smaller semi-refrigerated units. In the end, none of it related to the base case on which several ship orders had been predicated, and for long periods hire levels did not cover operating costs.

So what could go wrong with projections for CO2 demand? Firstly, the activity is mandated by government policies. What if these change? What if net zero 2050 becomes 2060? What if de-industrialization is the de facto answer to carbon emissions? Or producing plants are relocated to more sympathetic territories? What if the carbon price stays low and it makes more economic sense just to pay the tax? Don't forget, this is a sub-zero value material, with no direct commercial rationale that the owners can fall in behind.

The Northern Lights JV has ordered two 7,500m3-capacity dedicated CO2 carriers fro Dalian Shipbuilding Industry Co., Ltd. (DSIC) which will be used to transport liquid CO2 from European emitters to Northern Lights' Øygarden receiving terminal in Norway

And then there are some technical factors particular to CO2. The most important is the lack of certainty as to which containment system to commit to. Will the market call for medium-pressure ships? Or will the low-pressure type find favour? Or the elevated-pressure design? From a commercial perspective, each has its own strengths and weaknesses. But until there is a far greater degree of definition coming out of the projects, the choice of containment system represents a further layer of speculation.

If low-pressure CO2 ships are future-proofed to carry fully-refrigerated cargoes (e.g. LPG, ammonia, or even ethylene), they will be more costly than the non- CO2 ships competing in the same trades. That was not the case with the 1970s gas carriers built against the US LPG import story. As for medium-pressure ships, they would represent fully-pressurised/partly-refrigerated LPG carriers. From a commercial point of view, there is a very limited role for ships of this type larger than 11,000 cbm.

None of these elements may come into play. But they must still form part of an owner's evaluation.

Of course not every shipowner sits in the same place on the risk spectrum. The fact that some speculative orders have occurred is proof of that. Yet although there are many owners seeking to enter the world of CO2 shipping, the existing owners/operators of semi-refrigerated ships (technically speaking these are the closest to low- and medium-pressure CO2 designs) have yet to show interest in speculative construction. They are not without experience of illiquid, and at times overbuilt, markets.

From a charterer's point of view, a decision to wait for owners to go ahead and build ships is a speculation of the reverse kind. There are three possible outcomes. The first is overconstruction. That would yield a very happy result for the projects. Apart from freight competition there would be the possibility to reduce the period of commitment.

The second is that just enough ships are built speculatively to ensure a good balance of supply and demand. Not the worst result, taken all in all. The worst possible outcome for projects is the third, which is that not enough ships are built. That will mean dramatically elevated freight rates, damaging the cost model, and with the few owners who have built on speculation being handsomely rewarded. Still worse would be the inability to ship product at all, with the investment in costly and now redundant capture and sink facilities potentially wasted.

And by then it will be rien ne vas plus and too late to wish that you had placed a different bet.

More information

www.clarksons.com

Ocean-inspired technology could capture shipping emissions

Researchers at USC and Caltech, in collaboration with startup company Calcarea, have developed a device to capture carbon emissions directly from cargo ships and other diesel-powered vessels that support the global shipping industry.

The ocean's natural carbon capture cycles, which take hundreds of thousands of years, cannot keep pace with human-generated carbon emissions. The global shipping industry alone contributes roughly 3% of global CO2 emissions. Now, a new technology inspired by the ocean itself offers a potential solution.

"Our technology mimics the ocean's natural carbon capture process but at an exponentially faster rate," said William Berelson, the Paxson H. Offield Professor in Coastal and Marine Systems at the USC Dornsife College of Letters, Arts and Sciences and one of the project's lead researchers. "What takes nature years, our reactors achieve in mere minutes," said Berelson, who spoke with USC News at AltaSea, the public-private ocean institute headquartered at the Port of Los Angeles — one of the largest harbors in the world and the busiest port in the United States by volume.

Limestone, a type of calcium carbonate and the main ingredient in antacids, is abundant on the seafloor. Just like taking a tablet to neutralize acid in an upset stomach, the ocean uses limestone to neutralize the excess CO2 it absorbs from the atmosphere. The byproduct of this reaction is bicarbonate, a natural component of seawater.

The researchers' technology, a pair of reactors aptly named Ripple 1 and Ripple 2, works similarly. The reactors presently route CO2 directly from engine exhaust and convert it into a solution slightly enriched with bicarbonate. This solution is then safely released back into the ocean with minimal impact on the water's overall chemistry. Essentially, the reactors return water at a slightly saltier version of its natural state, with negligible impact on marine life.

From lab to sea

The reactor technology underwent rigorous development. The researchers developed the Ripple 1 prototype at USC's University Park Campus to test carbon capture in ocean water under carefully controlled conditions.

Promising results from these initial tests paved the way for the Ripple 2 reactor. This iteration is currently undergoing testing at AltaSea. All along, USC scientists have been checking to see that Ripple effluent does not harm ocean life.

"The beauty of this technology lies in its scalability," said Berelson, who recently won the USC Wrigley Institute for Environment and Sustainability Faculty Innovation Award in recognition of this carbon capture research. "Our goal is to develop this technology into a commercially viable solution that can be easily integrated into existing shipping operations. By implementing it on a commercial scale across the shipping sector, we hope to make a massive dent in global CO2 emissions."

The carbon capture device mimics the ocean's natural carbon capture process but at a faster rate. (USC Photo/Nina Raffio)

"Over 90% of the products we use in our daily lives traveled on a ship at some point. If we're going to think about how to deal with our CO2 problem as a society, we have to be mindful of the fact that we can't electrify all parts of the industry," said Jess Adkins, founder and CEO of Calcarea and the Smits Family Professor of Geochemistry and Global Environmental Science at Caltech.

"Shipping is a good example of an industry that doesn't electrify well. It's hard to imagine ships running off batteries, even though we must, as a society, get ourselves onto renewable energy," he said.

The technology is already gaining traction within the shipping industry. Calcarea recently announced a partnership with Lomar Shipping's corporate venture lab, lomarlabs, to commercialize and deploy their shipboard carbon capture system.

"Our technology offers lower energy demands, lower costs, and has lower infrastructure requirements than comparable alternatives to cut emissions from shipping," Adkins said. "But we need traction from ship owners and operators themselves to get our system out into the industry and in use. This collaboration will accelerate the testing and maritime engineering needed to get our system in use and, ultimately, reducing emissions."

More information

sustainability.usc.edu

Cause of seismic activity at Illinois CO2 injection site determined

Pore pressure diffusion generated by carbon dioxide injected underground at a carbon storage site in the Illinois Basin is the likely cause of hundreds of microearthquakes that took place at the site between 2011 and 2012, according to a new analysis.

The modeling study published in the Bulletin of the Seismological Society of America indicates that pressure diffusion along existing faults into the basement rock could have destabilized the faults where the microseismicity—ranging from Mw -2 to 1—occurred, said Ruben Juanes of MIT and colleagues.

There are some similarities between CO2 injection and wastewater injection from oil and gas operations, although globally the volumes of injected wastewater so far exceed that of injected CO2. Wastewater injection has induced small to moderate-sized earthquakes around the world, however, making it important to study how CO2 injection produces seismicity and whether it might also induce larger earthquakes.

The new findings confirm the importance of characterising subsurface faults in places selected for CO2 sequestration, the researchers noted.

The first injection period at the Illinois Basin-Decatur Project (IBDP) ran from November 2011 to November 2014, during which time one million tons of CO2 were injected to a depth of 2 kilometers underground. The researchers focused on the first year of CO2 injection at the project.

The IBDP injection layer is separated from the basement rock by a sandstone layer that is not very porous or permeable, leading researchers to wonder how CO2 injection could have reached the basement to trigger seismicity.

The model created by Juanes and colleagues shows that changes in rock pore pressure from the injection traveled along faults that connected the injection layer and the basement.

"During fluid injection, the pore pressure increases at the injection well and diffuses away from the well because of fluid migration. This is analogous to how temperature 'diffuses away' from hot areas to cold areas," Juanes explained.

"As a result of this pressure increase, the effective stress on a fault will decrease, resulting in the destabilisation of the fault."

Fluid injection can also expand rock, in a mechanism called poroelastic stress. The deforming rock can lead to stress changes that either destabilize or stabilize faults. In the IBDP case, the poroelastic effect stabilized the faults, Juanes and colleagues found.

Rob Finley, principal investigator on the Illinois Basin-Decatur Project, turns the main valve to start injection of CO2 into the Mt. Simon saline reservoir. | Daniel Byers/ Illinois State Geological Survey

Their analysis also suggests that the faults hosting the microearthquakes were very close to failing prior to CO2 injection. Characterizing these small faults—where they are and how close they are to failure—poses a significant challenge to carbon sequestration projects, Juanes noted.

"The main challenge is that remote sensing methods rely mostly on propagation of seismic waves through the surface," said Josimar Silva, first author of the study and a postdoc at MIT during the project. "Seismic waves attenuate rapidly for distances away from the source, and therefore have limited resolution when they reach the depths of interest."

One way to illuminate smaller faults at a carbon storage site might be to start with small-scale injection, he added.

"CO2 injection at Decatur is a good example. The first period of injection, the one we analyzed in the paper, led to hundreds of microearthquakes. The second period of injection, which took place at a shallower depth and not as close to the faulted basement, resulted in virtually no seismicity," Juanes said.

Injection rates in CO2 projects have been "much, much lower" than wastewater injection rates in the 2000s and 2010s, said Juanes, which might explain why moderate-sized induced seismicity hasn't been seen at carbon sequestration projects.

"But another explanation is that generally, better subsurface characterization has been done for CO2 sequestration prior to injection than in the early days of geologic wastewater disposal, where it was common to inject into, or very close to, the faulted basement rock," he added.

More information

www.seismosoc.org

Transport and storage news

OGCI partners with GCMD on shipping decarbonisation

www.ogci.com

www.gcformd.org

The Oil and Gas Climate Initiative (OGCI) and the Global Centre for Maritime Decarbonisation (GCMD) have signed a two-year coalition agreement to work on a range of solutions to decarbonise the shipping industry.

Areas of collaboration will focus on energy efficiency to reduce emissions, future fuels that are lower in carbon intensity, such as ammonia, methanol and biofuel blends, and onboard carbon capture pathways.

"This partnership is a great example of cross-industry collaboration to achieve emissions reductions as it combines knowledge and expertise from two critically important industries – energy and shipping – to unlock solutions to help decarbonize this hard-to-abate sector," said Julien Perez, Managing Director, OGCI.

OGCI is working on the development of low-carbon fuels, such as biofuels, ammonia, hydrogen and E-fuels and has supported the development of onboard carbon capture and storage (OCCS) for ships. OGCI also brings expertise and knowledge from developing land-based carbon capture projects at CCUS hubs to the partnership to mature OCCS, which is at much earlier stage.

GCMD is supporting the decarbonisation of the maritime sector through pilots and trials. Their initiatives include enabling ammonia as a marine fuel, assuring the quality, quantity and emissions abatement of drop-in green fuels, unlocking the carbon value chain through OCCS and scaling the adoption of energy efficiency technologies.

Most recently, GCMD's projects include a landmark study on offloading onboard captured carbon dioxide, a report examining the propensity of biofuel degradation in marine supply chains, and a pilot addressing concerns of long-term, continuous biofuels use on vessel operations.

The partnership builds on an existing collaboration between OGCI and GCMD known as Project REMARCCABLE, an initiative to demonstrate end-to-end onboard carbon capture at scale. Phase 1 of this project is now complete and findings will be published later this year.

Energean launches new carbon storage group

www.enearth.earth

EnEarth will look to create green hubs by identifying and exploring suitable geological structures, including depleted oil & gas fields, that can be suitably repurposed into sustainable and efficient carbon storage fields.

Using existing infrastructure and innovative technologies, the company says it hopes to play a crucial role in combating climate change. EnEarth's objective is to support hard to abate industries to achieve net zero targets, protecting regional industrial capacity, competitiveness and employment, whilst also reducing the carbon footprint of the Mediterranean.

EnEarth's initial operations will focus on a number of options:

• Carbon Storage: Initially at Prinos with a mandate to search for new regional projects. EnEarth will continue the development process of the regionally unique Prinos CO2 Project, which is designed to eventually reach an injection capacity of up to 3 million tons of CO2 a year. This project is hoped to act as an industrial hub that will help create a new low carbon / environmental services industrial incubator / hub in Northern Greece

• CO2 transport: Proposed partnership with Prime Marine to ensure efficient & safe transport of CO2 from various emissions sources in the Mediterranean region to Prinos.

• EnEarth will also consider investing in / partnerships around new technologies and approaches to the carbon capture and storage value chain.

EnEarth has recently submitted an application for a CO2 Storage License at Prinos, to the Hellenic Hydrocarbons and Energy Resources Management Company. The application seeks to gain approval for the suitability as a CO2 storage site and therefore the activation of the right to store CO2.

EnEarth will complete and submit the Environmental and Social Impact Assessment within the summer. The non-binding market test will begin this summer, with the aim of completing the binding market test within the year.

CPGC to use BASF CO2 capture system on LNG carriers

www.cpgc.net.cn

www.oase.basf.com

CSSC Power (Group) Corporation Limited (CPGC) will install its Onboard Carbon Capture System (OCCS) on multiple liquefied natural gas (LNG) carriers using BASF's OASE® blue technology.

Both parties signed a Framework Agreement on the actual ship application of the OCCS at the 2024 Shanghai International Carbon Neutrality Expo in Technologies, Products and Achievements. OASE blue is BASF's gas treatment technology designed for CO2 capture application in flue gas.

OASE® blue was developed specifically as an optimized large-scale post-combustion capture (PCC) technology.

Chen Haifeng, General Manager of Environmental Protection Business Department, CPGC, said, "Guided by global carbon reduction goals and the megatrend of low-carbon transformation in the shipping industry, CPGC, a subsidiary of China State Shipbuilding Corporation, has proactively undertaken the responsibility of promoting low-carbon development in the shipping industry with a forward-looking vision."

"We have worked closely with BASF to jointly address greenhouse gas emissions in the shipping industry and build a brighter future for low-carbon shipping. CPGC will continue to drive innovation and breakthroughs in low-carbon shipping technology, making every vessel a solid force in protecting our blue planet."

The actual ship application marks another significant milestone in the partnership, which follows completion of the system prototype testing. Currently, CPGC and BASF are working on optimising the detailed design of the OCCS unit based on actual ship conditions, to achieve commercial applications for different types of ships.

Over the past year, CPGC and BASF have conducted technical performance tests on the system prototype. The performance test runs have been validated by marine classification societies, which include the American Bureau of Shipping, Bureau Veritas and Nippon Kaiji


Image: ©Climeworks