Carbon Capture Journal

CCUS in Canada

Getting CCS projects to FID

Alberta invests $3.8M in CO2 storage monitoring

Study of water impacts of CCUS development in Alberta

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Mission Zero deploys third DAC at Deep Sky Alpha

Image: Mission Zero

- KAIST DAC achieves CO2 capture using only smartphone power
- CO2 capture and liquefaction from food and beverage manufacturing
- Northern Lights begins injecting CO2 at world's first commercial storage
- Evaluating CO2 capture technology options through technology screening

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

Editor
Keith Forward
editor@carboncapturejournal.com

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

Subscriptions
subs@carboncapturejournal.com

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

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Front cover: In its first international deployment Mission Zero is testing its third containerised DAC system with 250 tonnes of CO2 being stored underground (pg. 7)

Back cover: Deep Sky Alpha allows for real-world operations and optimisation of multiple technologies under identical conditions (pg. 6)

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Getting to Final Investment Decisions for CCS projects in Canada

In "Getting to FID" the International CCS Knowledge Centre looked at the questions that need to be answered by large emitters to greenlight investment in CCS projects, zooming in on Alberta as an example of how the challenges and risks to investment are being addressed.

The 2024 Global CCS Institute Status of (Carbon Capture and Storage) CCS report lists 534 projects at early and advanced stages of development, with only 44 under construction – in addition to 50 operating projects globally. The more capture projects that move forward, across key industries like fertilizer, steel, cement, plastics, chemicals and energy, the bigger the reduction in GHG emissions in our collective attempt to battle climate change.

In Alberta, there have been over 43 announced carbon capture projects over the past several years though with only 5 under construction and 5 operating. But why is there such a big gap between announcements and projects moving forward?

In October 2024, The International CCS Knowledge Centre released a Getting to FID report. Funded by the Government of Alberta, the report was developed with feedback from a series of meetings with executives considering CCS projects, hosted by Emissions Reduction Alberta (ERA) and the Knowledge Centre's near-decade experience supporting dozens of prospective and operating CCS projects.

The window for CCS projects is opening worldwide due to:

- A growing number of jurisdictions are developing carbon management strategies, regulatory frameworks and incentives.
- A growing recognition that carbon management is a necessity for any net-zero future.
- The readiness of CCS technology to reduce emissions from key industrial processes
- The severe consequences of global temperature rising and stakeholder sentiment for GHG emission reductions.

Alberta has existing advantages in CCS including the geology, know-how and many large emitters that can support a CCS industry. The Government of Alberta in collaboration with industry has been working for over a decade to create a robust regulatory framework.

More recently both Alberta and Canada have created incentives to unlock private investment, most notably Canada's CCUS Investment Tax Credits (CCUS ITC) and the Alberta Carbon Capture Incentive Program (ACCIP).

Alberta has begun to see projects get the green light. Since 2023, the province has seen 5 capture projects make positive final investment decisions and five sequestration hubs secure rights to permanently store carbon dioxide.

The full report takes a deep dive into the key questions large emitters look to answer before reaching an FID on a CCS project.

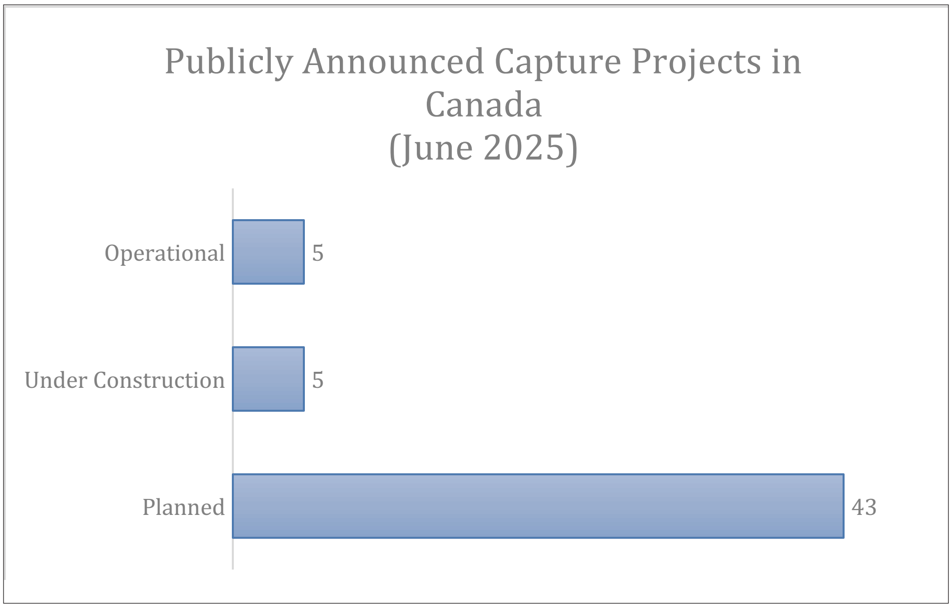


Figure 1 - Planned, Under Construction and Operational Capture Facilities in Alberta (June 2025)

Why Carbon Capture and Storage

Countries the world over have committed to reducing Greenhouse Gas (GHG) emissions and adapting to the impacts of climate change. These commitments show the need to develop large-scale emission reductions for industrial activities, with CCS playing a role in reducing CO2 emissions. International climate organizations including the Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA) both state carbon management technologies play a considerable role in efforts to limit global temperature increases and meet countries' respective commitments.

In pursuit of reducing industrial GHG emissions, governments have developed a set of carrots and sticks to draw private investment in emission reduction projects. This often includes the use of regulatory levers to mandate emission reductions from specific industrial facilities, broader industrial sectors, or the economy as a whole. These regulatory mechanisms can be strict limits such as specific facility emission intensity limits or flexible market-based systems such as emissions trading schemes.

Many of these regulatory structures seek to be technology agnostic, allowing industrial emitters to determine their path for reducing emissions. CCS projects represent one pathway for facilities to meet emission reduction regulations and avoid potential penalties. Due to the substantial emission reductions possible and the ubiquity of key industries that need CCS to reduce emissions, governments have also developed CCS-specific incentives.

Beyond government-driven requirements, corporate strategies also include major emission reduction commitments. CCS can be an attractive option in meeting those commitments for hard-to-abate sectors as capturing emissions from existing processes allows facilities to maintain production while substantially reducing emissions. In the words of an Executive Series participant, they see CCS as a tool to decarbonize without the need to deindustrialize.

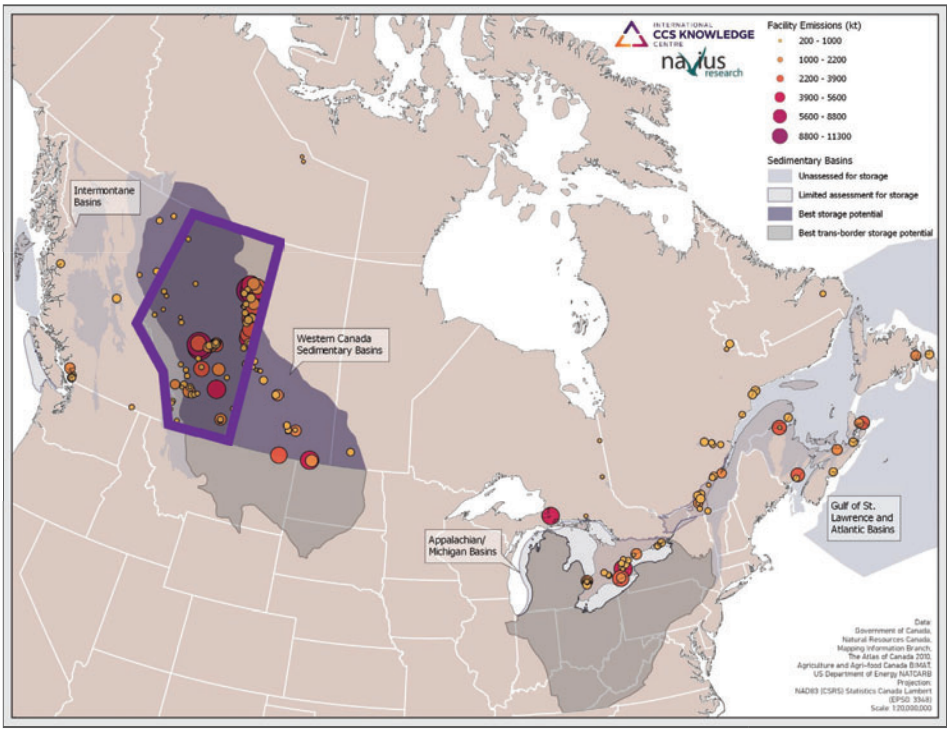


Figure 2 - Carbon storage potential in Canada

Basics prerequisites for CCS development: Storage, transportation and capture technologies

CCS projects operating at a large scale permanently store captured CO2 by injecting it into geologic reservoirs or utilizing the CO2 in an enhanced oil recovery process while permanently storing the CO2. Globally, it is anticipated that the vast majority of captured CO2 will need to be stored in geologically dedicated storage locations. In the near term, CO2 Enhanced Oil Recovery (EOR) will be an important source of revenue for CCS projects and facilities – increasing oil production while permanently storing CO2. Ensuring potential access to a storage site is the first criterion that needs to be confirmed before considering the feasibility of a capture facility. Without access to store captured emissions, major capture projects cannot go forward.

Evaluating an industrial facility's proximity and access to geological storage sites is a key step in evaluating the economic viability of any CCS project. The shorter the distance to an accessible sequestration location the lower the costs for a CCS project. Similarly, it is beneficial for multiple emitting facilities to access shared CO2 transportation and storage infrastructure to lower costs and manage and share risks, resulting in stable support for an emitter to achieve economies of scale and emissions reduction targets.

Many early CCS projects were fully integrated single source and sink projects pursued by individual proponents developing and operating most portions along the CO2 chain. As technologies have matured a growing distinction in specialization between capture, transport, and storage development and operations is forming, with CO2 transport and/or storage often contracted on a merchant basis. This enables projects without the capabilities to engage in either CO2 transport or sequestration to focus on core business and develop a capture facility at the site. Overall, this model enables expanded opportunities for CO2 capture across the economy and relies on business partnerships and competitive contractual relationships.

The selection of capture technology is a key determinant of the capital and operating costs and requirements of capture projects. With a push for adoption by a 2030 timeline to capitalize on ITC funding, most near-term capture projects are expected to use commercially proven technologies, specifically amine-based technologies. Known capabilities and lower technology risk were noted as desirable by executive series participants at the events that supported the report development. Depending on a company's risk tolerance and specific context, emitters have a range of capture technologies available for projects. The selection of capture technology in hard-to-abate industries is highly specific to the industrial location dynamics, including access to and the price of utilities, post-capture transportation, storage, and usage protocols. As a result, moving towards a 2050 timeline, a mix of technologies is expected.

Regulatory and incentive frameworks that enable CCS development

The purpose of CCS regulations and legislation to govern CCS projects varies depending on how involved the government is in building and incentivizing projects. Overall, regulatory oversight helps build assurance for projects to be developed responsibly and for public benefit. Jurisdictions where CCS projects are being developed have developed schemes to manage access to pore space for geologic sequestration as well as permitting processes and measurement, monitoring and verification requirements to ensure the integrity of environmental attributes of a project and public safety is prioritized.

Additionally, as CCS business cases require significant public investment, governments have tied knowledge sharing, labour and social justice requirements to funding to maximize public benefits for public investment.

Access to pore space is a crucial element in any CCS project. Like other subsurface resources, governments play a key role in managing access and resolving disputes related to pore space. While granting licenses for CO2 storage typically focuses on technical, environmental, and public safety aspects, the allocation of pore space is more about managing the resource and the associated rights.

Permitting, as related to CCS development, is defined as a series of approvals, consents, and licenses that a project must achieve after attaining pore space rights and before operation can begin. This can include permits for evaluating, testing, constructing, operating, and eventually closing CCS projects. The main purpose of permitting processes is to ensure compliance with environmental and safety standards.

An MMV plan is a multi-step framework designed to ensure the safety and effectiveness of ongoing CCS operations, primarily for CO2 sequestration. MMV plans describe the suite of technologies intended to monitor the environment and CO2 once sequestered. MMV plans are developed by the project operator in response to identified risks,and are generally a regulatory requirement. They provide a plan to collect the data and assurance that conditions specified in project approvals are satisfied.

Alberta, as an early adopter of CCS technologies, has developed a robust regulatory and incentive framework to enable CCS development in the province. The Alberta Energy Regulator with decades of experience permitting and monitoring subsurface projects is responsible for the permitting process for CO2 pipeline transportation and storage projects as well as capture projects built by oil and gas sector emitters.

Alberta Environment and Protected Areas is responsible for permitting all other capture projects and for maintaining Alberta's emission trading system under the Technology Innovation and Emission Reduction (TIER) regulation which governs the generation of a variety of CCS-related credits. Alberta Energy and Minerals is responsible for managing Alberta's pore space resources and developing critical policies that support CCS development including the potential for long-term liability transfers of CCS projects post-closure. The province with the ACCIP program that is expected to be in full force in 2025 shows the commitment of the region to supporting the implementation of CCS projects.

The business case for CCS projects

A critical element to draw private investment for CCS projects is developing a business case to compete for limited capital funds. Due to the scale and costs of projects, the relative nascence of CCS labour and supply chains, and the reliance on policy-based incentives, developing a business case for a CCS project is the biggest barrier for project proponents.

Every major project's financial viability is evaluated through capital costs or capital expenditures (CapEx) and operating expenditures (OpEx). Overall capture costs vary due to many key factors, including the type of industrial process, capture technology selected, flue gas characteristics (e.g. CO2 concentration and presence of trace constituents), and availability of heat and power. Megatonne-scale CCS projects can cost multibillions of dollars. Emitters must consider the cost of capitalizing on such projects and other uses, including other emission reduction projects.

Different approaches to determining how CCS projects should be funded have been taken globally. Typically, governments use a carrot-and-stick approach whereby regulations force large emitters to reduce emissions, and funding provides a pathway to build and operate CCS facilities.

The variation in approaches stems from the fiscal position of the jurisdictions, existing emission reduction approach, geography/geology, and public preferences. The United Kingdom for example, covers a relatively small area, has emitters close together, expects all storage to be offshore and has a history of regulating utility infrastructure. Therefore, the approach for CCS projects is to serve specific investment-ready clusters that have shared infrastructure for transportation and storage and tailored business cases that set a floor and ceiling for returns for projects.

The UK plans to transition these supports to a less regulated and more free market approach over time. The United States, which does not have any national carbon pricing regimes, developed production tax credits which results in an output-based incentive that rewards efficiency and lower project costs. Canada, like the US, has ample storage capacity in large areas of the country. However, Canada and its provinces have long-standing carbon pricing regimes and are used a revenue generation opportunity for CCS projects and has developed additional capital supports to improve overall project economics.

There are pros and cons to each of these approaches. Determining the sufficiency of these incentives in each of the jurisdictions will depend on the specific characteristics of a project, a proponent's risk tolerance and expected returns. Regardless of approach, stability of climate policies and bankability of incentives are critical for final investment decisions. Executive series participants emphasized that the uncertainty in return on investments due to uncertainty in the longevity of enabling incentives increases the risk on investment in CCS projects.

Purely policy-based incentives have "stroke of pen" risk in which key revenue sources such as emission pricing may be altered as governments change. In Canada and many European countries, carbon contracts for differences and other policy certainty vehicles have been developed to reduce these risks for proponents. The Canada Growth Fund through several mechanisms is committed to four CCS projects to reduce the risk of investment through favourable loans, carbon off-take agreements and stage-gated investments in projects. The effectiveness of these measures will be demonstrated if and when these projects reach FID in the coming years.

Beyond policy certainty, the Getting to FID report also explores other risks to investment in CCS projects in Canada, including labour supply, supply chains and public support. CCS projects are a major source of employment, requiring a substantial workforce for completion. The construction of the Boundary Dam exemplifies the labour-intensive nature of these projects – employing about 1,700 contractors and SaskPower employees at its peak and accumulating nearly 5 million person-hours of work.

This significantly boosted the economy of the rural town of Estevan, Saskatchewan. However, if several CCS projects are being developed across western Canada at the same time, there is a risk that the pool of skilled labour required to construct, commission and operate the projects may not be available. This is further complicated by the labour requirements and time-limited nature of incentives. For example, Canadian projects accessing the

CCUS ITC are required to finish construction before January 1, 2031, or only receive half of the incentive. This could lead to more labour shortages or increased costs for scarce labour in the lead up to 2031.

Similarly, the supply chain is a critical component in the successful execution of any major project. Disruptions in the supply chain can lead to significant delays, cost overruns, and even project failure. Therefore, a comprehensive understanding of supply chain risks and their mitigation is essential for making an FID on CCS projects.

There are several long lead-time components for capture projects including CO_2 compressors and if a project includes a combined heat and power unit, natural gas turbines have lead times that currently can extend to 5 years. The CCUS ITC is set to halve for projects in Canada in 2031, meaning that orders of these key items will need to take place in the next couple of years to be take advantage of the full 50% rate for capture expenditures.

Building public understanding and support for CCS projects is critical for several reasons. First, as mentioned above, CCS projects are most often investments that receive public funding to provide a public benefit - major CO_2 emission reductions. Second, onshore CO_2 transportation and storage facilities are located below public and private properties. Adequate consultation and education of the public are critical to ensure public support for CCS projects.

Since the release of the report, other uncertainties for industrial investment in projects have been jolted by the potential of trade tariffs and other protectionist measures. Emission-intensive trade-exposed industries have additional core business uncertainties to manage while considering emission reduction investments.

Looking forward to FIDs

The development of large-scale CCS projects is essential to achieving significant reductions in greenhouse gas emissions from critical industrial processes. As highlighted in the Getting to FID report, Alberta provides a compelling case study for navigating the complex regulatory, financial, and technical landscapes required to advance these projects to an FID. The urgency of reaching FID is underscored by the global need to scale up CCS deployment rapidly to meet climate targets.

Alberta has the people, know-how, geology, and regulatory framework needed to build CCS projects. However, the climate for investment, policy certainty and other risks may limit or delay CCS investments. Only time will tell how many projects will reach positive FIDs in the short term, but the foundation is there for Alberta to continue its leadership in implementing CCS technologies as we try to balance economic development and greenhouse gas emissions.

More information

Download the full Getting to FID report at:

https://ccsknowledge.com/insights

www.eralberta.ca

www.alberta.ca

Alberta invests $3.8 million in underground CO2 storage monitoring

Funds from the industry-funded TIER program will be used by Carbon Management Canada to test a new cost effective real-time monitoring system for carbon dioxide storage.

Carbon Management Canada (CMC) will develop real-time and cost-effective systems for monitoring, measurement and verification (MMV) of CO_2 geological storage. The next generation of geophysical techniques will be combined and integrated with geochemical and reservoir engineering methods for the Advanced Multi-Physics Sparse (AMPS) Project, with results benchmarked against established MMV technology at the Newell County Field Research Station.

At Newell CMC injects CO_2 underground and partners with industry, tech developers and researchers from around the world to test and develop technologies that accurately track CO_2 plumes underground.

Further deployment of the AMPS approach will be pioneered at a commercial site during the project. MMV is an essential component of commercial CCS projects, required for regulatory permits and to demonstrate the security and permanence of storage. CMC will develop a comprehensive report on integrated MMV system performance and practical guidelines to support industry-wide, cost-effective implementation.

The Technology Innovation and Emissions Reduction (TIER) Regulation is at the core of emissions management in Alberta. The TIER system implements Alberta's industrial carbon pricing and emissions trading system, helping industrial facilities find innovative ways to reduce emissions and invest in clean technology to stay competitive and save money.

"This new project will enable CMC, in collaboration with our joint industry partnership, to develop cost-effective and real-time, innovative monitoring solutions for CO_2 geological storage," said Neil Wildgust, President and CEO, Carbon Management Canada.

"Monitoring systems are an essential component to derisk and establish secure operations at geological carbon storage sites that support CCUS deployment. The work will be undertaken primarily at CMC's Newell County Field Research Station and is made possible with financial support from the Government of Alberta through Emissions Reduction Alberta."

More information

https://cmcghg.com

www.alberta.ca

Deep Sky Alpha first DAC facility in North America to store CO2 underground

Located on 5 acres in an industrial park in Innisfail, Alberta, Deep Sky Alpha went from breaking ground to operational in just 12 months.

The facility brings together multiple direct air capture (DAC) technologies, enabling scale, speed, and innovation. Alpha allows for real-world operations and optimisation of multiple technologies under identical conditions, accelerating the industry's path to cost-effective, scalable carbon removal.

“This is a defining moment—not just for Deep Sky, but for the global carbon removal industry,” said Alex Petre, Deep Sky CEO. “In just one year, we went from breaking ground to pulling carbon from the sky and locking it underground for good. Companies around the world are looking for high-quality, durable carbon removal to offset carbon footprints. With Deep Sky Alpha, we’re proving that it’s not only possible—it’s here.”

The project represents an industry first for the private development of scalable CDR and the first cross-technology project in the world

With this milestone, Deep Sky Alpha becomes the first DAC facility in North America to sequester CO2 underground. The CO2 captured at Deep Sky Alpha is permanently stored underground in deep geological formations called saline aquifers, which are abundant in Alberta.

“Alberta continues to lead the way in attracting world-class innovation and this is an example of another company that has chosen Alberta because of our skilled workforce, strong regulatory system, and commitment to responsible development,” said Rebecca Schulz, Minister of Environment and Protected Areas. “We’re proud to see companies investing here — and proving once again that Alberta is the best place in the world to build, innovate, and grow.”

Captured CO2 comes from multiple Direct Air Capture units on site from all around the world – with additional units being installed this fall and room for up to 10 units total. Featured units that are currently commissioning include UK based Airhive and Mission Zero Technologies, and Quebec based Skyrenu. Subsequent DAC units will be installed this year.

Deep Sky Alpha's strategic location provides access to renewable power and proximity to permanent geological storage. The facility, entirely powered by solar energy, will capture 3,000 tonnes of CO2 annually. The project has generated more than 110 construction jobs and will employ approximately 15 full-time operators. Monitoring of Alpha’s capture and sequestration progress will be conducted on an ongoing basis using proprietary software and be available on Deep Sky’s website.

Deep Sky Alpha represents the first step in a worldwide carbon removal effort being developed by Deep Sky, with large-scale projects already underway across Alberta, Quebec, and builds on Deep Sky's recent $40 million grant from Breakthrough Energy Catalyst and carbon removal credit purchase agreements with buyers including Microsoft and Royal Bank of Canada.

Carbon credits for Deep Sky Alpha are already pre-sold but buyers interested in reserving credits from subsequent commercial projects can contact the company.

More information
https://deepskyclimate.com

Mission Zero deploys third DAC at Deep Sky Alpha facility

Marking Mission Zero Technology's first international deployment, the containerised system will recover up to 250 tonnes of CO2 from the atmosphere per year powered entirely by solar energy.

The third deployment of its Direct Air Capture technology (DAC) is now live at Deep Sky's flagship Alpha project in Alberta, Canada. The system progressed rapidly from first delivery through to live operations in the space of 10 months. The captured carbon will be processed by Deep Sky and stored securely underground, once the Alpha site becomes fully operational later this summer.

Captured carbon will be processed by Deep Sky and stored securely underground, once the Alpha site becomes fully operational later this summer

Deep Sky Alpha is the world's first cross-tech DAC hub aiming to accelerate the path to low-cost, high-quality carbon removal at scale. The site demonstrates DAC solutions from multiple providers, including Mission Zero Technologies.

Co-founder and CEO of Mission Zero Technologies, Dr Nicholas Chadwick commented, "I am proud to prove a third commercial use case for our direct air capture technology on a new continent. This third deployment demonstrates that we've established an exportable model for scaling internationally and is a testament to our teams' ability to deliver critical climate solutions at pace."

This deployment represents MZT's third DAC system and first outside the UK, joining two systems already in operation. The company's second DAC facility, developed in partnership with O.C.O Technology (O.C.O) and the UK Department of Energy Security and Net Zero (DESNZ), is also capable of recovering around 250 tonnes of CO2 per year from the atmosphere.

This carbon supply is fully-integrated for direct use in O.C.O's building materials production facilities to enable carbon-negative limestone.

Meanwhile, Mission Zero Technologies' first plant, developed in partnership with the University of Sheffield, recovers 50 tonnes of atmospheric CO2 annually for the production of a pioneer Sustainable Aviation Fuel. By comparison, this latest Canadian deployment represents a fivefold increase in carbon capture capacity, alongside a 60% reduction in cost.

This underscores the pace of technical progress achieved since this initial deployment in 2023, as well as the value of the operational data collected and the pace of iteration as MZT develops its next-generation products, capable of multi-kilotonne annual CO2 recovery.

Establishing diversified end-use carbon pathways enables the de-risking of this underlying technology, the company said. Proving the ability to deliver viable commercial and sustainable DAC systems globally, using 'off-the-shelf' components and established global supply chains helps to validate its approach.

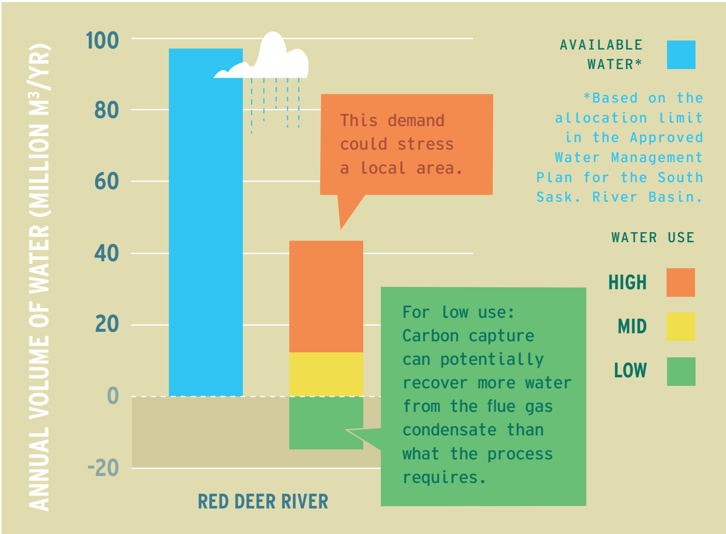
Deep Sky CEO, Alex Petre, said, "This represents an important step for the wider DAC industry, as Deep Sky is beginning to operate multiple technologies at its DAC hub in Canada. We are excited to have Mission Zero be one of the first technologies live at Alpha this summer."

More information

www.missionzero.tech

Study of water impacts of CCUS development in Alberta

A report from WaterSMART demonstrates that the full build out of the CCUS sector in the province is likely to necessitate trade-offs within the water-energy-food nexus.



Comparison of water available on an annual basis to water required for new CCUS projects in the Red Deer River

With funding and support from Alberta Innovates, Emissions Reduction Alberta, Lafarge, and other industry partners, WaterSMART Solutions Ltd., a Hazen Company, has prepared a report studying the potential water impacts of CCUS development in Alberta. The work builds upon WaterSMART's previous study of hydrogen's potential water impacts and is motivated by the anticipated scale and speed of CCUS deployments in Alberta.

The study highlights the impacts that design decisions can play in CCUS' water use, with some projects having the potential to generate more water than they consume, while others will be net water users. These water generation and consumption dynamics will be important for project proponents and sector participants to understand and manage as part of the energy transition.

Many CCUS projects are expected to recover more water than they consume. With the appropriate management, the recovered water could potentially be used to offset other water demands.

The report aims to inform policies, regulations, and investments that will best enable the sector's growth while strategically balancing trade-offs within the water-energy-food nexus context.

Comparing water supply with demand

In Alberta, the amount of water available for use varies greatly by location, time of year, and year over year. This variability is managed by regulators and users to meet ecological and human needs while making water available for economic development. Rivers in southern Alberta, which flow through more populated areas, face higher competition for water resources compared to other regions.

Many CCUS production facilities are proposed across Alberta. Using a 2050 time horizon, the Figure above compares water that is available for new uses to the anticipated consumptive water demands of proposed CCUS development for the Red Deer River Basin, which are expected to require new water licences. The Red Deer River serves as an illustrative example of a basin nearing its maximum allocation capacity. Other rivers exhibit unique patterns of water availability and demand.

In some locations, limited water availability introduces project risks for carbon capture, and carbon capture development may lead to trade-offs in the context of the Water Nexus. On the other hand, existing facilities which are retrofitted with carbon capture may already have sufficient water licenses to accommodate a demand increase, potentially leading to a net-neutral impact on water availability.

Alternatively, carbon capture projects which generate more water than they consume could lead to net-positive impacts on water availability. For each project, a good understanding is required of its basin-specific water context as well as its potential water impacts.

The link between hydrogen and CCUS

CCUS has been recognized as one of the four pillars of the global energy transition, alongside renewable power generation, bioenergy, and hydrogen. In Alberta, the province's Hydrogen Roadmap explicitly links hydrogen development and CCUS, a position which has been echoed by industry. WaterSMART's 2023 study on the water impacts of hydrogen development in Alberta estimated that it could potentially consume between 121,100 and 503,360 dam3/yr.

When the announced carbon capture projects are layered onto this potential hydrogen development, the combined water use across the province ranges between 20,513 and 705,504 dam^3/year. Carbon capture projects have the potential to reduce the net water consumption of hydrogen development, assuming that water recovered from the capture processes can be used to offset the demands for hydrogen production.

For both hydrogen and CCUS development, water impacts, risks, and opportunities should be analyzed on a location-specific basis.

More information

https://watersmartsolutions.ca
https://albertainnovates.ca
www.eralberta.ca

Canada news

Carbon Upcycling breaks ground on cement plant CCUS in Canada

www.carbonupcycling.com

www.ashgrove.com

Carbon 1 Mississauga is a Canadian first-of-its-kind commercial carbon capture and utilisation facility at Ash Grove's cement plant in Mississauga, Ontario.

The project will use Carbon Upcycling's patented technology to capture CO2 from the cement kiln and use it to transform locally produced industrial byproducts into high-quality, low-carbon supplementary cementitious materials (SCMs). Once operational in 2026, the facility will have the capacity to produce up to 30,000 tonnes of SCMs annually, directly contributing to Canada's climate and clean manufacturing goals.

In recognition of its innovation and environmental potential, the Carbon 1 Mississauga project has been awarded up to $10 million in federal funding through three key Canadian programs.

Carbon 1 Mississauga is supported by Next Generation Manufacturing's Sustainable Manufacturing Program, the Environment and Climate Change Canada's Low-Carbon Economy Fund and is receiving advisory services and funding from the National Research Council of Canada Industrial Research Assistance Program (NRC IRAP).

"Clean technology, including carbon capture, will play an integral role in our efforts to decarbonize," said The Honourable Julie Dabrusin, Minister of Environment and Climate Change Canada.

"Projects such as this one present significant economic opportunity for Canadian industry in clean technology, clean energy and decarbonization. We will continue to work with partners across sectors to accelerate the adoption of this kind of technology and ensure Canada is a global leader in carbon capture investments."

The Carbon 1 Mississauga project is being delivered through a multi-stakeholder collaboration. CRH Ventures, the venture capital unit of CRH, has invested in Carbon Upcycling and is playing a key role in scaling the company's technology.

The project at Ash Grove's cement plant will use Carbon Upcycling technology to capture CO2 from a cement kiln to produce low carbon materials

Enhance's Origins CCS Hub receives regulatory approval

https://enhanceenergy.com

The Alberta Energy Regulator has granted approval for its Origins saline aquifer CCS project in central Alberta.

The project will enable commercial-scale emissions management for industrial emitters through permanent sequestration of captured CO2.

Enhance has been operating the Clive CCS project with enhanced oil recovery for over five years with 7 million tonnes of industrial sector CO2 emissions permanently stored. The project has resulted in economic revival of legacy hydrocarbon fields.

Repurposing existing mature infrastructure to permanently store CO2 and produce previously unrecoverable resources is one way of growing Alberta's low carbon energy sector.

Enhance is Canada's largest geological sequestration operator that credits emission reductions under provincial and federal compliance programs and was a founding partner of the Alberta Carbon Trunk Line (ACTL) Project.

The project will manage CO2 from hard-to-abate industries, like cement, oil and gas, power generation, and petrochemicals along Alberta's Edmonton-Calgary Corridor — including the Alberta Industrial Heartland and existing large emissions sources or carbon dioxide removals in central and southern Alberta.

Research on ice-forming compound could improve pipeline safety, CCS

www.usask.ca

www.lightsource.ca

Work by USask researchers advances understanding of clathrate hydrates, crystal "cages" of ice that can trap gas, liquids. By Brian Owen.

These hydrates can form in natural gas pipelines and cause explosions if they block the line. The BP Deepwater Horizon disaster in the Gulf of Mexico in 2010 was caused by hydrate formation, says John Tse, Canada Research Chair of Materials Science and a professor of Physics at the University of Saskatchewan (USask).

Because the reactions that form hydrates happen so quickly, the researchers needed a way to both slow them down and observe them in progress. So Tse cooled down a mixture of water and a chemical called tetrahydrofuran (THF) to -263°C in a vacuum, then used the powerful X-ray beamlines of the Canadian Light Source at USask to watch how the molecules moved and changed shape as he slowly warmed up the mixture.

Understanding more about how hydrates behave could lead to many different practical applications beyond just protecting against pipeline explosions. They could also be used in natural gas transport and storage – a single cubic foot of hydrate can store up to 150 cubic feet of gas – or for carbon capture and storage projects.

Evaluating carbon capture technology options through technology screening

As part of its RePowerEU project, VTT has developed a model for screening and techno-economic assessment of post-combustion carbon capture technologies. By Onni Linjala, Research Scientist, VTT.

Carbon capture has been identified as a crucial complementary technology for climate change mitigation. With this several technology suppliers are competing to establish themselves as technology leaders to better secure upcoming projects in the emerging market. Despite the competition, there will be room for many types of solutions as carbon capture becomes more mainstream and suitable for variety of applications.

The broad range of options will benefit potential technology implementors as different technologies excel at different applications. As part of VTT's RePowerEU project, VTT has developed a model for screening and techno-economic assessment of post-combustion carbon capture technologies.

Most carbon capture projects have focused on capturing CO2 from stationary emission point sources of energy production and industrial processes, which can be referred to as point source capture. However, CO2 can be captured from a variety of sources like the atmosphere, oceans, or mobile applications like ships or road vehicles.

Many types of technologies have been developed for carbon capture, utilizing physical and chemical phenomena like absorption, adsorption, electrochemical potentials, selective membrane barriers, cryogenics, oxyfuel combustion, chemical looping, and various hybrid configurations (Figure 1). Furthermore, these technologies can be implemented with various capture mediums, material choices, equipment configurations, and energy integration solutions, making the portfolio of technology options even broader.

The technologies differ in terms of technological readiness, retrofittability, scalability, and operational characteristics such as energy consumption, emissions, and ability to response to dynamicity. There is no one-fits-all solution and each process has case-specific advantages and challenges, especially in point source capture where properties between different applications can vary significantly.

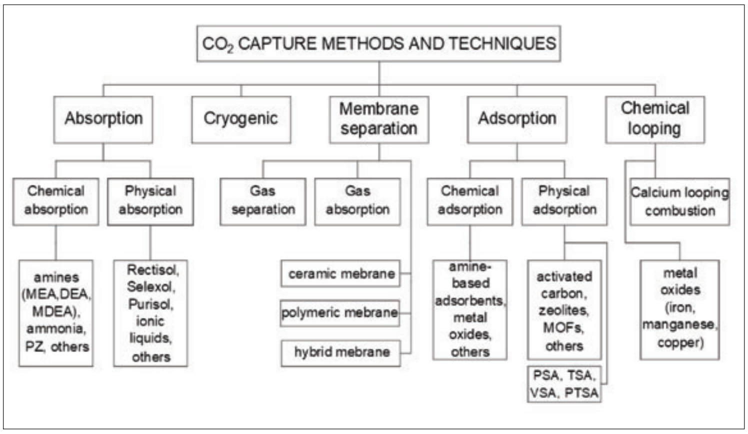


Figure 1 - Carbon capture methods and techniques (Madejski et al. 2022)

Due to several technology options and still a low number of commercial references, potential implementors are left wondering which technology would best suit their needs. Choice of optimal technology for a certain application as well as performance of the process is case-specific, being affected by the desired capture performance, characteristics of the emission source, and the operating environment. These factors are evaluated through technology screening and techno-economic assessment to identify the best technology choice for a carbon capture project.

Desired capture performance, i.e., capture efficiency and purity of the captured CO2, is a key factor for technology choice and process design. It determines how selective capture process is needed and what are the conditioning demands after capture. Selectivity refers to how well CO2 can be isolated from other compounds in the source. Generally, processes based on chemical reactions are more selective than physical reactions, but they often yield higher energy demands due to stronger bonds that take place between CO2 and the capture medium. In point source capture, capture rates of 90–95 % and purities of >99 % are typically pursued, but in some cases lower or higher performance may be desired. Optimization of the capture performance is a balance between performance and costs.

Alongside the desired capture performance, concentration and partial pressure of CO2 in the source are the primary factors to determine how selective capture process is needed. They also largely impact energy demand and capture costs that increase as CO2 concentration decreases since more work is required for the separation. Chemical absorption with liquid solvents based on amines and carbonate salts is favored in sources with low to moderate CO2 concentrations (~3-25 %) and atmospheric pressures such as combustion flue gases.

Physical solvents, solid adsorbents, membranes, and cryogenic separation are more common for sources with higher CO2 concentrations and pressures that occur, for instance, in natural gas processing. In sources with nearly pure CO2 exhaust streams, such as ethanol fermentation and biogas upgrading, removal of moisture and some impurities may be only needed.

Other source properties such as impurities, temperature, and stability of operation should be also considered to determine suitable technology choices, pre-capture conditioning needs, and heat integration opportunities. Impurities may degrade some capture mediums and materials or weaken process performance. High temperatures can also degrade some capture mediums but can provide opportunities for heat integration. Also, it should be estimated how well the technologies can response to potential dynamicity within the process like load changes and fluctuation of CO2 concentration, which may affect capture performance. Seasonal load variation should be also considered as it affects dimensioning and operational profile of the capture process.

Scale is another key factor for technology choice. Typically, the scale of a carbon capture project is reported as tonnes of annually captured CO2. Liquid solvent processes are often better scalable to large industrial processes with several hundred kilotonnes of annual CO2 emissions, whereas technologies like solid adsorbents, fuel cells and membranes are more modular and may excel at smaller scales and gain cost benefits from mass production of fixed units.

Carbon capture is often energy-intensive, making energy integration one of the most important factors regarding technology choice and process design. Energy streams available at the site (e.g., steam, electricity, low-grade heat, and cooling) affect how the process can be most cost-efficiently powered. Many capture processes have been designed to use low-pressure steam, but applications with optimized steam balances could benefit from fully electric configurations as otherwise the steam balance is affected, or new steam generation capacity would be needed.

With fully electric configurations electricity transmission capacity and dynamicity of electricity prices should be evaluated. Some applications may also have low-grade waste heat available that could at least partly power some capture processes with little impact on the energy balance. Some carbon capture processes also yield heat at recoverable levels, which could provide synergy with district heating networks or other heat demand applications. However, it also raises the question of where to direct the heat load at periods of low heat demand.

Site layout and operating environment should be also considered. In compact sites such as oil and chemical refineries there may be restrictions on size or footprint of any additional equipment and low equipment footprints may have to be prioritized. Utility demands like water and chemical use as well as emission and waste management should be also considered. Site location, readiness for logistics, and proximity of utilization applications or storage sites should be also assessed, as these factors affect logistical options and the feasibility of the value chain. As in all mechanical engineering, factors like weather conditions, humidity, and altitude should be also considered.

After technology screening, some form of techno-economic assessment (TEA) is often

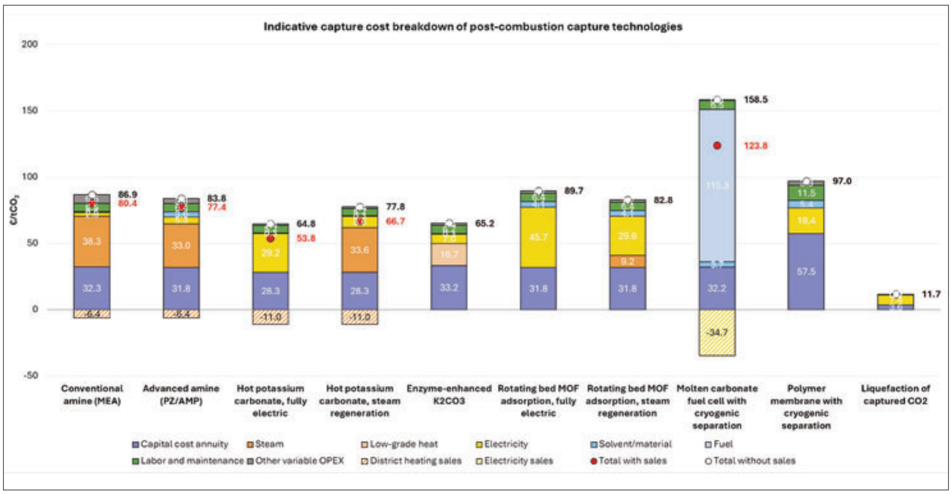


Figure 2 - Breakdown of indicative capture costs (€/tCO2) for post-combustion capture technologies calculated for a plant with 500 kt of annual CO2 emissions

beneficial to estimate the economics of technologies that have been identified potential. TEA consists of outlining properties and operating profile of the CO2 source and modelling energy and mass balances of the capture processes. Furthermore, cost information is collected about the examined technologies, which are scaled and modified to fit the application in question. TEA can be performed with varying levels of detail, from simple spreadsheets to process simulations validated with experimental data. Typically, process models and TEA are detailed as the project progresses from concepts closer to full-scale.

As part of the RePowerEU project on CO2 supply for P2X processes, VTT has developed a calculative model for technology screening and techno-economic assessment of post-combustion carbon capture technologies. The model was constructed based on cost data collected from literature and it includes several mature and emerging capture technologies: conventional amine absorption (MEA), advanced amine absorption (PZ/AMP), hot potassium carbonate (HPC) with fully electric and steam regeneration configurations, enzyme-enhanced K2CO3 absorption, rotating-bed MOF adsorption with fully electric and steam regeneration configurations, polymer membrane separation, molten carbonate fuel cell-based capture, and liquefaction of the captured CO2.

Based on inputs regarding scale, energy prices, and investment parameters, the model calculates an indicative CO2 capture cost breakdown (€/tCO2) for each technology. Figure 2 presents an example of the results, with capture costs calculated for a plant with 500 kilotons of annual CO2 emissions. The model can be also used to conduct sensitivity analysis to identify the most influential cost factors and examine different operating scenarios.

While the tool provides valuable information about the cost structure of post-combustion capture technology options, the results are indicative, depend largely on the inputs used, and do not necessarily represent views of the technology developers and suppliers. As the operating parameters have been collected from public sources, assumptions and methodology between some of the parameters may vary. To obtain the most accurate capture cost estimates, process simulation tools validated with experiments and cost data provided by technology suppliers should be used.

In addition to post-combustion capture, VTT's RePowerEU project on CO2 supply for P2X processes has focused on integrating power-to-X technologies with direct air capture, as well as advancing the CO2 economy through development of CO2 logistics and hubs. In future work, VTT will continue to advance process simulation tools, experimental research capabilities, and novel technology concepts regarding various carbon capture value chains.

More information

Learn more on VTT's competence on CCU/S and find our contact information:

www.vttresearch.com/en/ourservices/carbon-capture-and-storage-or-utilization-ccs-ccu

CO2 capture and liquefaction from food and beverage manufacturing

An increasing number of North American companies engaged in food and beverage production are focusing on the capture and liquefaction of carbon dioxide from their waste processes to benefit from cost reductions and additional revenue streams while expanding their sustainable portfolios by reducing greenhouse gas emissions. By Benjamin Burfeind and Manuela Hoellinger, Kanadevia.

Converting to sustainable business practices is becoming more business relevant for corporations in all sectors. A recent Kearney survey shows that 80 percent of buyers consider the environmental impacts of their purchases. Responding to this, companies continue to build sustainable practices into their operations, creating value for their customers and stakeholders.

For larger business operations, the integration of sustainability projects is more likely part of a broad-scoped strategy to optimize all facets of their business, from facility operations through process functions, manpower and distribution, while incorporating sustainable materials and procedures.

A crucial aspect of any sustainability initiative is minimizing a company's carbon footprint. As global demand for energy rises, so does the need for solutions to minimize the influence of CO2 released from fossil fuels and other unsustainable sources into the environment. Food and beverage manufacturing operations, as significant consumers of energy and a source of carbon emissions in the global economy, need to play a contributing role in partnership with sustainability.

CO2 can increase the efficiency of crop growth. (Image courtesy Kanadevia Inova)

CO2 Capture and Liquefaction

While preventing carbon dioxide from being released into the atmosphere continues to be a key objective of sustainable practices, more recent decarbonization efforts have focused on CO2 capture, with subsequent storage and/or reuse. Essentially, capturing CO2 from food and beverage manufacturing operations, then either sequestering CO2 into deep underground storage, or converting it into reusable by-products.

Whether sequestering or repurposing CO2, it first must be converted from a gaseous state to a fluid state to be transported and stored. The liquid state of CO2 is typically between a temperature of -11°F (-24°C) and -18°F (-28°C), at a pressure between 206 – 261 PSI (g).

Repurposing Liquefied CO2

Solutions providing repurposed and renewable liquefied CO2 are becoming increasingly important in numerous areas of application, enhancing circularity, decarbonization, improving supply security, and reducing transportation costs. The fact that liquefied CO2 is needed in food and beverage production and storage is increasingly directing attention onto this renewable by-product as a valuable commodity.

Food Production and Preservation

The importance of pressurized CO2 in the food industry cannot be underscored enough. The food industry largely relies on this liquid gas for crop growth, refrigeration, preservation, storage and softening.

Crop Growth

CO2 is used in agriculture to increase crop growth and photosynthesis, and to minimize crop waste. Plants use CO2, water, and sunlight to produce carbohydrates and oxygen through photosynthesis. Higher levels of CO2 can improve the efficiency of photosynthesis, allowing plants to use light more effectively and produce more energy for growth.

This can also improve water conservation because carbon dioxide reduces the rate at which plants lose water through evaporation. Supplemental CO2 in greenhouses can increase a crop's ideal temperature range, which can lead to higher production even in warmer temperatures.

Food Preservation

The food supply chain uses many strategies to increase food production, extend fresh food availability and shelf-life, and reduce waste.

CO2 is used in controlled storage atmospheres as a cooling agent to reduce food spoilage and extend the shelf life of fruits, vegetables, meats, seafood, and other perishable products. It inhibits the growth of certain bacteria and molds, which are common causes of food spoilage. By creating an environment that slows down the degradation process, CO2 ensures that food products remain fresh for longer periods.

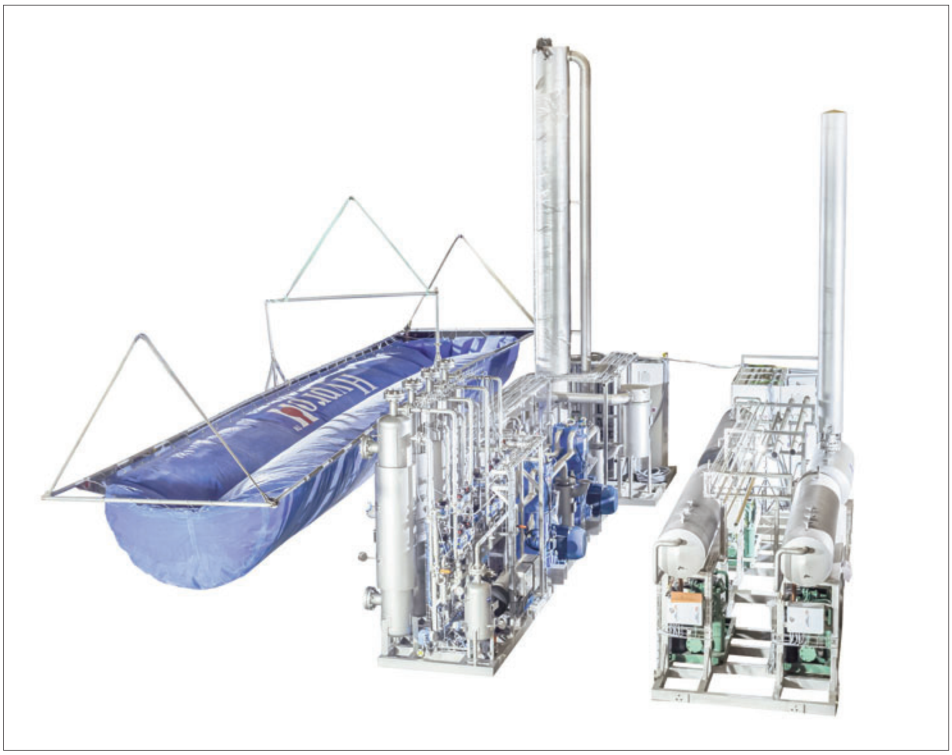
Fresh fruits and vegetables are alive and continue to respire even after harvest. Fruit respiration is necessary for ripening. However, it has a downside: It can negatively affect internal and external fruit quality attributes. The higher the respiration rate, the more perishable the produce is, so high respiration rates result in less shelf-life.

CO2 technology in produce preservation is a leading post-harvest method to preserve food quality and extend yield from the farm to retailer's shelves. Carbon dioxide has three main functions in the post-harvest phases: 1) reducing respiration rate; 2) reducing microbial and pest infestation; and 3) cryogenic cooling.

CO2 is effective in the storage of frozen foods. It can be used in combination with other gases to create a protective atmosphere around frozen items, further inhibiting the growth of spoilage microorganisms. This technique retains the color, flavor and texture of frozen goods for a longer time by limiting the formation of ice particles.

In the baking and pastry industry, carbon dioxide is produced to help dough rise, resulting in baked goods like bread, cakes, and pastries with a light, airy texture.

Food-grade CO2 can be incorporated into food packaging to inhibit the growth of microorganisms. CO2 is non-toxic, has a natural bacteriostatic power, and is a sustainable and eco-friendly solution to traditional preservation methods.



Hypro Kanadevia Inova CO2 liquefaction process. (Image courtesy Kanadevia Inova)

Beverage Production

Spirits Distilling

Fermentation creates CO2. Rather than releasing it into the atmosphere, distillers can capture carbon dioxide as a byproduct which can be sold on the market, such as to soda or beer producers for carbonation, or to greenhouses to grow plants that will, in turn, sequester more carbon and store it as soil organic carbon (SOC).

Brewing

All beer leaves the brewer carbonated. This is accomplished in one of two ways – natural and forced carbonation. In both cases, beer and carbon dioxide are sealed in a container under pressure. The beer absorbs the CO2 giving the beer its fizz.

One of the main ways breweries can control CO2 emissions is to capture and reuse the gas produced during fermentation. During the brewing process, yeast converts sugar into alcohol and carbon dioxide. Capturing and reusing this carbon dioxide allows breweries to reuse the gas at various stages of production, and for cleaning process equipment. By integrating such a closed-loop system, breweries can more efficiently utilize their resources while reducing CO2 emissions.

Soft Drinks

Compressed CO2 is used to carbonate soft drinks and add flavor, but is also used to fill the packaging of the drinks to maintain the proper pressure and environment for the carbon dioxide to remain in the soda. The CO2 used to carbonate soft drinks can come from a variety of industry sources.

Decaffeination of Coffee and Tea

Liquefied CO2 has increasingly become an important commercial solvent due to its role in chemical extraction, in addition to its relatively low toxicity and environmental impact. It is used as a method to remove caffeine from coffee and tea. This process is chemical-free and natural which does not damage the cell structure or components responsible for the aroma and taste.

The relatively low temperature of the process and the stability of CO2 also allows compounds to be extracted with little damage or denaturing. The solubility of many extracted compounds in CO2 varies with pressure, permitting selective extractions.

CO2 Liquefaction Processes

Although variations exist in CO2 liquefaction process technologies, one that stands out with exceptionally high performance is the latest-generation technology from Hypro Engineers

Pvt Ltd. (Hypro) in collaboration with Kanadevia Inova USA, LLC. The two companies have an exclusive agreement on providing their solutions to the American CO2 markets.

As being among the leading technology suppliers for CO2 liquefaction in North America, Kanadevia Inova and Hypro offer integrated and standalone solutions, tailored for the respective industries, and ensuring the levels of CO2 purity required by the food and beverage industry.

The fundamental process steps for CO2 liquefaction with plants designed and manufactured by Hypro for Kanadevia Inova include the following:

Scrubbing – the CO2 gas is fed into a scrubber unit to wash and cool down the gas.

CO2 intermediate storage – the carbon dioxide is being stored in a balloon after some trace contaminants are removed.

Cooling and two-stage compression with drying – this process cools down the water-saturated feed gas, then separates the bulk water. The cooled gas is sent to a CO2 compressor which increases the pressure to meet operating conditions.

Drying and absorption – the remaining water and traces and other chemical components are removed from the CO2 gas stream with interchangeable dryers. Depending on requirements, various absorbers and filters are installed downstream to remove further components.

Liquefaction – the liquefaction process occurs through the condenser whereby the liquid CO2 is cooled down to temperatures below -13°F (-25°C).

Optional rectifier and reboiler – the dry CO2 liquid passes through the rectifier and a reboiler, allowing for the non-condensable impurities to be passed through the vent stack and the liquid to be sent to storage tanks. A portion of the liquid CO2 is then sent back to the condenser, improving the product quality as a part of a feedback loop.

Storage and loading for transport – the liquefied CO2 is stored in pressurized tanks. For offtake and/or on-site applications. The CO2 is then potentially further pressurized by means of additional compression and transformed into a supercritical state, then transported via a pipeline network. Another option is that the CO2 from the storage tanks is transported via trucks, railway cars, or ships for non-sequestration use, typically food and beverage-production applications.

Kanadevia Inova's automated operations and controls dynamically adjust the processes to meet changes in feed gas composition and plant loads, achieving an output quality of 99.99 percent pure liquified CO2. This supports maximized revenue return and heightened sustainability profiles for operations in multiple industries such as food production and preservation, spirits distilling and brewing.

Interface Technologies

With more than 1,600 waste-to-energy and renewable gas plants across the world, including more than 80 in North America, Kanadevia Inova encompasses project development, planning, procurement and construction for the CO2 liquefaction processes, as well as associated upstream and downstream interfacing processes. These include:

• High-solids anaerobic digestion (Dry AD)

• Low-solids anaerobic digestion (Wet AD)

• Gas upgrading (membrane technology and amine scrubbing)

• Trace impurity removal (H_2S, VOC)

• Carbon capture technology

• Hypro CO2 liquefaction plant designed and manufactured by Hypro for Kanadevia Inova

• Biological and catalytic methanation

• Recovering energy from waste via thermal treatment

• Flue gas and residue treatment

Economic Advantages of CO2 Liquefaction

In addition to the reduction of greenhouse gases released into the environment, CO2 liquefaction pays off monetarily by providing additional revenue streams with the sale of CO2 to other sectors of industry, or OPEX reduction by recirculating the captured and liquefied CO2 into the production process, hence making the system more self-sufficient. Data from different industries vary and indicate that CO2 can be captured on a larger scale with a capacity range of medium size systems producing 11,000-12,125 short tons or 10,000-30,000 metric tons per year, respectively, to even larger scale production facility that produce 82,650 to 165,350 short tons (75,000-150,000 metric tons) per annum.

The value of the capture and, ultimately, liquefied CO2 is i.a. contingent on whether it is sequestered, diverted into a depleted oil field (EOR – Enhanced Oil Recovery), sold directly f.i. into the food and beverage industry, or recirculated into the production process to minimize or completely remove the LCO2 (liquified CO2) transportation costs from the cost equation.

Additionally, the carbon credits from CO2 liquefaction can be traded on the voluntary carbon market (VCM), both nationally and globally. For food and beverage manufacturers, CO2 liquefaction presents a viable addition to further diversify a company's income portfolio.

About Kanadevia Inova USA, LLC

Kanadevia Inova Group is a global cleantech company operating in Waste-to-Resources (WtR) and renewable gas (RG). Kanadevia Inova acts as project developer, technology supplier and engineering, procurement and construction (EPC) contractor delivering complete turnkey plants and system solutions for thermal and biological waste recovery. Its solutions are based on efficient and environmentally sound technologies, are thoroughly tested, and can be flexibly adapted to customer requirements.

About the authors

By Benjamin Burfeind, (PhD, MS, BS), Director Product Management Renewable Gas NAM, Kanadevia Inova USA, LLC

benjamin.burfeind@kanadevia-inova.com

Manuela Hoellinger (MS, BS), Manager Marketing and Communications NAM, Kanadevia Inova USA, LLC

More information

www.kanadevia-inova.com

Report: The UK State of Carbon Dioxide Removal

The report from CO2RE presents a comprehensive overview of the state of Carbon Dioxide Removal (CDR) in the UK, exploring the research and innovation landscape, the role of UK-based companies in advancing CDR technologies, and trends in voluntary carbon market activity.

The report also assesses national policy frameworks, governance structures, and public perceptions related to CDR. Finally, it takes stock of current deployment levels and examines the role of CDR in the UK's pathways to net zero.

There is a wide and growing range of CDR methods, the report says, including forestry (the planting of new woodlands and enhancement of existing ones), bioenergy with carbon capture and storage (BECCS), direct air carbon capture and storage (DACCS), enhanced rock weathering and biochar.

The UK's approach to CDR is evolving within the broader context of its net zero goal for 2050. The Net Zero Strategy published by the previous government included ambition of at least 5 MtCO2/year of novel removals by 2030, scaling further to 23 MtCO2/year by 2035.

The government has tasked the British Standards Institute with developing standards for BECCS and DACCS projects, but MRV frameworks for other methods including biochar and enhanced rock weathering, are not in development at the project level or at the level of national reporting for climate targets.

The government has signalled an intention to integrate BECCS and DACCS into the UK Emissions Trading Scheme as a long-term commercial mechanism, supported by carbon Contracts for Difference (CfDs). Support for other CDR methods, including biochar and enhanced rock weathering, is not currently in development. Consequently the UK is off-track to meet its removal targets.

Novel removal methods, such as BECCS, and DACCS, as well as biochar, remain at the pilot or early demonstration stage. Based on reported deliveries of carbon credits, total novel removals during 2022 to 2025 are estimated at less than 8,000 tonnes.

Public awareness of CDR in the UK is currently low. Nevertheless, recent national public appraisals show a rejection of the notion that there should be no CDR in UK climate policy, and different levels of support for different CDR methods. DACCS is viewed relatively less favourably than other CDR methods in national public appraisals, lower only than BECCS and biochar.

Despite some policy progress and some inherent uncertainty in precise levels of CDR required, it is clear that the current pipeline of CDR in the UK is insufficient to meet the government's 2030 ambition.

Some key priorities to enable scale are likely to include:

• Continuing research & development to expand the set of viable options, test them through demonstration, improve methods for measurement, and understand wider social and environmental effects;

• Establishing and improving protocols for measurement, reporting and verification. This includes at the project level and for national inventories, which are necessary for CDR methods to count towards emission targets;

• Providing stable and de-risked policy mechanisms that allow projects to become commercially viable according to their ability to deliver effective carbon dioxide removal;

• Delivering enabling infrastructure for CO2 transport and storage;

• Building public trust and legitimacy, including through ensuring safety, wider environmental benefits, and alignment with ambitious emissions reductions;

• Collaborating internationally, to maximise the benefits of R&D in improving effectiveness and bringing down costs, to reduce policy conflicts, and to raise capability in the UK and elsewhere.

Conclusion

The report concludes that CDR plays an increasingly well-defined role in UK net zero pathways. While early strategies relied heavily on BECCS and afforestation, newer scenarios, including the Seventh Carbon Budget, incorporate a more diverse mix of methods, and anticipate lower overall volumes.

The reduced reliance reflects updated data on emissions trends, and a greater emphasis on demand-side mitigation and direct decarbonisation.

In any scenario, the successful delivery of CDR across these pathways faces several challenges. Tree planting rates remain below required levels, peatland restoration efforts must scale rapidly before 2030, and progress on CO2 transport and storage infrastructure is still at an early stage.

For novel removals, policy and investment mechanisms remain under development. Removal methods, such as biochar and enhanced rock weathering, are now included in official pathways, but lack dedicated MRV standards and commercialisation frameworks, limiting their ability to attract investment or scale with confidence. Addressing these gaps will be important to support a balanced and resilient portfolio of CDR options.

The evidence from UK pathways confirms that CDR is not a substitute for rapid emissions reductions, but a necessary complement to address residuals from hard-to-abate sectors. The scale and role of CDR will continue to evolve alongside technological innovation, policy priorities and societal choices.

More information

https://co2re.org/wp-content/uploads/2025/07/UK-State-of-CDR-Report.pdf

Can we quantify the risk of CO2 storage?

CO2 storage risks are usually assessed "qualitatively" by making lists of adverse events that could imperil these projects and ranking them. If we could "quantify" the risk with a numerical framework, that would help. Rose Subsurface Assessment has developed such a framework. By Karl Jeffery.

CO2 storage risks are usually assessed "qualitatively," such as by trying to judge how good the seals are, or the condition of the wells, and then judge if the concerns are adequately mitigated.

If we could "quantify" the risks, putting numbers on them, that could help a great deal, including in making a stronger case to regulators, helping us determine what level of insurance we need, or presenting a case to the public.

While regulations may not require such an in-depth analysis, it will demonstrate that you have thought very deeply about the risks in an objective and consistent way, and make your project stand out from others which merely seek to make a convincing argument.

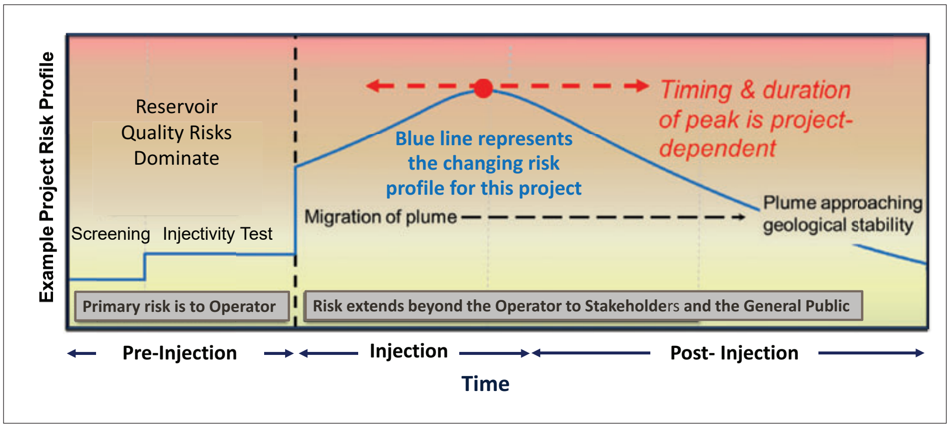
"Regulators are getting better at assessing whether the permit applications on their desks are risk averse or risk tolerant", said Creties Jenkins, Partner, Rose Subsurface Assessment.

A "quantitative" assessment can be based on numbers we already have about risks. While there is not much operational history from subsurface CO2 storage projects, there is a great deal of data from more than one hundred years of underground natural gas storage, and decades of experience injecting CO2 in enhanced oil recovery projects.

The assessment begins by building a register of the various risks. This requires answering questions such as "what's the chance that injected CO2 will escape upwards through an old existing well?".

Estimates are made regarding the chance of such adverse events occurring, including the range of possible outcomes (uncertainty), and how bad that outcome could be (risk).

Then a computer simulation is run thousands of times, sampling the chance that an adverse event will happen and its financial impact. The results are then aggregated (added-up) to tell you your most likely financial exposure due to risks, as well as the best and worst possible outcomes.



Quantitative risking allows us to understand how risk changes over the course of a CO2 project

The main risks of CO2 storage are well-known. CO2 rising up through those leaky old wells; the subsurface seal being less effective than expected; CO2 moving through faults; CO2 causing subsurface damage (fractures or faults opening) as the pressure is increased; and CO2 finding its way into a higher permeability path that takes it to an unexpected location, among others.

Rose's methodology draws on their quarter-century of experience assessing uncertainty and risk in the oil and gas industry. The framework was presented at a Finding Petroleum webinar on March 28 by Creties Jenkins and his colleagues Peter Carragher, Pieter Pestman and Rosalie Constable.

An indication of the risks of CO2 storage was demonstrated last year when the first permitted US CO2 injection project had its permit revoked. The Decatur Project (IBDP)in the Illinois Basin found corrosion in a monitoring well that allowed CO2 to leak into an unauthorised formation above the seal.

This leak posed no danger to sources of underground drinking water, but their permit was still revoked, Mr Jenkins said. "The rest of us have to be concerned about how this makes us look."

Data sources

There are many data sources that can be used to help quantify risk. One of the most useful is a study about all the failures associated with natural gas storage in North America over the past 100 years ("A review of underground fuel storage problems" – Evans, 2009). It found that most failures consisted of well and facility issues, but 5-10 per cent of the failures were geological.

You can access databases of well failure events, including blowouts or releases, calculated on a per year or per well basis. There are also databases regarding the potential for seismicity (earthquakes). These can help calibrate a risking tool.

Events which led to costs or compensation payments provide data you can use to estimate the costs if something similar happens to you. For example, you can examine the cost of the Aliso Canyon gas leak in California in 2015.

There is also data available about how many projects are completed on time and on budget from the consultancy Independent Project Analysis.

The oil and gas industry has a great deal of data from its projects in CO2 enhanced oil recovery. For example, Oxy has 50 years of experience and has sequestered approximately 200 million tonnes of CO2 in the Denver Unit of the Wasson San Andres field (Permian Basin).

Weaknesses of Qualitative Risking

As an example of how a risk might be qualitatively risked, Mr Jenkins presented an example of a CO2 reservoir containing a fault. The operator stated that the shale above the fault is expected to 'smear' along the fault, creating an impermeable seal.

But there are other interpretations that could lead to CO2 escaping up the fault. If parts of the shale contain less clay, that would give it less smear effectiveness. The fault could split into multiple fault planes. There could be natural fractures adjacent to the fault. The fault could be reactivated through natural seismicity (earthquakes) or through injecting CO2 at high pressure. There may be other faults nearby.

"Coming up with a simple interpretation and anchoring on that is not, in our view, the best way to think about risk," Mr Jenkins said.

An operator's analysis may also be influenced by their desire to obtain a permit, which makes them less likely to consider adverse outcomes and objectively assess whether injecting CO2 is a good idea.

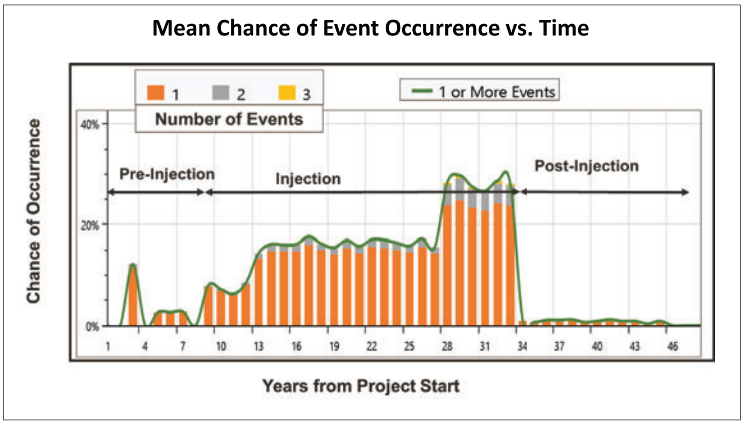
Risks over project life

The risks are different at different points in the project life - pre-injection, injection, post injection.

The greatest risk is likely to be at the end of injection when reservoir pressure is greatest. You could see the increased pressure eventually opening up a fault, for example. So, it helps to have a good model of how the pressure front will interact with the faults.

There may be risks at the beginning of a project as well, not from actual CO2 leakage, but rather a discovery of factors demonstrating the project cannot be an economic success or gain regulatory approval.

As CO2 injection proceeds, you might find the CO2 plume moving in a different direction than expected. This may include traveling upwards due to buoyancy after injection has finished, creating more pressure against the topseal and perhaps causing it to fracture.



The chance of a bad event occurring can increase over the injection phase as pressure builds up, and then drop to very low post injection

Mapping the risks

An element of the approach that Rose Subsurface Assessment takes, based on its work over 25 years in oil and gas, is to hold "framing sessions" for its clients, to help them identify key uncertainties, risks, and mitigation options, and then close the gaps between what they know and what they need to know in order to move forward.

The framing sessions help clients understand the information they have about their project, what's missing, and how they can help fill the gaps by identifying suitable analogues (projects similar to their current one).

Then the information can be used to build a probabilistic model of sufficient complexity to provide a realistic understanding of what can go wrong, and the likelihood and impact of that. The process is also key to identifying and overcoming biases such as overconfidence and anchoring.

There are also problems if your model is not complex enough. For example, some companies simply list the risks in a "risk register," such as "limited storage volume." This is insufficient--you need to consider risks, uncertainties, and both preventative & mitigative safeguards together.

Some companies construct a "risk matrix" showing the likelihood and severity of various events. But this may not provide much insight and could cause greater confusion.

For example, a low chance that a large amount of CO2 will exit the reservoir is much more impactful (should an event occur) than a high chance of a negligible amount of CO2 exiting the reservoir. However, a risk matrix may classify both of these as a "medium risk".

Defining the events

As mentioned previously, you need to define the possible adverse events and their potential impacts. These events can be different in each project stage (pre-injection, injection, post injection). You need to define the chance that the event will occur, the scale of possible outcomes, and their potential impact.

As an example, a pre-injection stage risk would be not knowing whether the reservoir temperature and pressure is sufficient to store CO2 in the dense phase, which could mean the project is not viable.

Once you answer a set of questions to define the various adverse events that could happen, you need to estimate the probability that any given event could occur on an annual basis.

For example, a 10 per cent chance of an event occurring on an annual basis over a period of 100 years is considered "highly probable". A 1 per cent chance per year is considered "possible" and a 0.0001 per cent chance per year is considered "almost impossible".

Here, you can turn to past data for calibration. Using publicly available information, the well release (leakage) frequency on an annual basis for gas injection wells is 8.8 x 10-5. The well release frequency on an annual basis for abandoned wells is 2.3 x 10-5.

So if you have 3 gas injection wells and 25 abandoned wells over a given area, the total well release frequency on an annual basis is 8.4 x 10-4, which is 0.084 per cent per year, which can be rounded up to 0.1 per cent per year.

Another method is to estimate the "frequency of exceedance," which is defined as the frequency with which a random process exceeds some critical value based on past data.

If there are operations from other companies nearby which may affect your operations, then you need to try to ascertain the probability and impact of that too. For example, if their injection pushes CO2 into your reservoir, this could increase the pressure and cause fractures through which CO2 can escape.

If there is no data, then you'll have to rely on expert judgement. This is where well-developed oil and gas skills can be really useful. "Our experience is that we're pretty good at assessing chance in many aspects of the subsurface," says Peter Carragher, managing partner of Rose.

Calculations

Once you have estimated the annual frequency of each type of adverse event, you can estimate the cost by selecting from a range of monetary impacts. Such costs could include having your license revoked, or paying for CO2 emissions at the current carbon price, or having to compensate your emitters for not providing a service.

Rose favors the oil and gas industry P90-P10 system, where P90 indicates a 90 per cent chance that a given event will cost a certain amount or more, while P10 indicates a 10 per cent chance it will cost a certain amount or more.

For example, there could be a 90 per cent chance that an event will cost $12m or more, a 10 per cent chance it would cost $50m or more, and a 0.1 per cent chance it would cost $137m or more.

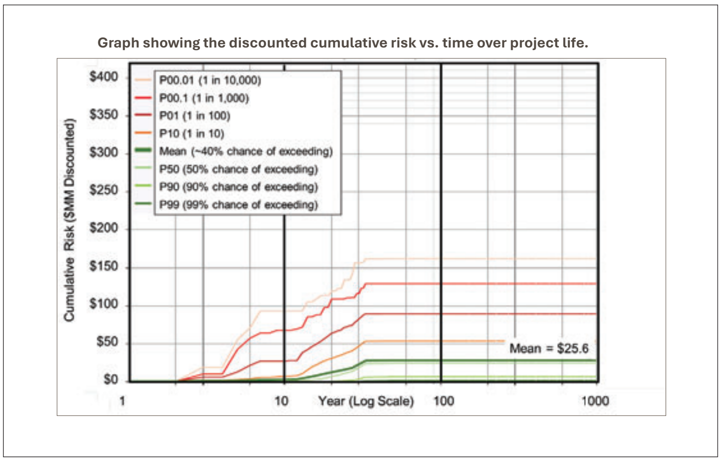
You might also assign a given event to multiple project stages. For example, there could be a 30 per cent chance of a certain event happening on an annual basis in the pre-injection stage, and a 50 per cent chance of it happening in the injection stage.

It is especially important in this process to capture low probability, high impact events, because these are the ones which can ruin the entire project. This can be done by running thousands of trials by computer, so that even the low probability events occur over the expected long project lives.

You can display the cumulative monetary risk over time (either discounted or undiscounted) and see what the average(mean)total risk of the project is likely to be. The discounted value can be set aside to cover mitigating the risks, or you can obtain insurance coverage for this amount.

It is also possible to calculate the "chance weighted mean impact" of each adverse event. This could be, for example, the chance that the project won't be "technically mature and executable," or the chance that the reservoir pressure will exceed the seal closure stress.

The entire process provides a quantitative answer to the broader question of "what liability do these projects potentially pose for us over the decades ahead."



Example of a calculation of risk over project life, from P99 (99 per cent chance of exceeding) to P00.01 (1 in 10,000 chance of happening)

Understanding risks

In the US, operators often dismiss CO2 storage sites in depleted oil and gas fields containing legacy wells. This is because it can cost over a million dollars to abandon a well if it has not been properly abandoned in the first place. It is necessary to look at the history of each well and test them to ensure they have mechanical integrity.

But on the positive side, you know a reservoir that has held oil and gas has a trap and a seal, so you can have more geologic confidence in it. You don't know that for a saline aquifer.

CO2 escape from an individual well is not necessarily a "failure," it may not cause a project to be terminated. Instead, this can be classified as an "event" that can be mitigated.

CO2 permanent storage projects tend to have higher risks than enhanced oil recovery projects because they involve building up pressure in the reservoir. With EOR, the pressure is released by producing oil at the same time. As such, a more rigorous assessment is required for a permit to inject CO2 for storage (a Class VI permit in the US) versus less rigor for a permit to inject CO2 for EOR (a Class II permit in the US).

Overall, risks are likely to decrease as project confidence grows over time. But still, it will be necessary to monitor the project closely to ensure, for example, that the injected CO2 stays where it was placed.

It won't be acceptable, for example, to simply check the area containing the injection well and old legacy wells to see if there has been a CO2 leak at the surface. This approach has apparently been used of see if natural gas injection wells have been leaking (as evidenced by dead vegetation around the wellheads).

Instead, downhole monitoring will be needed to identify leaks, with the recognition that there could be a loosening of requirements as time goes by and trust is built between storers, regulators and pore space owners.

Natural gas storage projects do monitor the pressure in the storage complex to ensure it does not exceed the closure stress of the seals. These projects don't exceed this limiting stress, and companies know where all their gas is because it's contained in a geologic trap.

For CO2 projects, Mr Jenkins recommends giving older wells greater scrutiny than modern wells, because they have decades of wear and tear, and have not been constructed with modern techniques. "The older they are, the bigger the problem they're going to be," he said.

More information

To watch the webinar on video, go to **www.findingpetroleum.com**, then events, past events, and scroll to "Quantifying and mitigating subsurface risk in CO2 storage projects, 28 Mar 2025.

www.roseassoc.com

Domestic CCS can be the start of something much bigger for Australia

New research about the potential for Australia's domestic CCS industry highlights an even bigger opportunity to contribute to regional emissions reduction, the Asia Natural Gas and Energy Association (ANGEA) says.

ANGEA CEO Paul Everingham said the EY report, Beneath the surface: The economic potential for carbon capture and storage in Australia's eastern states, underlined the ability of CCS to decarbonise hard-to-abate industries and drive economic and job-creation benefits.

But the full impact of CCS in Australia will come with the creation of cross-border CO2 value chains that involve storing of emissions from other countries in Asia Pacific.

"This report from EY is welcome. CCS can make a vital contribution to reducing emissions in Australia and the projection of up to $66 in economic activity in the eastern states alone is very encouraging," Mr Everingham said.

Conditions	Moderate growth	Accelerated deployment	Sequestration nation
How CCS might develop on the east coast	Gradual expansion of CCS in industrial clusters	Coordinated efforts and investments enable widespread CCS adoption across industries and regions, lowering barriers for smaller-scale facilities	CCS becomes a cornerstone of Australia's decarbonisation strategy, supported by strong policy alignment, advanced technologies, and significant investment, positioning Australia as a global leader in CCS
How CCS could support industries on the east coast	Steady adoption in select industrial clusters in Victoria, with minimal expansion into other regions or industries	CCS technologies deployed at scale across states, with an emerging storage as a service and H_2-CCS industry	Industrial onshoring, decarbonisation of metallurgical coal mining through VAM CCS, and development of a domestic hydrogen sector increases the demand for CCS
Minimal scale thresholds for facilities which can afford to access CCS	Very large facilities producing around 1 $MtCO_2$ per year	Large facilities producing around 0.5 $MtCO_2$ per year	Medium-large facilities producing around 0.25 $MtCO_2$ per year
Regulatory conditions	Few changes from current settings	Supportive – Carbon storage permitted in Queensland from 2035	Supportive – Carbon storage permitted in Queensland from 2030

Overview of the east coast CCS development scenarios. Source: EY analysis

Note: These scenarios aim to explore the potential of CCS on Australia's east coast and were developed for the purpose of this study only

"Over the past year we've seen the Moomba project come online and store more than a million tonnes of CO2, demonstrating that CCS is a proven technology for decarbonising at scale.

"Australia's biggest opportunity in CCS will come through cross-border networks. Australia has billions of tonnes of storage space for CO2, which key trading partners such as Japan, South Korea and Singapore all lack.

"By becoming a storage destination for emissions from Asia, Australia can make an enormous contribution to the regional decarbonisation that will be necessary to progress climate objectives.

"The importance of CCS for reducing emissions has been brought into stark focus by the challenges faced by emerging technologies like green hydrogen.

"There are also massive economic opportunities that would result from Australia's involvement in cross-border CCS. Research by Boston Consulting Group, has suggested CCS in Asia Pacific could support up to 300,000 jobs regionally and add $US220 billion in GDP annually by 2035."

Mr Everingham said the "missing piece" for cross-border CCS remained regulatory and policy settings that would help unlock significant investments required to underpin regional value chains.

"Australia has an opportunity to be a leader in this space, working with its trade partners around the region to ensure development of cross-border CCS is not held back by uncertainty around policy, regulation or legal aspects," Mr Everingham said.

"It was pleasing to see Australia's Resources Minister Madeleine King attend the launch of the EY research and show support for CCS.

"ANGEA has published an Accelerating Cross-Border CCS In Asia Pacific Study that governments can use as a guide as they negotiate agreements around cross-border CCS.

"We look forward to working with key stakeholders around the region to help convert the potential of cross-border CCS into reality."

More information

https://angeassociation.com

https://letaustralia.com.au/reports/the-economic-potential-for-carbon-capture-and-storage-in-australias-eastern-states

US backtracking creates opportunity for Europe and UK on CO2 removal

The United States is "squandering its competitive edge" in carbon dioxide removal and creating an opening for Europe and the UK, according to a new report by LSE. The nascency of BECCS and DACCS means the competitive landscape may rapidly evolve, leaving scope for new players to emerge and break into relevant markets.

Published by the Grantham Research Institute on Climate Change and the Environment at the London School of Economics and Political Science, 'The innovation race on geological carbon removal: who is best placed to lead?' argues that the dismantling by the United States Government of climate departments and the potential revocation of generous subsidies for carbon dioxide removal (CDR) "may spur companies to redirect investments" to other countries.

Siyu Feng, Postdoctoral Research Associate at the Smith School of Enterprise and the Environment at the University of Oxford, said, "Our research shows that countries with longstanding oil and gas industries are uniquely positioned to take the lead on carbon dioxide removal, if public investment is prioritised now."

"Well-targeted policy support for carbon removal can accelerate deployment in the right sectors and, if designed carefully, will complement rather than compromise broader climate goals."

The authors state that "while the US has been home to substantial patenting and deployment of relevant technologies to date, many European countries — such as France, Germany, the UK and the Netherlands — appear to be well specialised in geological CDR innovation."

Alongside rapidly reducing new emissions, existing and future carbon dioxide will need to be removed from the atmosphere to meet global climate goals. The global market for CDR could be large, with various grey literature estimates suggesting that it will be worth over US$40 billion by 2030 and over US$300 billion by 2050.

In the report, the authors analysed data on global patenting between 2000 and 2020 to shed light on countries' innovative strengths relevant for two CDR technologies: bioenergy with carbon capture and storage (BECCS) and direct air CCS (DACCS).

The report points out that countries that have transferable capabilities from historical efforts in oil and gas and other energy sectors are likely to have a head start in geological CDR innovation. The authors also found that oil and gas companies are responsible for substantial portions of innovation relevant for geological CDR in many countries, including China, India, Saudi Arabia, the UK and the US.

The researchers found that the United States is by far the largest historical innovator in both bioenergy and carbon capture (BECC) and direct air carbon capture (DAC), followed by Japan, Germany and China in both instances (in a different order). But the researchers highlight that the most specialised innovators are a largely different set of countries, including many in Europe.

According to their analysis, Denmark, Belgium, the Netherlands, Spain, France and the UK are among the top 10 most specialised innovators in BECC, while France, the UK, the Netherlands, and Germany are among the most specialised innovators in DAC.

The authors highlight that the UK has the potential to be a leading player with its abundant geological storage capacity, relatively low-carbon electricity supply and a transferable skills base from a long-standing oil and gas industry. The UK Government has recently launched its industrial strategy, which identifies carbon capture, usage and storage (CCUS), including geological CDR, among the frontier industries it will prioritise.

The authors state that UK's performance in DAC "particularly stands out". The authors found that the UK is the third most specialised innovator in DAC globally and its specialism in DAC exceeds its specialism in all other clean technologies analysed, except one (tidal stream energy). Analysed technologies that DAC comes ahead of include offshore wind, nuclear, hydrogen and clean cars.

The report is a partnership between the CO2RE Hub at the Smith School of Enterprise and the Environment at the University of Oxford and the Grantham Research Institute, the Centre for Economic Performance (CEP), the Programme on Innovation and Diffusion (POID) and the Productive & Inclusive Net Zero (PRINZ) research project at the London School of Economics and Political Science.

Esin Serin, Policy Fellow at the Grantham Research Institute on Climate Change and the Environment at the London School of Economics and Political Science, said, "The United States has been the main country innovating on geological carbon removal for a long time, but the current policy uncertainty means it is squandering its competitive edge."

"With the United States deciding to take a back seat on climate action, other countries can step up and capitalise on the opportunity from geological carbon dioxide removal. The UK should seek to take the lead to benefit both its economy at home and the global effort against climate change."

"As countries race to capture the market for carbon dioxide removal, predicted to be worth billions of pounds, it will be crucial to ensure investments in this field only complement, not replace, ambitious investment in near-term emissions reductions."

More information

https://www.lse.ac.uk/granthaminstitute/publications

Leading steelmakers launch CCUS Hub Study to accelerate decarbonisation in Asia

An industry consortium led by BHP is undertaking a pre-feasibility study to assess the development of CCUS hubs across Asia.

The study is expected to conclude at the end of 2026 and the Consortium is open to new members

The CCUS Hub study will be the first independent industry-led study of its kind in Asia and will examine the technical and commercial pathways to utilising CCUS in hard-to-abate industries across Asia. The study will focus on the potential to develop large-scale projects which can repurpose, or store, captured carbon dioxide.

The consortium is comprised of leading steelmakers ArcelorMittal Nippon Steel India, JSW Steel, Hyundai Steel Company and other value chain players, BHP, Chevron, Mitsui & Co., Ltd. with others invited to join.

The study will seek potential applications for captured CO_2 in industrial processes, or transport captured CO_2 via pipeline or shipping to storage sites in Asia or Northern Australia.

The plan is for each participant in the study to be included in at least one hub, and the study will deliver conceptual development strategies for each hub including cost and schedule estimates, and potential commercialisation pathways.

The study will also look at non-technical enablers required to make CCUS hubs a reality, for example regulatory assessments including intra and inter-regional assessments of CCUS and cross border transport.

“BHP is committed to supporting our steelmaking customers on their journey to decarbonise the industry," said Dr Ben Ellis, Vice President Marketing Sustainability, BHP. "With more than 1 billion tonnes of production a year in Asia coming from blast furnace capacity that is relatively early in its production life, it’s important for industry to progress technologies to decarbonise existing steelmaking assets while new commercial pathways to decarbonise steelmaking are developed over time."

"By leveraging shared knowledge and resources with our partners, we are investing in support for innovative solutions—like the potential of CCUS—that we see as an essential part of decarbonising hard-to-abate sectors such as steelmaking.”

The Consortium, which is open to additional members joining and contributing to the study, has appointed Hatch as Project Management Officer in collaboration with Global CCS Institute, McDaniel, and Pace CCS.

The study is expected to conclude at the end of 2026, with findings to be shared publicly to promote broader industry learning and support the development of enabling policy and regulatory frameworks.

A role for CCUS is well represented in a number of external global climatic scenarios. Carbon capture technologies used in a range of existing industrial applications are relatively mature, and able to integrate with existing facilities.

The Consortium is prioritising the next important step – the study of scalable utilisation and storage solutions to test the potential for broader adoption to support decarbonisation, especially in regions where regulatory hurdles and market maturity limit progress.

By concentrating on regional hubs, the Consortium’s study will look to find ways to solve the challenge of scale by aggregating captured carbon into sufficiently large quantities to:

• Optimise the unit cost of capture, transportation, and storage through economies-of-scale

• Provide sufficient scale for economic utilisation solutions

• Unlock novel solutions for multiple hard-to-abate industries at once, to enable regional decarbonisation efforts to be accelerated, and/or

• Ensure cost and risk is appropriately shared among interested parties.

Yonghee Kim, Vice President of the Process R&D Sub-division, Hyundai Steel, said, “Hyundai Steel is committed to leading the decarbonisation of the steel industry, despite it being one of the most carbon-intensive and technically challenging sectors to decarbonise.”

“This consortium goes beyond conventional technological development – it aims to deliver real and measurable emissions reductions through collaboration with global partners, sharing knowledge and experience across borders.”

More information
www.bhp.com

Projects and policy news

HyNet partners selected expanding UK Track 1 CCUS cluster

www.hynet.co.uk

www.ccsassociation.org

Five projects are now in priority negotiations to connect to the HyNet CO2 transport and storage network with five more in reserve, marking another step forward in the UK's clean energy transition.

The UK Government has concluded its assessment of applications into the Track-1 expansion of the HyNet CCUS cluster process following the financial close of Liverpool Bay CCS, which will establish the cluster's transport and storage network.

The five projects taken forward into priority negotiations Includes two new projects, Connah's Quay Low Carbon Power and Ince Bioenergy with Carbon Capture and Storage (InBECCS), alongside three existing projects, Protos Energy Recovery Facility (Encyclis), Padeswood Cement Plant (Heidelberg Materials), and Hydrogen Production Plant 1 (EETH).

The standby projects are:

• Essar Energy Transition Industrial Carbon Capture (EET ICC), EET Fuels

• Hydrogen Production Plant 2 (HPP2), EET Hydrogen / Progressive Energy

• Parc Adfer Energy from Waste Industrial Carbon Capture Project, Enfinium Group Ltd

• Runcorn Carbon Capture Project, Viridor

• Silver Birch, Climeworks UK Ltd

The Government said the priority projects together represent its current preferred configuration for the cluster, representing the configuration which it currently considers to best deliver against its objectives, including energy security, emissions reduction, and sector diversity.

The Carbon Capture and Storage Association (CCSA) welcomed the commitment to two new priority projects, but said projects on the standby list will also be critical to protecting and decarbonising the region's industrial activities. The CCSA urged the Government to continue to develop a clear pathway for their connection to HyNet.

"Despite the welcomed progress announced today, the number of projects on the standby list – all of which have invested significant sums to date in the development of their projects - makes clear that there must be a long-term plan for bringing additional projects to market," it said. "This is vital to decarbonising our foundational industries and delivering secure clean power."

Evero Energy's Ince Biomass plant was selected as a priority project for HyNet and will be the nation's first BECCS facility

The CCSA said it is engaging with the Government to ensure that these and other projects can move forward as the market scales up, including industry working with consumers to grow demand for low carbon products. This is vital to ensuring the UK's long-term decarbonisation targets can be met and industrial competitiveness preserved.

Integrating greenhouse gas removals in the UK Emissions Trading Scheme

www.gov.uk

The UK ETS Authority has set out further detail on the design of the UK ETS market for greenhouse gas removals (GGRs), including how GGRs will be integrated into the scheme and the safeguards that will apply.

In this response, the Authority made the decision to aim to legislate to integrate removals in the UK ETS by the end of 2028, aiming for integration to be operational by the end of 2029 subject to consideration of appropriate legislative powers, regulatory assessments and further consultation.

Along with this response, the Authority has published interim responses on expanding the scheme to Energy from Waste (EfW) facilities and the maritime sector. The Authority confirmed that EfW operators will be required to voluntarily monitor their emissions from the 1st January 2026. Full expansion of the ETS to the EfW sector in 2028 is still subject to information gathered during this voluntary period.

Mike Maudsley, CEO of enfinium, a leading UK energy from waste company, commented, "The UK has demonstrated a world leading ambition to include carbon removal projects in the UK Emissions Trading Scheme by the end of 2029. This will significantly boost the economic case for waste to energy carbon capture facilities, which could generate millions of tonnes of high-integrity carbon removal credits to mitigate emissions elsewhere in the economy."

"The waste sector's 'MRV-only' period in 2026 and 2027 provides a welcome opportunity for the waste industry to work with government and local authorities to ensure that a fair and accurate approach to monitoring emissions is developed ahead of full inclusion in the ETS in 2028."

The response contains key details on the expansion to maritime, including:

• the intention to launch the UK ETS Maritime regime on 1 July 2026

• the scope, which will include UK domestic journeys and emissions while in UK ports for vessels of 5000 gross tonnage (GT) and above

• details on monitoring, reporting and verification (MRV) requirements and who is responsible for complying with the scheme

Dr Gabrielle Walker, Co-Founder & Chief Scientist of CUR8, a UK based company scaling carbon removals, commented, "Bringing greenhouse-gas removals into the UK Emissions Trading Scheme is a watershed moment."

"By putting a clear price signal on removing carbon, not just avoiding it, the Government is creating the demand that will turn today's promising UK projects into tomorrow's gigaton-scale industry. Clearly this offers a significant opportunity for hard-to-abate sectors, like aviation and automotives in particular."

Elimini and HOFOR sign agreements to develop Danish BECCS project

Greater Copenhagen's public utility HOFOR will explore the development of a large-scale bioenergy with carbon capture and storage (BECCS) facility at the Amagerværket combined heat and power plant in Copenhagen.

The strategic collaboration will cover the development of the BECCS facility, with the aim of entering into a Joint Venture Agreement to transform Unit 4 (AMV4) at the site to capture CO2 and generate high-quality, verified carbon removal credits (CDRs) in addition to renewable electricity and heat. The project is among 10 pre-qualified projects that are eligible for the Danish Energy Agency's CCS subsidy scheme.

"This ambitious partnership with HOFOR is a breakthrough in the scaling of carbon removals," said Ross McKenzie, Chief of Staff and Senior Vice President, Corporate Affairs and Business Development at Elimini. "Together, we're developing a first-of-its-kind model that will capture biogenic CO2 – reducing CO2 levels in the environment – and will generate verified, high-integrity carbon credits."

By supporting the deployment of reliable renewable electricity and removing CO2 from the atmosphere, the partnership will play an important role in enabling Denmark to achieve its carbon removal and broader climate targets while stimulating both job creation and economic growth.

Unit 4 at the Amagerværket Power Station in Copenhagen will be transformed to capture CO2 and generate high quality verified carbon removal credits

The Amagerværket Power Station, which produces 9.900TJ heat, equivalent to 25 percent of Copenhagen's district heating using biomass while generating 670 GWh of renewable electricity annually, is one of Denmark's largest point sources of biogenic CO2. HOFOR has an established biomass supply chain to purchase certified sustainable wood pellets and wood chips.

The project intends to establish a full BECCS value chain with the capability to remove CO2 from heat and power production at the facility totaling hundreds of thousands of tonnes annually, supporting Copenhagen's ambition of being climate positive by 2035.

The Danish Government recognises that capture and storage of biogenic CO2 is an effective tool to fight climate change and key to achieving national and international climate ambitions. To support Denmark's goals, in 2024 the Danish Energy Agency established a USD 4.2 billion CCS fund to support the development of capture, transportation and geological storage of CO2 over a 15-year period.

In parallel, Elimini and HOFOR have agreed a CDR marketing agreement under which Elimini will lead the commercialisation pathway for the project's verified carbon removal credits.

"This agreement represents a pivotal step to supporting Copenhagen's target of being climate positive and decarbonizing the city's district heating," said Gorm Elikofer, Chief Operating Officer at HOFOR. "By collaborating with Elimini on carbon capture at Amagerværket, we are building the technical and commercial foundations that will help to advance carbon capture solutions that benefit our city and the broader energy transition."

Elimini is a development partner for the project in this first stage, using its expertise in BECCS to support HOFOR with the project and marketing for the carbon removal credits. Following further project evaluation, and subject to agreement by both Elimini and HOFOR, the parties will explore the potential formation of a joint venture.

More information

www.hofor.dk/ccs

https://elimini.com

KAIST DAC achieves over 95% CO2 capture using only smartphone power

The KAIST research team has succeeded in capturing over 95% high-purity carbon dioxide using only low power at the level of smartphone charging voltage, without hot steam or complex facilities.

Professor Dong-Yeun Koh's research team from the Department of Chemical and Biomolecular Engineering, in collaboration with Professor T. Alan Hatton's group at MIT's Department of Chemical Engineering, has developed the world's first ultra-efficient e-DAC (Electrified Direct Air Capture) technology based on conductive silver nanofibers.

High energy cost has been the biggest obstacle for conventional DAC technologies so the study is regarded as a breakthrough demonstrating real commercialisation potential. Overseas patent applications have already been filed, and because it can be easily linked with renewable energy such as solar and wind power, the technology is being highlighted as a "game changer" for accelerating the transition to carbon-neutral processes.

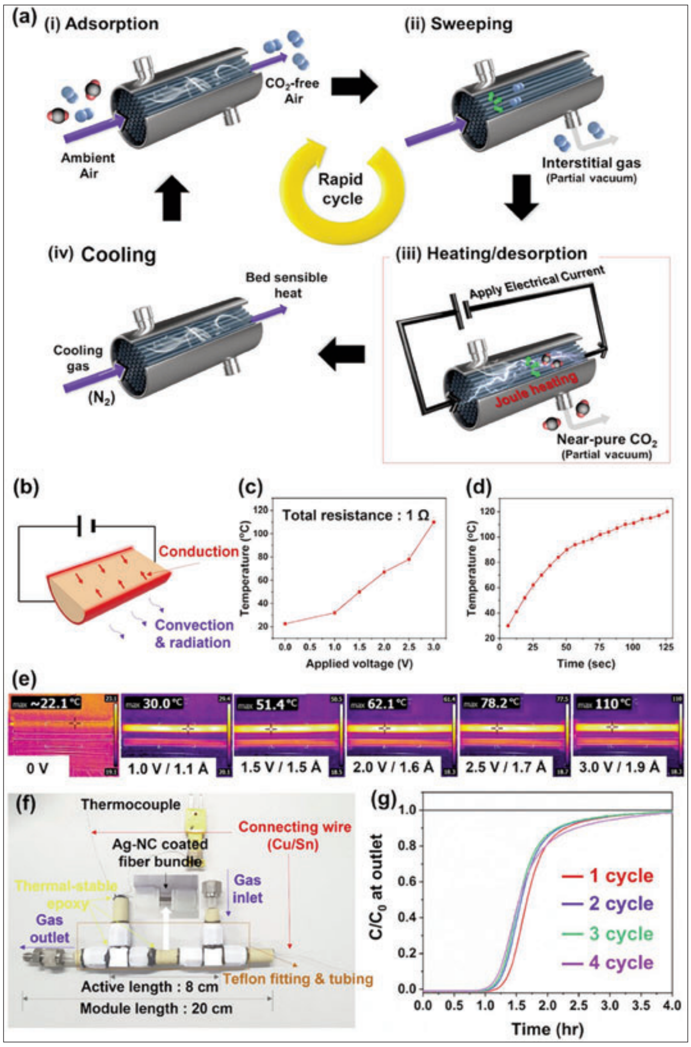
Conventional DAC processes required high-temperature steam in the regeneration stage, where absorbed or adsorbed carbon dioxide is separated again. This process consumes about 70% of the total energy, making energy efficiency crucial, and requires complex heat-exchange systems, which makes cost reduction difficult. The joint research team, led by KAIST, solved this problem with "fibers that heat themselves electrically," adopting Joule heating, a method that generates heat by directly passing electricity through fibers, similar to an electric blanket. By heating only where needed without an external heat source, energy loss was drastically reduced.

This technology can rapidly heat fibers to 110°C within 80 seconds with only 3V—the energy level of smartphone charging. This shortens adsorption–desorption cycles dramatically even in low-power environments, while reducing unnecessary heat loss by about 20% compared to existing technologies.

The core of the research was not just making conductive fibers, but achieving a breathable conductive coating that achieves both electrical conductivity and gas diffusion.

The team uniformly coated porous fiber surfaces with a composite of silver nanowires and nanoparticles, forming a layer about 3 micrometers (µm) thick—much thinner than a human hair. This 3D continuous porous structure allowed excellent electrical conductivity while securing pathways for CO2 molecules to move smoothly into the fibers, enabling uniform, rapid heating and efficient CO2 capture simultaneously.

Furthermore, when multiple fibers were modularized and connected in parallel, the total resistance dropped below 1 ohm, proving scalability to large-scale systems. The team succeeded in recovering over 95% high-purity CO2 under real atmospheric conditions.



The e-fiber sorbent module achieved a desorption temperature of 110 °C in 80s at 3V.

The biggest innovation of this technology is that it runs solely on electricity, making it very easy to integrate with renewable energy sources such as solar and wind. It perfectly matches the needs of global companies that have declared RE100 and seek carbon-neutral process transitions.

Professor Dong-Yeun Koh of KAIST, said, "Direct Air Capture (DAC) is not just a technology for reducing carbon dioxide emissions, but a key means of achieving 'negative emissions' by purifying the air itself. The conductive fiber-based DAC technology we developed can be applied not only to industrial sites but also to urban systems, significantly contributing to Korea's leap as a leading nation in future DAC technologies."

More information

www.kaist.ac.kr/en
https://cheme.mit.edu

University of Houston researchers develop membraneless CO2 capture

Led by Mim Rahimi, a professor at UH's Cullen College of Engineering, the team made two significant breakthroughs that could reduce the cost of capturing harmful emissions from power plants.

Sometimes less really is more — at least that is the case when it comes to improving carbon capture systems, according to a team of researchers at the University of Houston.

The first breakthrough, published in Nature Communications, introduces a membraneless electrochemical process that slashes energy requirements for amine-based carbon dioxide capture. The second breakthrough, featured on the cover of ES&T Engineering, demonstrates a vanadium redox flow system capable of both capturing carbon and storing renewable energy.

"Climate change mitigation was basically the reason we pursued this research," Rahimi said. "We need solutions, and we wanted to be part of the solution. The biggest suspect out there is CO2 emissions, so the low-hanging fruit would be to eliminate those emissions."

"By removing the membrane and the associated hardware, we've streamlined the EMAR workflow and dramatically cut energy use" - Ahmed Hassan author of the paper

Originally published in a research paper titled "A Membraneless Electrochemically Mediated Amine Regeneration for Carbon Capture," the team first focused on replacing the conventional ion-exchange membrane in the electrochemically mediated amine regeneration process with gas diffusion electrodes.

That proved to be a game-changer. Not only were the membranes the most expensive part of the system, but they were also a primary reason for performance issues and maintenance cost.

By engineering the gas diffusion electrodes, the team was able to achieve more than 90% CO2 removal, nearly 50% more than traditional EMAR approaches. That's a capture cost of approximately $70 per metric ton of CO2, which makes it competitive with state-of-the-art amine scrubbing methods, according to Ph.D. student Ahmad Hassan.

"By removing the membrane and the associated hardware, we've streamlined the EMAR workflow and dramatically cut energy use," said Hassan, who was leading author of the paper. "This opens the door to retrofitting existing industrial exhaust systems with a compact, low-cost carbon capture module."

Fellow Ph.D. student Mohsen Afshari built on those advances, publishing his findings in "A Vanadium Redox Flow Process for Carbon Capture and Energy Storage." That paper presented a reversible flow battery architecture that absorbs CO2 during charging and releases it upon discharge.

Using the vanadium's chemistry, the process displayed strong cycle stability and a high capture capacity, suggesting the technology could provide carbon removal and grid balancing when paired with intermittent renewables.

"Integrating carbon capture directly into a redox flow battery lets us tackle two challenges in one device," Afshari said. "Our front-cover feature highlights its potential to smooth out renewable generation while sequestering CO2."

These discoveries could reduce the costs for carbon capture technology and the energy industry going forward.

"These publications reflect our group's commitment to fundamental electrochemical innovation and real-world applicability," Rahimi said.

"From membraneless systems to scalable flow systems, we're charting pathways to decarbonize hard-to-abate sectors and support the transition to a low-carbon economy."

More information
https://uh.edu

Advances in chemistry unlock new pathways for industrial carbon capture

A new study discusses how breakthroughs in chemistry are enabling more efficient and scalable carbon capture solutions for heavy industries such as oil and gas, steel, cement, aluminium and chemicals.

Recent key advances in chemistry could tackle emissions from the world's most polluting industries, according to a new study from a team led by Professor Mercedes Maroto-Valer, Champion and Director of the Industrial Decarbonisation Research and Innovation Centre (IDRIC) and Director of the Research Centre for Carbon Solutions (RCCS) at Heriot-Watt University, and Dr Steve Griffiths, Professor and Vice Chancellor for Research at American University of Sharjah (AUS)

The paper, titled "Chemistry advances driving industrial carbon capture technologies," was published in Nature Reviews Chemistry.

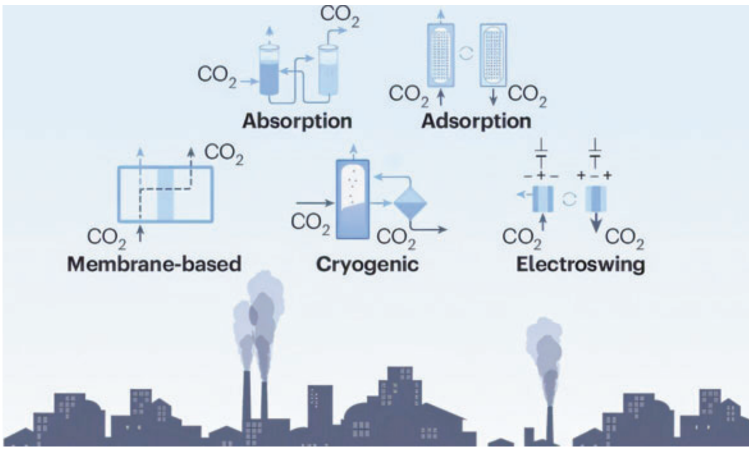
"We believe this novel approach can help players across both industry and academia pinpoint research opportunities to lower the cost and scale up the commercial deployment of the carbon capture technologies available today," said Professor Mercedes Maroto-Valer, Heriot-Watt University.

According to the Intergovernmental Panel on Climate Change (IPCC), global carbon capture capacity must increase more than 100-fold—from around 50 million tonnes today to between 4 and 6 billion tonnes annually by 2050—to help limit global warming to 1.5 °C.

While carbon capture technologies are already established in the oil and gas industry, their adoption across other carbon-intensive industries like cement, steel, and chemicals has lagged significantly. This review shows that advances in chemistry are increasingly positioning carbon capture as a viable solution for large-scale industrial decarbonization.

The research highlights innovations including novel amine blends that reduce energy consumption by over 30 percent, metal-organic frameworks (MOFs) that can selectively capture CO2 with extremely high efficiency, and new electroswing technologies that operate at low temperature using renewable electricity instead of energy-intensive heating.

"With heavy industries accounting for a major share of global emissions, advancing these technologies is critical if we're serious about ever achieving net-zero emissions."



The paper provides insights into the CC technologies, which based on absorption, adsorption, membrane separation, cryogenic gas separation and electroswing, poised to have the greatest impact on industrial decarbonisation

"Our review highlights the state-of-the-art chemistry behind industrial-scale carbon capture and potential breakthroughs that may further make industrial carbon capture more efficient, scalable and cost-effective. Our aim is for this work to provide the insights necessary for carbon capture to advance at the pace required to achieve global sustainability targets," said Dr.Griffiths.

The paper reviews five main types of industrial carbon capture technologies—absorption, adsorption, membrane separation, cryogenic gas separation and electroswing systems—and provides insights into how chemistry innovations are improving both their effectiveness and affordability.

"Our work has identified carbon dioxide capture technologies that have progressed to the early stages of development to decarbonise industrial sectors, with a focus on the chemistry that underpins these technologies," said Professor Mercedes Maroto-Valer.

"We took a global perspective, recognising that carbon capture must be tailored to local contexts. The performance parameters outlined in our research enable industry players to compare materials and technologies more effectively than has previously been possible. We believe this novel approach can help players across both industry and academia pinpoint research opportunities to lower the cost and scale up the commercial deployment of the carbon capture technologies available today."

Additional authors include Prof John M. Andresen from the School of Engineering and Physical Sciences and Dr Jeannie Z. Y. Tan from the Research Centre for Carbon Solutions (RCCS), both at Heriot-Watt University, as well as Mr Joao M. Uratani from the University of Sussex's Science Policy Research Unit (SPRU).

More information

https://idric.org
https://rccs.hw.ac.uk
https://www.aus.edu

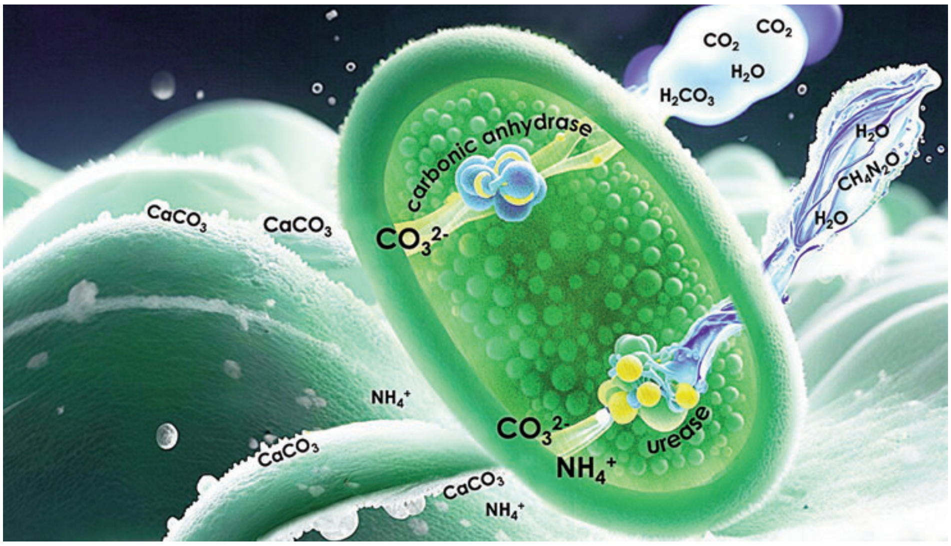
The multitasking microbe that naturally turns CO2 into minerals

Researchers from EPFL have demonstrated that Bacillus megaterium – a resilient and versatile microorganism – can mineralise carbon dioxide into calcium carbonate, the mineral that forms limestone and marble.

The researchers from EPFL's Soils Mechanics Laboratory, the University of Applied Sciences and Arts of Southern Switzerland (SUPSI) and the EPFL start-up Medusoil SA contributed to the study which has been published in Scientific Reports.

What sets this study apart is not just the biological feat itself, but the quality and origin of the mineral formed. Under high-CO2 conditions – specifically, at concentrations over 470 times those found in the atmosphere – B. megaterium shifted its metabolic strategy.

Using an enzyme called carbonic anhydrase, it converted CO2 into bicarbonate, which then reacted with calcium ions to form solid calcite. Astonishingly, 94% of the resulting mineral was derived directly from CO2, not from nitrogen-based compounds like urea.



At more than 470 times the atmospheric concentration of CO2, a humble soil bacterium does something extraordinary: it turns gas into stone

"We know that dozens of bacteria have the potential to mineralise crystals", says Dimitrios Terzis, corresponding author, Research and Teaching associate at EPFL's Soil Mechanics Laboratory and co-founder of Medusoil SA.

"However, what is unique about our work is that we showcase this can be done by directly using CO2. The potential that lies ahead is huge, and our teams can't wait to upscale and maximize it."

This biological duality is rare. B. megaterium possesses two metabolic pathways to induce mineral formation: ureolysis, which depends on nitrogen compounds, and carbonic anhydrase activity, which uses CO2 directly. While the former has long been studied in the context of microbially induced calcite precipitation (MICP), it produces unwanted byproducts such as ammonia. The latter, by contrast, offers a cleaner route – capturing CO2 and converting it into solid mineral without toxic residues.

"This study shows how environmental microbiology, when combined with advanced laboratory techniques, can reveal mechanisms that would otherwise remain hidden" says Pamela Principi, researcher at SUPSI.

"The use of C13-labelled urea was key to tracing the origin of the carbon in the mineral, allowing us to quantify the microbial pathways with precision. It's a great example of how multidisciplinary approaches – bridging microbiology, geochemistry, and materials science – can lead to impactful discoveries".

Small microbes, big potential

As conversations about climate action shift from carbon offsetting to emission prevention at the source, this research points to a new path forward – especially for industries like construction and materials manufacturing, which are among the largest direct emitters of greenhouse gases. By embedding carbon into mineral form, this microbe opens the door to bio-based, carbon-sequestering binders, and even conservation-grade materials for building and monument restoration.

This natural mechanism offers a tangible way to harness biology for climate-positive outcomes such as capturing CO2 at emission points, stabilising soils or enhancing the durability of infrastructure. "Medusoil has the know-how to operate bioreactors and scale up microbial production with field-ready solutions", says Dimitrios Terzis.

"This study shows that despite challenges like the high concentration of CO2 needed and the fact we have to vary its purity levels, critical parameters can be effectively controlled using conventional biotechnology. We're confident we can tune our recipes and growth conditions to bring B. megaterium to industrial deployment."

More information

https://actu.epfl.ch/search/enac/en

Capture & utilisation news

Capsol awarded first carbon capture study in the lime industry

www.capsoltechnologies.com

Capsol Technologies has signed a contract to deliver a feasibility study evaluating the use of CapsolEoP® (End-of-Pipe) for a European lime producer.

The facility would have the potential to capture several hundred thousand tonnes of CO2 annually, supporting the client's decarbonisation strategy.

"This is an important milestone in our mission to decarbonize hard-to-abate sectors like lime production and represents our first project within this industry," said Johan Jungholm, Chief Business Development Officer at Capsol Technologies. "Initial assessments indicate that CapsolEoP® would be particularly suited for carbon capture in lime production due to the energy-efficient design of the technology – featuring low energy consumption and operating without the need for external steam."

Lime is a key input for sectors including steel, glass, construction, agriculture, pulp and paper, and chemicals. According to the European Lime Association (EuLA), the sector aims to deploy carbon capture technologies for 5-10% of kiln-related CO2 emissions by 2030, with full capture of unavoidable process emissions by 2050.

With the integration of CCS, including BECCS and carbonation, the European lime sector aims to become net-negative – permanently removing up to 5 million tonnes of CO2 from the atmosphere each year.

Shell and Technip form global alliance to deliver CO2 capture

https://catalysts.shell.com

www.ten.com

Shell Catalysts & Technologies and Technip Energies will work exclusively together to deliver a post-combustion amine-based carbon capture solution using Shell's CANSOLV* CO2 Capture System.

The alliance combines Shell Catalysts & Technologies leading technology expertise with Technip Energies' integration and project delivery experience. The parties have agreed to work exclusively together to jointly offer an enhanced, complementary post-combustion carbon capture solution, aiming to deliver maximum value to customers.

The companies said they believe that this is the best model to make carbon capture more investable, scalable and accessible for industrial sectors – helping customers to decarbonise.

Arnaud Pieton, Chief Executive Officer, Technip Energies said, "By forming a global alliance with Shell Catalysts & Technologies in the field of carbon capture, we combine cutting-edge technology, smart engineering and excellence in project execution. This global alliance is the result of more than 10 years of collaboration and continuous innovation. Our ambition is to deliver a world designed to last by enabling hard-to-abate industries to decarbonise with greater certainty and affordably. Canopy by T.EN™ powered by Shell CANSOLV® carbon capture solution pragmatically delivers on this ambition."

The alliance builds on a strong foundation of proven performance, with two operating CANSOLV facilities, and four CANSOLV-based projects reaching a final investment decision within the last 24 months. This includes Net Zero Teesside Power, set to be the world's first gas-fired power station with carbon capture and storage.

CF Industries begins CO2 capture and storage at low carbon ammonia plant

www.cfindustries.com

The CO2 dehydration and compression facility at its Donaldsonville Complex in Louisiana has begun operations.

The facility will enable the transportation and permanent geological sequestration of up to 2 million metric tons of CO2 annually. ExxonMobil, the company's carbon storage partner for this project, will be transporting and permanently storing the CO2.

CF Industries' Donaldsonville CCS project will produce approximately 1.9 million tons of low-carbon ammonia (Image: Thyssenkrupp)

On an interim basis, ExxonMobil is storing CO2 from the Donaldsonville Complex in permanent geologic sites through enhanced oil recovery. Upon receiving its applicable permits, ExxonMobil plans to transition to dedicated permanent storage, starting with its Rose CCS project. Rose is one of many dedicated permanent storage sites ExxonMobil is developing along the Gulf Coast to expand its integrated CCS network. The U.S. Environmental Protection Agency issued a draft Class VI permit for Rose in July, and final permits are expected later this year.

"The start-up of the Donaldsonville carbon dioxide dehydration and compression facility and initiation of sequestration by ExxonMobil is a historic milestone in our Company's decarbonization journey," said Tony Will, president and chief executive officer, CF Industries Holdings, Inc. "By starting permanent sequestration now, we reduce our emissions, accelerate the availability of low-carbon ammonia for our customers and begin generating valuable 45Q tax credits."

As a result of its Donaldsonville CCS project, CF Industries expects to produce approximately 1.9 million tons of low-carbon ammonia on an annual basis. CF Industries also expects to qualify for tax credits under Section 45Q of the Internal Revenue Code, which provides a credit per metric ton of CO2 stored.

The need for CO2 tankers in Asia Pacific

If a carbon capture and storage industry is to develop in Asia Pacific, it will probably need CO2 tankers to transport CO2 large distances between emitters and storage sites. GCMD held a webinar to discuss. By Karl Jeffery.

The Global Centre for Maritime Decarbonisation (GCMD) of Singapore estimates there could be a need for 150 CO2 transport tankers, requiring $25bn investment, to serve the future carbon capture and storage industry.

GCMD recently wrote a study together with Boston Consulting Group.

CO2 is likely to need to be transported longer distances in Asia Pacific than for European CO2 projects. This pushes the economics towards larger vessels, carrying CO2 at lower pressure.

Speakers at the Global Centre for Maritime Decarbonisation webinar. Top row: Carl Clayton, BCG; Cheryl Ng, Shell; Alex Zapantis, Global CCS Institute. Bottom row: Dmitry Kosyak, Woodside; Eng Kiong Koh, GCMD

For now, the cost of CCS is higher than a saving a CO2 emitter would make from not having to pay costs of emission (a carbon price), so the industry is not economic.

But it is expected to gradually become more economic, due to regulation requiring the use of low carbon fuels in many industries (including in our own maritime industry), and other growing pressures on CO2 emission. Perhaps also government subsidies.

But there remains uncertainty about costs and regulation, which is hindering projects.

Vessel and terminal operators will need long term contracts from CO2 shippers to make them feel comfortable investing in vessels and infrastructure.

There will also need to be clarity from CCS system operators about the purity levels required, pressure and temperature conditions, to ensure that CO2 can be entered from one system and discharged into another.

There will need to be co-ordination agreements between governments to agree that CO2 can be moved from one country to another, given that it is a waste product and so restricted under the London Protocol.

Shell perspective

"The opportunity is massive," said Cheryl Ng, Head of Commercial and Business Development for Asia Pacific and Middle East, Shell Shipping & Maritime. "Shipping companies I know are born and bred entrepreneurs. They see an opportunity when it comes."

Shell has been working on CO2 shipping projects in Asia Pacific for 3-4 years.

"A lot of people see this as potentially 'the next LNG market'. They are very keen to build expertise and experience."

A CO2 ship gives flexibility and scalability to a CCS project. It can connect multiple emitter sources and hubs to multiple storage locations, she said.

But it is not clear to shipping companies when the right time to make the investment would be, and how much to invest. A shipping company would want to make sure a project had long term economic support, which could be used to pay for shipping, and this is not yet available.

Shipyards are showing increasing interest in building CO2 ships, she said. It saw this as a partner in Norway's Northern Lights CCS project. When Northern Lights sought shipyards and owners to build and operate the first CO2 carriers, there was "not so much interest to be honest."

But after it had taken the final investment decision for Phase 2, "we had very credible global players - yards, operators - interested in playing a part in the CCS value chain."

Shell sees its role as integrating the value chain together, from emitters to storage sites, she said.

CO2 ship designs

CO2 ship designs can be low, medium and elevated pressure. Higher pressure means less need for cooling to get CO2 to a liquid state, but needs thicker material, so a more expensive tank and a need to pay for compression.

Medium pressure CO_2 ships are "more prevalent in Europe". The Northern Lights vessels are medium pressure, said Shell's Cheryl Ng. The first Northern Lights vessels are 7,500m3, and the next phase of vessels may be "a bit bigger."

In Asia Pacific, low pressure vessels are more likely, enabling ships to be built at lower cost, which means vessels can be larger for the same cost. Voyage distances are likely to be much longer than in Norway.

If we have multiple vessels calling at multiple terminals, they will need to be compatible, so working at the same CO_2 pressure and specification.

Shell is also planning a joint industry project with DNV to look at elevated pressure vessels.

Getting to the next stage of development probably involves "fine tuning on exploring different materials," finding the right balance between strength and cost, she said.

GCMD's Eng Kiong Koh added that CO_2 at low pressure could be very close to the "triple point". With temperatures lower or pressures higher than the triple point, CO_2 will solidify, blocking flowlines.

It may turn out to be easier to run point to point projects than projects which connect multiple emitters to multiple storage sites, because there are much fewer parties to align on the CO_2 specification.

Woodside

The Angel carbon capture and storage project, in the North-West region of Western Australia, could hold 120m tonnes of CO_2. It is operated by Woodside, the largest oil and gas company in Australia.

"We are the most advanced [CCS} project with storage located in Australian waters," said Dmitry Kosyak, Angel CCS Development Manager, with Woodside.

The project is currently in early planning stages. CO_2 is likely to come from Australian industry, and brought in by ship.

The minimum size for a large scale multi user development could be 125m tonnes, allowing 5m tonnes a year for 25 years, he said. To achieve economic viability, "large scale is key," he said. This means a lower cost per tonne CO_2 stored.

Woodside also looks for ways to re-purpose infrastructure, such as jetties.

Need for regulation

A key change to get CCS moving in APAC is regulation to be adopted in countries seeking to be involved, covering "the full lifecycle of development, operation, closure, post-closure," said Alex Zapantis, Strategic Adviser, Emerging CCS Markets, Global CCS Institute.

"Without that, there's no ability to explore for pore space let alone utilise it."

"You must have that there to enable property developers to have the property rights for developing, operating and ultimately dealing with long term liability."

Then the countries generating and storing the CO_2 need to agree with each other that they allow this, and CO_2 will be stored safely. Probably the country sending the CO_2 will want to audit the country receiving the CO_2.

There needs to be clarity about how the CO_2 will be accounted for and who will get the carbon credit for the CO_2 not being emitted to the atmosphere.

It is much easier for investors if they know they will not be liable forever for the CO_2 being safely stored. In most countries with legislation in place, the liability can be handed back to the state storing the CO_2 after a certain period such as 20 years.

To achieve net zero, the Asia Pacific region will need to store 1 – 2 gigatonnes per year CO_2. "That's going to require much strong policy to create the business case for investment," he said.

Multi company projects

The first CCS projects in Asia Pacific are generally national oil companies storing into their own reservoirs, Mr Zapantis said. So there are no complex collaborations between companies required.

For example, in Indonesia, BP's Tangguh CCS project in Papua Barat, will take CO_2 from a LNG plant, and use it for enhanced gas recovery, aiming to sequester 15m tonnes CO_2 a year in its initial phase.

In Malaysia, the Petronas Kasawari CCS project off Sarawak aims to inject 3.3m tonnes CO_2 a year.

"Those projects are able to get to FID [final investment decision] because they are developed by very large oil companies with large balance sheets," he said.

However, "it is not going to create any revenue from the company in the short term."

And the big challenge is getting to the next stage, where CO_2 is captured from other industrial companies. This will need policy and carbon pricing. "There's lots of work to do."

More information

You can watch the webinar on online here:

https://gcformd.org/webinar-recap-co2-shipping-for-ccus-how-can-we-scale-up-in-the-next-5-10-years/

The report is online here:

https://www.gcformd.org/our-publications/?report-id=7512

Northern Lights begins injecting CO2 at world's first commercial storage

The first CO2 has been transported through the 100-kilometre pipeline and injected into the Aurora reservoir 2,600 meters below the seabed of the Norwegian North Sea in world's first commercial operation.

Northern Lights facility. Image: Torstein Lund Eik / ©Equinor

The CO2 is transported via ships from Heidelberg Materials' cement factory in Brevik. The CO2 is then offloaded and transported through a 100-kilometer pipeline and injected into the Aurora reservoir under the seabed of the North Sea.

"With CO2 safely stored below the seabed, we mark a major milestone. This demonstrates the viability of carbon capture, transport and storage as a scalable industry. With the support from the Norwegian government and in close collaboration with our partners, we have successfully transformed this project from concept to reality," said CEO of Equinor, Anders Opedal.

The Northern Lights Joint Venture is equally owned by Equinor, Shell and TotalEnergies. Equinor, as the Technical Service Provider (TSP), has been responsible for the construction of the Øygarden facility and the offshore facilities on behalf of the Northern Lights JV, and will also have operational responsibility of the CO2 plant.

"Lifting new value chains like CO2 capture, transport and storage requires collaboration and effort across the value chain - from governments, industry and customers. With Northern Lights in operation, we have proven that this is possible. Now, we look forward to leading safe and efficient operations on behalf of the Northern Lights partnership and use this as a stepping stone for the further development of CCS in Europe," said Irene Rummelhoff, Executive Vice President of MMP in Equinor.

The commenced injection of CO2 completes the phase 1 of the development, which has a total capacity of 1.5 million tonnes of CO2 per year (mtpa). The capacity of this phase is fully booked.

In March, the owners of Northern Lights made the final investment decision for the phase 2 of the development, which will increase transport and storage capacity to a minimum of 5 million tonnes of CO2 per year. This decision was made possible after signing of an agreement to transport and store up to 900,000 tonnes CO2 annually from Stockholm Exergi. The expansion is enabled by a grant from the Connecting Europe Facility for Energy (CEF Energy) funding scheme.

The expansion of Northern Lights builds on existing infrastructure and includes additional onshore storage tanks, a new jetty, and additional injection wells. The development of phase 2 with Equinor as TSP is well underway, with the delivery of nine new CO2 storage tanks at the Øygarden site this summer.

More information

https://norlights.com

Seabound's onboard carbon capture system installed on Hartmann vessel

Captured carbon on cement-carrying ship to serve as limestone input at Heidelberg Material's net zero cement plant in Brevik, Norway.

The solution equips the UBC Cork, a 5,700 gross tonne (GT) cement-carrying ship owned by Hartmann and managed by Inter-Maritime, with Seabound's compact carbon capture system. The captured carbon — bound in limestone and thus stored safely onboard — will be offloaded at the Port of Brevik, Norway, and used in Heidelberg Materials' Brevik cement plant. Recently inaugurated, this world-first industrial-scale carbon capture facility in the cement industry will produce net-zero concrete.

Marine shipping accounts for nearly 3% of global CO2 emissions, making it one of the most carbon-intensive and difficult-to-decarbonize sectors. In April, the International Maritime Organization (IMO) introduced a global carbon price of up to $380 per tonne of CO2, further adding pressure to shipowners. With few scalable alternatives to heavy fuel oil and existing efficiency measures proving insufficient, shipowners and global brands are seeking viable solutions to cut maritime emissions and meet ambitious climate goals.

Seabound is deploying its compact marine carbon capture system aboard the UBC Cork (pictured). The captured carbon will be offloaded as limestone at the Port of Brevik, Norway, for use at Heidelberg Materials' nearby cement plant

Seabound's containerised carbon capture system uses calcium looping technology to capture up to 95% of CO2 and 98% of sulphur emissions from ship exhaust. The process uses calcium hydroxide, derived from calcium oxide and commonly known as slaked lime, to absorb CO2 and convert it into limestone that is stored onboard until returning to port. The containerised system allows for easy installation with minimal vessel modification and is suitable for all vessel types. This design decouples carbon capture from post-processing, resulting in lower energy requirements, faster deployment, and reduced cost compared to traditional liquefied CO2 systems.

"We're proud to partner with industry leaders like Heidelberg Materials and Hartmann to deliver scalable carbon capture solutions," said Alisha Fredriksson, CEO and Co-founder of Seabound. "We're especially excited to be advancing this work in Brevik, a strategic location that's rapidly establishing itself as a global hub for CCS with Heidelberg's world-first facility and the Northern Lights pick up point. Together, we're demonstrating how onboard carbon capture can accelerate emissions reductions in carbon-intensive sectors."

The carbon captured on the UBC Cork will be offloaded as limestone at Heidelberg Materials' Brevik plant, where it will serve as an input in the production of carbon captured cement, which enables net-zero concrete. The Brevik CCS facility is already operational, capturing 400,000 tons of CO2 annually. CO2 transport and storage are provided by Northern Lights, the world's first cross-border CO2 storage hub beneath the North Sea.

"Shipping cement is emissions-intensive, and Seabound's system gives us a clear path to reduce those Scope 3 emissions while enhancing our circular use of captured CO2," said Lars Erik Marcussen, Project Manager, Logistics at Heidelberg Materials Northern Europe. "This project brings us one step closer to also decarbonising the logistics/transport part of our operations."

Heidelberg Materials aims to reduce its Scope 3 emissions from maritime transport by using a variety of methods — including Seabound's carbon capture technology — to accelerate its path to net-zero. Meanwhile, Hartmann's early adoption provides crucial operational expertise and strategically positions the company to meet evolving regulatory demands. Together, Seabound and Hartmann are committed to expanding carbon capture solutions throughout Hartmann's fleet, driving meaningful decarbonisation in maritime shipping.

The project is co-funded by the Eurostars partnership on Innovative SMEs which is part of Horizon Europe through the Cyprus Research and Innovation Foundation. This funding supports collaborative R&D projects that drive innovation in a range of industries, including maritime transport. The consortium of funding recipients supporting this initiative includes the Cyprus Marine and Maritime Institute, a centre of excellence in maritime research with an interest in advancing new decarbonisation technologies.

More information

www.seabound.co
www.heidelbergmaterials.com

Transport and storage news

DECARBONICE completes the first transport of CO2 in solid form at sea

www.decarbonice.org

Danish start-up DecarbonICE aims to develop a full CO2 transport value chain with CO2 in solid form as dry ice.

DecarbonICE said it wants to demonstrate several important benefits compared to CO2 transport in liquid form in pressurised cryogenic tanks.

In the DecarbonICE concept dry ice is transported in pellet form in standard 20 ft containers with extra insulation, but without active cooling. The transport takes place at atmospheric pressure and at a temperature of minus 78.5°C. The safety philosophy for transport of CO2 is therefore like transport of natural gas as LNG, namely at atmospheric pressure and low temperature.

DecarbonICE has just completed an important milestone by transporting dry ice at sea in a container from Århus in Denmark to Reykjavik in Iceland. The container was first transported on road by truck for 100 km from the dry ice loading site to the Port of Århus. The smooth intermodal shift from truck to ship was demonstrated at the port without any intermediate storage needs.

The transport of the DecarbonICE container took place on the deck of Eimskip's Bruarfoss - a 2.150 TEU Container ship. The container was handled like any other container in the ports and on board the ship. Each DecarbonICE container can carry 20 tons of dry ice, and the transport loss of CO2 due to sublimation was measured to 0.3% per day.

Among the main benefits of its concept, DecarbonICE emphasises safety, since transport takes place at atmospheric pressure as well as the use of an existing container transport chain which reduces the CAPEX needs and which can be scaled very fast.

In addition, the cost of a DecarbonICE container is 15-20 times lower than an ISO tank container for the same amount of liquid CO2, and the cost of a container ship with containers for transport of 20.000 tons of CO2 is 60% lower than the similar cost for a LCO2 tanker.

Intermodal shifts are straightforward between transport by truck, ship, train or barge, and without a need for extensive safety zones. Loading and unloading is straightforward, and the dry ice containers can be mixed with other containers providing a large flexibility and allowing a gradual build up.

The DecarbonICE solution requires additional CAPEX and OPEX to transform captured and liquefied CO2 into dry ice, and to a much smaller degree to convert dry ice back into liquid or gas form. These additional costs are, however, fully recovered by lower costs for the transport system and in particular for transport that includes a maritime leg, the company said.

DecarbonICE said it will continue to develop the commercialisation of its solution starting with a smaller project of transporting CO2 captured from a Biogas plant.

The modular Carbon Ridge system is designed for both retrofit and newbuild integration and is scalable and agnostic to fuel type

Carbon Ridge deploys first centrifugal CO2 capture on Scorpio tanker

www.carbonridge.net
www.scorpiotankers.com

The company has achieved a shipping first with the successful deployment of a centrifugal onboard carbon capture system (OCCS) aboard an LR2 product tanker owned by Scorpio Tankers.

The pilot marks the first deployment of a centrifugal OCCS system in maritime operations, establishing Carbon Ridge as the pioneer in bringing this method of carbon capture to the shipping industry. The pilot commenced in July at Besiktas Shipyard in Turkey aboard the STI SPIGA.

Chase Dwyer, CEO and Founder, Carbon Ridge said, "Unlike other CCS solutions, which are designed to be deployed on land and then adapted for ocean operation, we have specifically designed and developed this technology for the maritime industry."

"The centrifugal carbon capture system is unlike anything that has been deployed on a vessel before and, offers a cost effective, flexible and modular solution to support the maritime industry in its decarbonisation efforts. Our ambition is to lead the way for CCS in shipping, and we are excited to see the results of this deployment with our partner Scorpio Tankers."

Carbon Ridge said the technology offers a modular design that reduces both initial capital investment and ongoing operational costs while delivering superior capture efficiency compared to conventional technologies.

The technology's compact design means that space requirements are reduced by up to 75% compared to conventional OCCS columns, and flexible installation options - vertical or horizontal depending on vessel constraints - accommodate a variety of vessels. Captured CO2 is compressed, liquefied, and stored safely for the duration of the voyage.

The OCCS technology is combined with an end-to-end logistics solution for captured CO2 to offer full value-chain compliance with maritime and regional regulations.

The system is designed for both retrofit and newbuild integration and is scalable and agnostic to fuel type, offering ship owners flexibility without requiring major propulsion system overhauls.

Carbon Ridge also completed an additional financing led by Katapult Ocean and Alfa8, with participation from Crosscut Ventures and Berge Bulk. This brings the company's total funding to over $20M USD.

Deep Sky Alpha operational in Alberta

DEEPSKYCLIMATE.COM
/**ALPHA**