Carbon Capture Journal

CCUS in Australia

Fast-tracking DAC testing at CO2CRC's Otway Test Centre

'Carpooling carbon': Net Zero Zones to boost climate action

Modular, low-cost hybrid capture technology

July / Aug 2023 Issue 94

Northern Lights Phase 1 "80% ready" - read our report from the ZEP Brussels Forum

Image: Northern Lights

The need to measure carbon dioxide flows accurately for CCUS

Achieving emissions reduction targets in the iron and steel industry

How US carbon tax credits are accelerating global CCS commerciality

CCS Europe calls on EU leaders to back CO2 storage and transport policy

UK falling behind on Net Zero ambitions says climate change committee

In a crucial period for delivering progress, key departments did not deliver on recommendations made by the Committee last year and confidence in delivering Net Zero goals has fallen.

Support is lacking for decarbonised industry in a new era of global competition says the UK Committee on Climate Change in its progress report. Government has high ambitions for decarbonised steel production but has no clear policy to deliver it. Wider incentives are still needed for electrification of industry. The recent announcement of up to £20 billion funding for carbon capture and storage is welcome, but detail and implementation of these spending plans is still to come.

Beyond 2025, industrial decarbonisation depends heavily on CCS. According to publicly-available information, the current pipeline is insufficient to meet the Government's target of 6 MtCO2 by 2030. However, it was recognised that not all projects in development have been made public.

While good progress has been made in developing plans to support the first Energy from Waste (EfW) facilities to install carbon capture technology as part of the industrial CCS cluster programme, a more strategic approach to decarbonising the fleet is needed.

Key recommendations on CCS

• Publish a comprehensive long-term strategy for the delivery of a decarbonised, resilient, power system by 2035. This should comprise a portfolio approach to developing the full range of low-carbon flexibility options, including demand flexibility, storage, hydrogen, gas CCS and interconnection capacity.

• Publish a detailed timeline specifying each stage of the process of CCS development for Tracks 1 and 2 of the CCUS Cluster Sequencing Programme from now through to first capture and storage of CO2 in each cluster and sector, including completion of engineering design, contracts and permitting, construction and commissioning, and publish a plan of how the Government will ensure this timeline aligns with their planned first capture dates for each cluster and sector.

• Finalise and deliver the Transport and Storage Regulatory Investment business model in 2022, consistent with the Government's ambition to establish at least two CCS transport and storage clusters in the mid-2020s. This will require promptly beginning the process of awarding permits and construction of the necessary infrastructure, to ensure that it is ready in time for deployment.

• Ensure that large-scale unabated biomass power plants are converted to BECCS as early as feasible, and are not given extended contracts to operate unabated at high load factors beyond 2027.

• Ensure new gas plant are genuinely CCS- and / or hydrogen-ready as soon as possible and by 2025 at the latest.

• Publish details of the £20 billion spending commitment for CCUS, including what it is to be spent on and how much is earmarked for different types of CCUS.

• Continue to work with the UK Government on industrial decarbonisation in Wales, formally requesting some specific support measures, including for the adoption of CCUS and hydrogen in the South Wales Industrial Cluster.

Key messages include:

• Policy progress on CCS. The Government has announced eight projects to progress negotiations for the first two CCS clusters and it has launched the process for choosing the next two clusters. The Government has committed up to £20 billion of funding to support the development of CCUS over the next 20 years. This is welcome, but there remain some risks to delivering these technologies at the scale and speed required. The UK's first carbon storage licensing round has been launched, receiving 26 bids.

• Remaining gaps for CCS. The Government's broader CCS programme is behind schedule and detail is light on the timelines for selection and support of the second pair of clusters. Details of the up to £20 billion spending commitment for CCUS have not been released. There is still no detailed plan or policy framework for CO2 transport from dispersed sites and the Transport and Storage Regulatory Investment business model has not yet been finalised.

• Engineered removals and CCS clusters. Both BECCS and DACCS rely on access to the UK's CCS network to function. However, no engineered removals projects are being taken forward in Track 1 of the CCUS cluster programme. Clarity is required around how engineered removals projects will integrate with these clusters.

• Funding mechanisms for engineered removals. Due to high capital and operating costs, together with technology and construction risks associated with novel technologies, engineered removals will require Government support in their early stages of deployment. Clarity on the form that this support will take is now overdue.

Ruth Herbert, Chief Executive at the CCSA said, "This report makes clear that the UK must get moving and accelerate deployment of CCUS to have any chance of reaching our net zero targets. The CCC spell out that there is currently no clear policy for UK industries to decarbonise. CCUS offers an opportunity to decarbonise heavy industry, while protecting and creating jobs."

"We urgently need a CCUS deployment plan for the whole of the UK. We're still waiting for contracts to be signed for the first eight carbon capture projects, and for ministers to confirm the next steps on expanding the clusters on the east coast and north west of England, as well as a timeline for selecting further clusters in other parts of the UK, which is necessary to meet the Government's ambition of four CCUS clusters by 2030."

More information
www.theccc.org.uk

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Front cover: CO2 receiving terminal in the municipality of Øygarden in western Norway. The facilities are under construction and will be ready for operations in 2024 (pg. 12)

Back cover: ANRAV the first project in Eastern Europe - read our update from the ZEP forum in Brussels on companies and projects (pg. 15)

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Leaders - CCUS in Australia

Projects and policy

Capture and utilisation

Transport and storage

CO2CRC's Otway International Test Centre fast-tracking DAC testing

The OITC, an advanced field scale CCUS research site located in Australia, is fast-tracking the testing, demonstration and scale-up of Direct Air Capture (DAC) technology.

The need for Direct Air Capture (DAC) technology is driven by the global need to mitigate climate change and reach net zero emissions. To reach net zero emissions, it is necessary to reduce emissions from all sources, including energy production, transportation, and industry. However, some sources of emissions, such as those from agriculture, land use changes and fugitive emissions are difficult to reduce.

DAC technology provides a solution to this challenge by allowing us to capture and remove CO2 from the atmosphere, thus reducing the overall concentration of CO2 in the atmosphere and mitigating the effects of climate change.

In the Sustainable Development Scenario (SDS) of International Energy Agency (IEA), direct air capture is scaled up to capture almost 10 Mt CO2/year by 2030. This is within reach but will require several more large-scale demonstrations to refine the technology and reduce capture costs. It is estimated that 0.5–1 Gt CO2/yr is a sustainable global removal potential for DAC in 2050.

However, DAC technology is still in its early stages of development although it has the potential to play a significant role in achieving net zero emissions. This is because DAC has the potential to capture CO2 from the atmosphere at a large scale, and to store it safely and securely in underground geological formations. By reducing the concentration of CO2 in the atmosphere, DAC can help to mitigate the effects of climate change and support the transition to a low-carbon future.

DAC technology with CO2 sequestration has many advantages over other negative emission technologies (NET) like afforestation and bio energy with CCS. DAC has a smaller land and water footprint and presents the possibility of being located close to suitable storage or utilisation sites, eliminating the need for long-distance CO2 transport. DAC is also a suitable technology to offset the emissions from distributed emission sources like the transport sector which is Australia's third largest source of greenhouse gas emissions (96 Mt CO2-e per year) and aviation sector that emits around 9.99 Mt of CO2-e per year. Without DAC, combined with carbon storage, the target of net zero emission is hard to achieve. As DAC technology is still new and evolving, the testing, demonstrating, and scaling-up of various DAC technologies is a crucial step in progressing towards large scale industrial deployment to contribute to the net zero emission challenges.

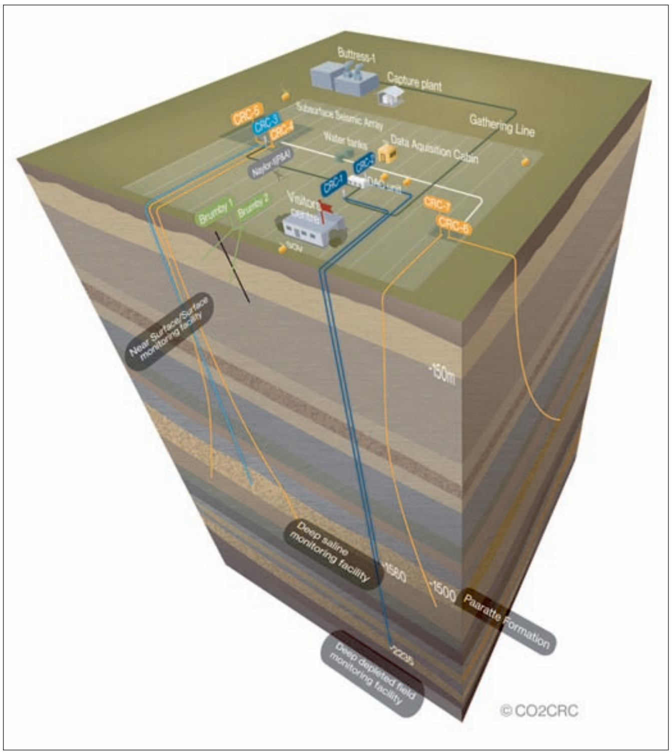

Figure 1: Schematic of existing infrastructure in Otway International Test Centre (OITC) – complete with injection wells and subsurface Monitoring & Verification (M&V) solutions

Testing DAC technology is important to evaluate its performance, identify technical challenges, optimize the design of the system and to scale up the technology. This can include evaluating the efficiency of the CO2 capture material, the energy consumption of the system, the purity of the captured CO2, dependency of performance on ambient conditions, and the durability and longevity of the equipment. This information can be used to improve the overall design of the DAC systems and make them more efficient, compact and cost-effective.

Demonstrating DAC technology is important to demonstrate its technical feasibility and to build confidence in the technology among potential investors and customers. This includes showing that the technology is capable of capturing CO2 from the air on a continuous basis, and that the captured CO2 can be safely and efficiently stored. Demonstrations also help to show the performance and reliability of the technology under various conditions, including different weather conditions and levels of CO2 concentration in the air.

Scaling-up DAC technology is important to prepare for commercial deployment, as it allows researchers and developers to identify and address any issues that may arise when the technology is deployed at a larger scale. This includes testing the performance of the technology under the conditions that will be encountered during commercial operation, evaluating the costs associated with scaling up the technology, and identifying any technical challenges that need to be addressed to make the technology more cost-effective at scale.

CO2CRC's Otway International Test Centre (OITC) is one of the most advanced field scale CCUS research sites globally with a state-of-the-art infrastructure and facilities for CO2 capture, CO2 sequestration, monitoring and validation. CO2CRC owns and operates the Otway International Test Centre; supporting CCUS technology advancement in Australia and internationally for more than 15 years, sequestering close to 100,000 tonnes of greenhouse gas safely and permanently in deep depleted gas reservoirs and saline formations.

The OITC is dedicated to delivering innovative research, products and services designed to improve the cost-effectiveness and demonstrate the environmental integrity of CCUS technologies and methodologies. The infrastructure of the OITC is ideal for the field testing of DAC technologies. With seven purpose-drilled wells for injection and permanent monitoring of the stored CO2, the OITC is ideally suited for DAC technology demonstrations and its systematic development with geological storage.

The OITC is equipped with a range of advanced Monitoring and Verification (M&V) surface and underground sensors and monitoring systems. Multiple sensors and monitoring systems for temperature, pressure, flow rates, and the concentration of CO2 and other gases in the inlet and outlet air streams can be tailored for specific DAC testing and demonstration programs.

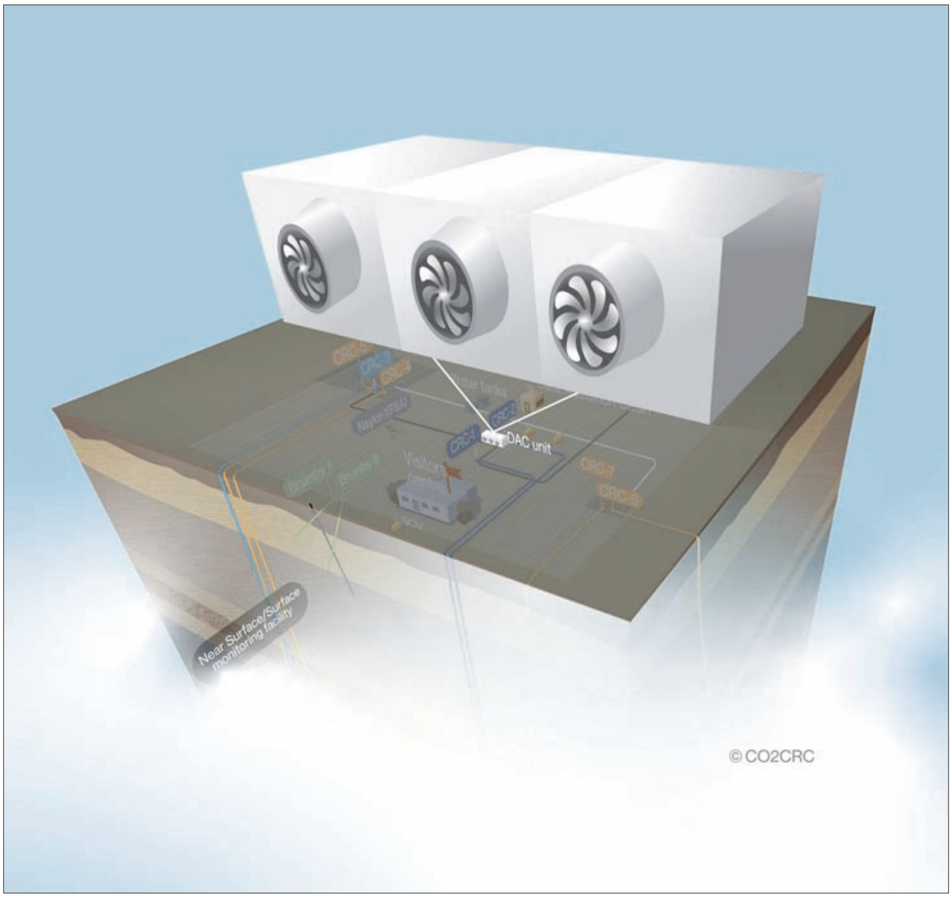

Figure 2 - Scaling-up DAC technology is important to prepare for commercial deployment, as it allows researchers and developers to identify and address any issues that may arise when the technology is deployed at a larger scale

This allows researchers to accurately measure and track the performance of DAC systems and make improvements to the design of the system based on the results of the tests. With the available infrastructure and facilities at OITC, the testing and demonstration of DAC as a real and verifiable Negative Emission Technology (NET) can be done in the shortest possible time.

The OITC also has the capability to test and demonstrate the whole capture-to-storage process. This allows researchers to evaluate the performance of DAC systems as part of an integrated carbon capture and storage system, which is an important aspect for commercial deployment to achieve negative emission solution. By evaluating the technical and economic feasibility of the entire process, researchers can identify any issues that need to be addressed to make the technology more cost-effective at scale.

CO2 from DAC presents some unique challenges for its geological storage. It includes variation in CO2 flow with the change in ambient conditions, and potentially frequent stop start of DAC according to the availability of renewable power to operate the unit. CO2CRC has recently completed the pre-engineering of the CO2 compression and injection system for CO2 storage to overcome the typical challenges of CO2 handling, transport, and storage of CO2 from a typical DAC process. CO2CRC has also completed an exercise on HSE and regulatory requirements for having DAC with CO2 storage at OITC.

Over the last 20 years, CO2CRC has been actively working on CO2 capture technologies based on solvent, membrane, adsorbents and hybrid technologies. CO2CRC has vast experience in CO2 capture technologies that can be contributed and applied to research and development of possible DAC systems.

With CO2CRC's experience in both capture and storage processes, we understand the challenges of employing the current capture technologies to DAC and identified some potential areas of immediate improvements. Any demonstration of DAC technology at the OITC will benefit from CO2CRC's operational expertise in demonstrating, troubleshooting and scale up of CO2 capture technologies.

The value of testing and demonstrating DAC technology with carbon storage at the Otway International Test Centre (OITC) cannot be overstated. Through such work, researchers and developers can gain a better understanding of the technology's performance and identify any technical challenges. The need to address the commercial challenge of the technology is also well understood with current capture costs alone estimated at between $250 - $600 / tonne of CO2. The commerciality of the technology must be addressed if DAC is to be deployed at the scale needed to materially decarbonize the atmosphere.

Some of the key benefits of CO2CRC's OITC for DAC testing, demonstration and scaling include but are not limited to:

• CO2CRC has an excellent safety performance history and an established track record of developing technologies for carbon capture, utilisation and storage.

• OITC infrastructure has been proven for various research and demonstration projects.

• Full operational support that can be tailored to customer requirements.

• OITC highly instrumented subsurface facilities; potential for continuous support for future DAC development in lowering DAC cost and negative emission/carbon abatement.

• OITC holds many of the necessary regulatory approvals required for such a test and is potentially the only testing facility in Australia (or even worldwide) which could perform end-to-end testing within a short timeframe.

• The OITC can support multiple DAC units with fully flexible operation, can be tailored for either short or long-term operation.

• Verification and assurance of key performance metrics in field operation to meet project objectives.

• Potential to support continuous DAC-CCU R&D in the future to increase carbon utilisation besides sequestration.

• Optimising DAC and CO2 sequestration operation to reduce the cost of DAC-CCS

In conclusion, the Otway International Test Centre (OITC) provides researchers and developers with an ideal facility to test and demonstrate Direct Air Capture (DAC) technology. The facility is equipped with a range of advanced measurement and monitoring systems and has the capability to test and demonstrate the whole end-to-end capture-to-storage process.

The importance of testing and demonstrating DAC technology at the OITC cannot be overstated, as it provides researchers and developers with a controlled environment in which to evaluate the performance of the technology and identify any technical challenges that need to be addressed. This can result in more efficient and cost-effective DAC systems that are better suited for commercial deployment and increase the chances of commercial success.

More information

co2crc.com.au/research/direct-air-capture

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Moomba progressing at pace - on track for 2024

Two of the most critical pieces of equipment, worth about AU$30 million, for Santos' Moomba CCS project are making their way to site after arriving in South Australia last week.

The imminent arrival in Moomba of the compressor and turbine follows the project recently marking the 60 per cent completion milestone, with first injection on track for 2024.

Santos Energy Solutions President, Brett Woods, said Moomba CCS will be the start of an exciting new industry, with carbon abated gas opening potential new revenue streams.

"Moomba CCS will help Australia reach net zero. Once complete, the project will support Santos to reduce our own emissions but crucially, we're also working with other hard-to-abate sectors to look at ways of using Moomba CCS to help reduce their emissions, too," Mr Woods said.

"With the turbine and compressor expected to arrive in Moomba any day now, we're excited to continue the strong progress we're making so we can inject CO2 into the depleted reservoirs from next year.

"Importantly, Santos is looking to the future. Through our energy transition business, Santos Energy Solutions, we are looking at CCS and other decarbonisation and clean fuels projects that will play a critical role in supporting Australia, and our region, transition to a lower carbon future."

Following first injection, Moomba CCS will safely and permanently store up to 1.7 million tonnes of CO2 per year, in the same geological reservoirs that held oil and gas in place for tens of millions of years.

The progress on Moomba CCS follows Santos' recent announcement of the execution of four Memoranda of Understanding for the proposed storage of CO2 emissions from third parties at the Bayu-Undan CCS project, offshore Timor-Leste.

Mr Woods said with 30 CCS projects in operation around the world storing over 42 million tonnes of CO2 per year, there is strong demand for CCS services.

"Increased deployment of CCS is critical to achieve the world's climate goals. Santos' progress on CCS reaffirms our strategy and our commitment to delivering emissions reductions solutions for our own operations as well as that of our customers, and third parties," Mr Woods said.

"There is a broad acceptance of CCS as a decarbonisation strategy, and with our plans also continuing for trials of Direct Air Capture (DAC) in the Cooper Basin later this year, there is potential for significant DAC with CCS scale-up, if successful.

"At Santos, we're working on real projects that aim to deliver real emissions abatement, in the South Australian outback. It's an exciting time to be part of the energy transition."

The Moomba CCS Project will capture CO2 already separated from natural gas at the Moomba Gas Plant in South Australia. It also provides an opportunity to launch further projects to store other sources of CO2 (such as from direct air capture) and it enables low-carbon hydrogen production..

More information

www.santos.com

Modular, low-cost hybrid carbon capture technology

CO2CRC in collaboration with its research partners in Australia, have developed a hybrid CO2 capture technology, HyCaps which combines solvent absorption with membrane separation in a single process, which exploits the advantages of both technologies to achieve a more efficient carbon capture system.

According to the IEA's "Net Zero Emission Scenario by 2050", about 50% of steel production, 85% of cement production, 65% of chemical industries and 35% of hydrogen production will be delivered by processes equipped with CCS.

In this scenario, the total amount of CO2 captured will reach 4.2 Giga tonnes per annum. To achieve this goal, large scale implementation of CCUS is necessary.

Among the available CO2 capture technologies, solvent absorption technology is the most advanced and has been commercially employed in various large scale CO2 capture facilities in the power, fertilizer and steel industries. However, the large footprint of the solvent based capture plants, handling of amine based solvents and energy requirements of the process are the major challenges in implementation of this technology at the scale necessary.

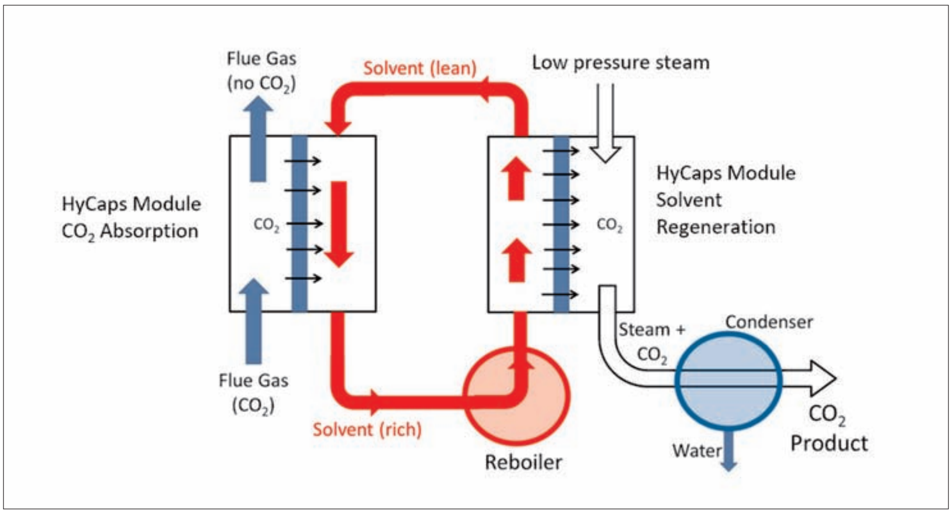

Figure 1- HyCaps process undertaking carbon capture and solvent regeneration

To accelerate the implementation of CCS to achieve Net Zero by 2050, cost effective, compact and easy to scale up CCS technologies are required. For solvent based technologies it means improved gas-liquid contact systems and better solvents.

The HyCaps process involves the preferential transfer of CO2 from the gas mix through a hollow-fiber membrane, where it is chemically absorbed into a solvent. This takes advantage of the highly selective nature of solvent absorption technology and the controlled flow regime of membrane technology.

Also, the membrane acts to physically separate the solvent and gas flows which enables much higher CO2 mass transfer into the solvent phase than is typically possible. The HyCaps process has a proven ability to be highly efficient at carbon capture with reduced energy requirements.

Figure 1 shows a typical flow sheet of the HyCaps process. The flowsheet is similar to that of CO2 capture with solvent absorption technology with conventional packed columns for absorption and solvent regeneration are being replaced by HyCaps module. In solvent regeneration with HyCaps, the physical separation of the solvent and gas phases by the membrane enables carbon dioxide to be drawn from the enriched solvent phase into the gas phase. This is achieved by reducing the corresponding partial pressure in the gas phase by a steam sweep gas.

This enables solvent regeneration to be achieved at temperatures lower than conventional packed columns solvent regeneration can be achieved without g vaporisation of the solvent phase. The salient features of HyCaps are:

• Solvent regeneration does not require reboiling/phase change, significantly reducing the solvent regeneration energy as compared to the conventional absorption technology.

• Steam is used only as a sweeping media for CO2 in regeneration, low pressure, low temperature waste steam can be used. This is a low-cost steam (or even free in power generation). This significantly reduces the energy demand relative to conventional solvent technology, resulting in a low parasitic load for carbon capture. This reduces the OPEX cost significantly.

• Hollow fibre based HyCaps modules provide very high surface to volume area. Consequently, the equipment size for carbon capture is significantly reduced compared to conventional solvent absorption columns.

• The HyCaps modules can be oriented in any direction without having an impact on the performance. Lower footprint, flexibility in orientation and modular nature of HyCaps also enable the capture process to be easily accommodated into limited spaces, making HyCaps very suitable for retrofit applications as well.

• The separation of the solvent and flue gas phases by the membrane eliminates solvent foaming, flooding and reduces liquid channeling, the major operating issues in solvent absorption in packed columns. Also, there is no need for solvent redistribution.

• Unlike tall, packed columns, in HyCaps modules need for intercoolers can be avoided, as the modules are not long enough to lead to temperature spikes.

CO2CRC Ltd and its researcher partners have successfully demonstrated the potential of HyCaps technology for both post-combustion and pre-combustion carbon capture scenarios, in Australian industry. This novel technology represents over a decade of laboratory research and three pilot plant industrial trials: as part of the CO2CRC's Vales Point, H3 and Mulgrave projects:

• The achieved research objective of the Mulgrave project was to capture carbon from syngas (generated from brown coal gasification) through HyCaps designs and to maximize the efficiency of the process, given the syngas pressure. HyCaps modules with polypropylene & PTFE materials were tested.

• The H3 project utilized HyCaps to undertake post-combustion flue gas capture (generated from a brown coal power station) and quantify the effectiveness of the process given the low-pressure conditions. The pilot rig was designed to take 200 kg/day of flue gas. The two test campaigns used PuraTreat solvent from BASF & carbonate based UNO solvent of CO2CRC Ltd.

• The last pilot plant trial at the Vales Point power plant undertook a closed loop HyCaps process for post-combustion carbon capture and solvent regeneration for an extended period, based on flue gas from a black coal fired power station. CO2CRC has successfully demonstrated the simultaneous and continuous operation of CO_2 absorption and solvent regeneration with HyCaps modules.

The pilot plant at Vales Point was the largest pilot plant demonstration, using a solvent based on 30 wt% monoethanolamine (MEA) with HyCaps modules undertaking both absorption and solvent regeneration (Figure 1). The solvent was chosen because of its well characterized performance and the industry standard for CO_2 solvent absorption.

Hence, the performance of the HyCaps pilot plant could be directly correlated with conventional solvent absorption processes, with improvements in carbon capture efficiency and energy penalty directly correlated to the HyCaps technology. In this process, the solvent regeneration operating temperature ranged between 90 to 102°C, well below the solvent vaporization temperature of 105°C.

Hence, the pilot plant proved that with HyCaps, solvent regeneration could occur without boiling the solvent – representing a significant energy and cost saving.

To ensure rapid scale-up of HyCaps technology, the membrane based HyCaps modules chosen were based on commercially available membranes, which were originally developed for other gas separation applications. Therefore, the technology can be rapidly uptake by industry and expanded without the need for membrane material development or construction of sophisticated membrane fabrication facilities, which hampers research into other gas separation membranes.

In the design of the HyCaps pilot plants, heat integration was not considered. The energy performance of the HyCaps process can be further improved through process and heat integration of HyCaps capture with the plant. In an integrated HyCaps process the need to store and hold solvent volumes at elevated temperatures is removed.

Most of the energy requirements of the HyCaps process therefore only consists of the thermal energy necessary to regenerate the solvent, , and the mechanical energy associated with the vacuum and solvent pumps and blowers, necessary to move the various gas and solvent phases through the process..

The development of the hybrid HyCaps represents a new approach in carbon capture that has clear advantages in terms of energy consumption and footprint, compared to conventional technology. Importantly, the technology, proven at three different industrial pilot plants, has demonstrated the deployment readiness of HyCaps to address carbon emissions from industrial sources.

More information

co2crc.com.au/research/capture-research

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Microbial renewable dimethyl ether (rDME) as a renewable fuel alternative

This article provides an overview of microbial renewable dimethyl ether (rDME) technology for 100% renewable DME that can potentially replace liquid petroleum gas (LPG), methane and diesel, and enable 100% renewable energy grid by providing backup power to solar and wind farms. By Adeel Ghayur, CO2CRC.

The microbial DME technology was researched and developed in Australia in the last decade with the overarching aim of developing a renewable fuel that: (1) replaces existing fossil fuels with minimal infrastructure changes; (2) has a production cost competitive to that of its fossil fuel derived analogues; and (3) has the capacity to produce at commercial scale; potentially over a million metric tonnes (tons) per refinery [1]. This demonstrates a potential pathway in addressing the challenges of emissions reduction in both transportation and power sectors.

The last decade's extensive research and development (R&D) into this process has progressed the technology towards commercial maturity. Initial simulation results based on laboratory data showing that a commercial scale microbial DME refinery can produce up to 1.1 million tons of renewable DME. At this scale, this is sufficient to fuel one million cars for a year. Simulations also show that this is enough to provide 3.5 TWh of power via solid oxide fuel cells, which is sufficient to provide reliable backup power to a wind and solar powered grid.

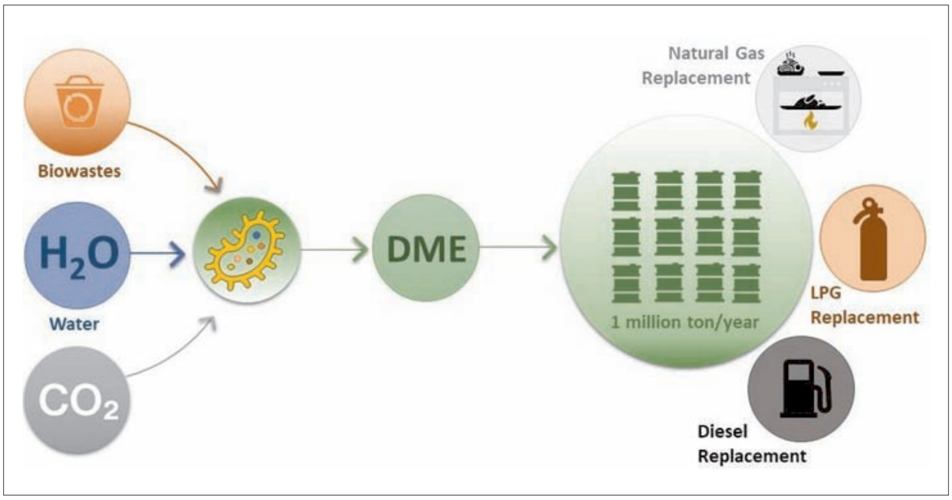

Figure 1: Microbial DME Process

Microbial DME Technology Description

In the microbial DME process (Figure 1), naturally occurring microbes feed on CO2 and biowaste to produce an intermediary chemical that is upgraded into renewable DME (rDME) via a thermo-catalytic process. Microbes get their hydrogen and energy from the biowaste for the fermentative process. In this process, biowastes are first fractionated into three basic components which are then fed to the microbes for the fermentative process that also consumes small quantities of CO2.

The process produces an intermediary chemical with minor impurities before going through a purification process. The purified chemical is then thermo-catalytically upgraded into DME via reacting with methanol. In order to achieve 100% renewable DME, renewable methanol will need to be used. The renewable methanol can be produced from renewable H2 and CO2. It is possible to integrate the renewable methanol production process with the intermediary chemical production process on the same site. In such an instance the methanol is produced via a catalytic CO2 hydrogenation process.

As shown in Figure 1, the process yields rDME — a fuel that could potentially replace LPG, methane, and diesel for the energy and transport sectors. Chemically identical to fossil fuel derived DME, it has the benefit of using the existing infrastructure and equipment without any major modifications. The minor drawback is the lower energy density of rDME at 28.8 MJ/kg, which is around 70% of diesel's energy density.

rDME's capacity to utilise existing infrastructure and its usage in internal combustion engines implies it is application ready. This paves the way for its immediate application as a transition fuel until the infrastructure for renewable hydrogen becomes available. In Australia, rDME also has immense application as a low-carbon fuel for backup power.

With largescale low-cost storage capacity, rDME would allow for an easy transition of the fossil fuel power grid to baseload solar and wind power. rDME has already been established as an alternative fuel for power generation via gas turbines. Additionally, it has also been tested as a fuel for solid oxide fuel cells, thus enabling faster and higher efficiency power production for peaker power plants.

Potential of large Scale Microbial DME Production in Australia and other regions in Asia

Large scale production of renewable fuels is necessary to meet the 2030 and 2050 emissions reduction targets. This is only possible if the renewable fuel refinery capacities match the existing fossil fuel refinery capacities. Today, typically, methanol and DME are coproduced in refineries and the typical nameplate capacities average around 1 million ton per annum.

Examples include La Brea DME-Methanol plant at 1 million ton, Couva Titan refinery at 0.88 million ton and Atlas refinery at 1.88 million ton. In view of these capacities, the microbial technology was designed to match these capacities and initial simulations were carried out at 1.1 million ton nameplate production capacity.

	Microbial	CO_2 Hydrogenation	Biomass Gasification	Biogas to DME
Carbon conversion efficiency	1 to 1	1 to 1	1 to 0.7	Low
Largest feasible size	1 million ton*	1 million ton	0.7 million ton	20,000 ton
Electricity demand for renewable hydrogen	500 MW	1,000 MW	0	Not Applicable
Land area for 1 million ton facility	Medium	Large	Small	Largest or may need multiple facilities
External energy demand	0	200 MW	0	0
Biomass flexibility	Yes	Not Applicable	Consistent biomass	Not Applicable
Biomass water content	No issue	Not Applicable	Needs torrefaction	Not Applicable
Catalyst sulfur poisoning	No	Not Applicable	Yes	Not Applicable
Gaseous CO_2 consumed	0.5 million ton	1 million ton	0	0
Total CO_2 Removed	1 million ton	1 million ton	0.7 million ton	Not Applicable

Figure 2 - Microbial rDME Technology Comparison with Other Renewable DME Technologies

Simulation results of this novel rDME refinery show that a commercial scale biorefinery consuming 5,000 metric tonnes per day of biowaste can annually produce 1.1 million tons of DME. All of the parasitic energy requirements can be fulfilled within the refinery, including energy for renewable methanol production. While the microbes fulfil their energy requirements from the biomass, the methanol energy requirement is fulfilled via a 500 MW windfarm in the simulation.

This energy requirement is 60% lower than competing CO2 hydrogenation technology for direct CO2 hydrogenated DME production (Figure 2). Compared to biomass gasification, the microbial process can be 30% more efficient, and is not impacted by impurities in the feedstock. Simulation results show that this 1.1 million ton rDME is enough to provide 3.5 TWh of power via solid oxide fuel cells [2].

In comparison, both South Australia and Tasmania's annual power demand stands at 11 TWh, each. These results demonstrate that even one microbial DME biorefinery has the capacity to significantly reduce emissions in Australian LPG, transport and power sectors.

The above figures underpin the importance of developing renewable feedstock based rDME production technologies that reduce energy demand and increase conversion efficiency [3]. As microbial rDME can be a hundred percent renewable, the CO2 is effectively locked-in, thus removed from the atmosphere as a part of an orycycling economy [4].

Technology Advantages

CO2 Removal Potential:

• There is global potential to annually eliminate millions of tons of new CO2 emissions using renewable DME.

• As all biomass itself is made from CO2, each commercial scale microbial rDME biorefinery, can potentially lock-in up to 1.5 million ton of CO2 via continual operation.

• Each production facility has the annual potential to sequester up to 1.5 million ton CO2 using current commercially available machinery. Further research, development and demonstration (RD&D) into this process and the associated technologies has the potential to further increase this capacity.

• While the CO2 sequestration is not permanent as the product is a fuel, it can still be considered removed from the atmosphere as long as the biorefinery is operational.

Compared to competing microbial processes:

• Unlike bioethanol biorefineries, the DME process does not consume food thus eliminates the food versus fuel issue. It consumes non-food and biowastes that are produced as a waste component of food crops. This also eliminates the issue of land-use as no food-growing land is earmarked to grow non-food crops for this process.

• Unlike bioethanol and biogas processes, the microbial rDME process does not emit CO2 •as a waste product.

• The microbe-based rDME process has the potential to be scaled up to 1 million ton of production using current commercial equipment.

• Preliminary techno-economic costing has already shown the process is commercially viable for Australia with potential to produces low-cost products [2]. This implies, the process may have better economics in developing countries with lower production costs.

• Naturally occurring microbes were specifically selected over genetic engineered ones to reduce any unknown potential risk to our environment in the future.

Compared to competing renewable rDME technologies:

• Microbial DME process is geolocation independent and can be placed anywhere with the availability of any biowaste such as crop waste, food waste, marine waste and so forth.

• There is no cost associated with CO2 utilisation as the process produces commercially viable products.

• Microbial DME process is a 30% more efficient compared to biomass gasification technologies.

• Microbial DME consumes 60% less energy compared to catalytic CO2 hydrogenation processes.

Preliminary techno-economics

Some preliminary costings were carried out as a part of a broader orycycle based industrial ecosystem [1] which showed the upfront cost for a half a million ton biorefinery at around Australian dollar (AUS$) 700 million in 2018. The operating cost was around AUS$ 200 million. As it was an industrial ecosystem simulation, multiple products were being generated.

This preliminary techno-economic study provides a good enough result to merit further investigation into this renewable DME as a potential replacement for liquid petroleum gas (LPG), methane and diesel, and enable 100% renewable energy grid by providing backup power to solar and wind farms.

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More information

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'Carpooling carbon': Net Zero Zones to boost climate action

A new report has revealed how Net Zero Zones could be created across Australia to bring together energy producers, emissions reduction technologies, manufacturing and industry to boost the net zero economy transformation.

The nine zones – based around existing resources, industrial and manufacturing regions – could be established with shared infrastructure for natural gas, renewables, CCUS technology and low-carbon hydrogen production.

The report found that the zones could cover 79 per cent of the 215 facilities captured by the Federal Government's Safeguard Mechanism and 92 per cent of their greenhouse gas emissions.

Possible zones could be located in Adelaide-Port Augusta and the Cooper Basin in South Australia; Perth and the Pilbara in WA; Melbourne-Gippsland in southern Victoria; Sydney-Newcastle in NSW; Brisbane and the Surat Basin as well as Central Queensland; and the planned Middle Arm Sustainable Development Precinct near Darwin.

The zone are conceptualised in "A Review of Net Zero Energy & Industrial Zones", an interim scoping study developed by the Australian Petroleum Production and Exploration Association (APPEA) with technical support from the Commonwealth Scientific and Industrial Research Organisation (CSIRO) to guide thinking and planning as part of the debate over how Australia reaches net zero.

APPEA will use the review's analysis as a foundation for discussions and engagement with governments, industry and stakeholders across the regions.

APPEA Chief Executive Samantha McCulloch said: "Net Zero Zones could help Australia accelerate to net zero and seize the economic opportunities of the energy transformation."

"In a way, it's like carpooling carbon emissions by working together to help achieve net zero in the fastest and most cost-efficient way for the economy."

"The zones could become magnets for regional investment and provide a framework for different industries to work together to speed up the path to net zero; reduce costs; create and protect jobs in manufacturing, mineral processing and industry; leverage existing infrastructure; provide a focal point for streamlined government approvals; and provide the foundation for net zero energy and industrial exports and imports."

"These zones would involve collaboration across different industries. It is about thinking wholistically about emissions reductions in these regions."

"Analysis confirms the important role of the gas industry and what it can contribute to the net zero challenge – cleaner energy and back up for renewable electricity while our infrastructure and expertise can help deliver step-change technologies such as CCUS and low-carbon hydrogen production."

"The report highlights that equipping these nine regions with natural gas supply, firmed renewable energy, CO2 transport and storage infrastructure, and low-carbon hydrogen would provide the building blocks necessary to reach net zero in the fastest, most cost-efficient way."

In other news, Ms McCulloch said the Federal Government's annual release of greenhouse gas storage acreage was a positive step in supporting the growing deployment of CCUS technology.

"Momentum is growing for carbon capture technology around the world, with places like the US and UK unveiling substantial incentives and programs to encourage investment," she said."

"Australia must seize the extraordinary opportunity before it – for emissions reductions and economic benefits given the chance to create a new industry and jobs in a cleaner energy future."

More information

www.appea.com.au

CSIRO report explores low-emission manufacturing in Northern Territory

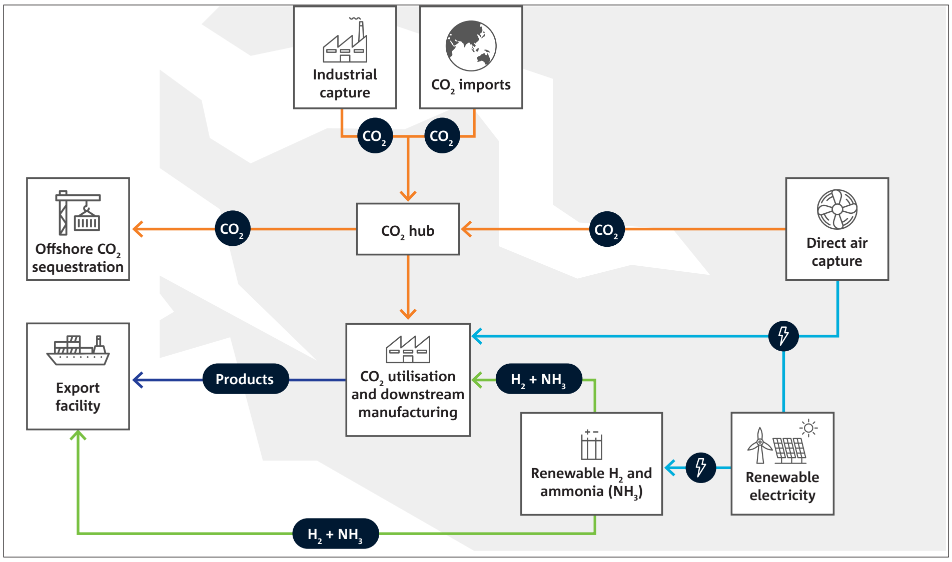
A new report from CSIRO, Australia's national science agency, has explored the potential for carbon capture and utilisation to support decarbonisation and economic growth in the Northern Territory.

CSIRO has delivered the "Opportunities for CO2 Utilisation in the Northern Territory" report to the NT Government and industry stakeholders to help inform the business case for a Northern Territory Low Emission Hub (NTLEH).

CSIRO scientist Dr Andrew Ross said CCUS was one of a number of critical pathways for the NT to reach net zero emissions by 2050.

"The proposed NT Low Emissions Hub could reduce existing emissions significantly by supporting the creation of new net-zero industries to continue beyond the energy transition," Dr Ross said.

"We identified five CO2 utilisation opportunities that could enable low-emission manufacturing and generate value for the NT's economy: methanol, jet fuel, urea, methane and mineral carbonates.



Long-term vision for Northern Territory CCUS hub (not to scale)

"The research examines the considerations and requirements of scaling up these opportunities over the short-to-long term to inform decision-making on the future hub," he said.

Techno-economic analysis conducted for the report found that CO2-derived products are currently more expensive than their conventionally-produced equivalents. However, all products have significant cost-reduction potential due to technological improvements, feedstock affordability, and economies of scale.

"In tandem, we need to continue exploring other emissions reduction alternatives at pace and at large scale, including geosequestration, if we are to meet Australia's net zero targets." Dr Ross said.

The report builds on CSIRO's 2021 CO2 Utilisation Roadmap.

The report found the NT's existing liquefied natural gas industry, export links with the Asia-Pacific region and high renewable electricity potential, position it well to create valuable CO2-derived products that can support emissions abatement objectives, particularly for 'hard-to-abate' industries such as the aviation sector.

Preliminary assessment identified five CO2 utilisation opportunities with potential for deployment in the Northern Territory.

• Methanol - CO2-derived methanol production could be a short-term opportunity for the NT because of its diversity in downstream uses and potential for hybrid production using renewable hydrogen and methane.

• Jet Fuel - The aviation industry has demonstrated interest in decarbonising via sustainable aviation fuels, including CO2-derived jet fuel.

• Urea - Renewable hydrogen and DAC-sourced CO2 could enable the production of renewable urea in the long term.

• Methane - CO2-derived methane could provide a low to zero-emission alternative to natural gas. Customers may be willing to pay a premium for CO2-derived methane where alternative solutions (such as hydrogen, ammonia, or electrification) are economically or technically unsuitable – especially when it is derived from DAC or recycled CO2. The NT would be well positioned to meet this demand due to its well-established LNG export and processing infrastructure and expertise.

• Mineral carbonates - CO2-derived mineral carbonates (such as mineral aggregates for building materials) can abate emissions and even create negative emission products. High-level analysis suggests that suitable mineral feedstocks, such as mafic/ultramafic rock formations, are present in the NT. However, waste from current mining operations is not expected to be suitable for carbonation. New mining projects may create opportunities for mineral carbonation in the NT.

More information

www.csiro.au

territorygas.nt.gov.au

deepC Store submits its CO2 supply specification to Australian Government

The company has submitted the CO2 supply specification for CStore1, dCS's floating CCS hub project, to the Australian Government to assist its review of the national "Action List" for the assessment of CO2 streams for sequestration as per the London Protocol.

The London Protocol obligates each Contracting Party to develop a national Action List to provide a mechanism for screening candidate wastes and their constituents on the basis of their potential effects on human health and the marine environment (noting the need of "the CO2 stream is of high purity, containing only incidental amounts of associated substances").

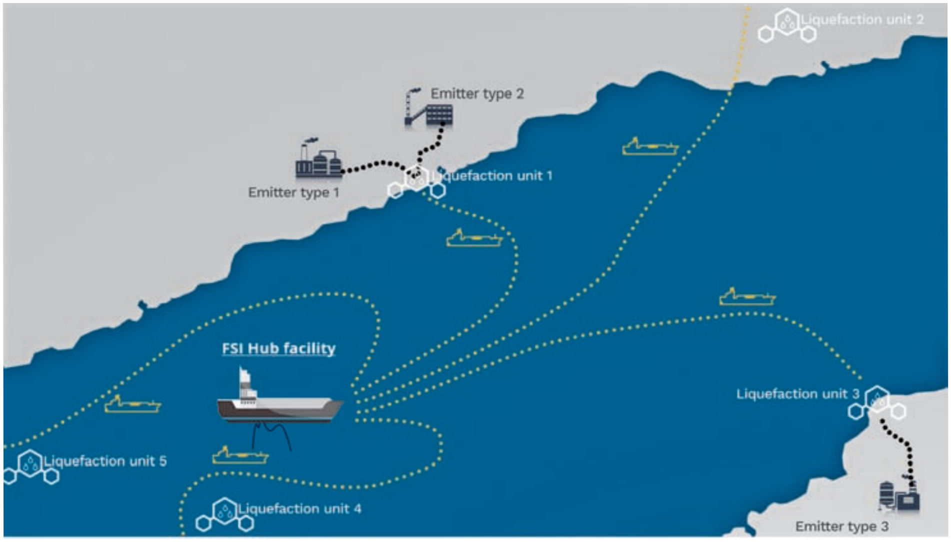
Daein Cha, Director of dCS, said, "We are pleased to publish our work with Pace CCS. The CO2 supply specification is one of the most important technical conditions to determine with our prospective CO2 suppliers. This ensures that no risk to downstream material integrity or other HSE risks are introduced to our CCS projects, and that we maximise flexibility such that cost of CO2 capture by the CO2 Suppliers is minimised. We trust that this information will assist other CCS project proponents to determine a pragmatic and robust CO2 supply specification for their projects."

dCS has co-developed its CO2 supply specification for CStore1 with Pace CCS, dCS's technical advisor. Upon finalising this CO2 supply specification, dCS and Pace CCS also sought input from dCS's industry partners and prospective CO2 suppliers.

Matt Healey, Managing Director of Pace CCS, said, "CStore1 is a world-leading project and we are delighted to share this specification publicly. All CCS projects must ensure integrity, while maximising uptime and allowing maximum flexibility for operations. We hope that this information is useful to regulators, and to other projects to find this balance."

Key takeaways from the CO2 supply specification for CStore1 are:

• dCS sets its CO2 supply specification for 2 potential delivery points for CO2 supply (one being pre-liquefaction of CO2, and the other being post-liquefaction of CO2).



CStore1, deepC Store's liquefied CO2 ship and offshore CCS Hub project. Image courtesy of Technip Energies

• The CO2 supply specification at pre-liquefaction consists of ≥ 95.0 mol% CO2, and a combined total ≤ 4 mol% of light ends (N2, H2, CH4, Ar, CO, C2H6).

• Regarding the CO2 supply specification at post-liquefaction:

- For the LP (approximately 7 bar, -49°C) and MP (approximately 19 bar, -25°C) shipping conditions, the liquefaction process will remove the majority of the light ends (N2, H2, CH4, Ar, CO, C2H6) and therefore the CO2 supply specification will be higher purity at shipping conditions.

- For the HP shipping condition (approximately 75 bar, 10°C), the light ends remain soluble in the liquefied CO2 and therefore the CO2 supply specification will remain the same as that for the battery limit at pre-liquefaction.

• Upon developing the CO2 specification, dCS and Pace CCS considered a wide range of potential CO2 supply sources. These include iron & steel furnaces, traditional fossil fuel power plants, biomass power plants and waste incinerators, refinery stack, cement plants & kilns, lime production, ammonia production, and carbon capture Direct from Air (DAC).

• Each industry has a different set of non-CO2 components associated with its CO2, with this range of non-CO2 components considered in the development of the CStore1 CO2 specification. dCS notes that:

- dCS will apply its CO2 supply specification to all CO2 suppliers. dCS does not plan on setting specific / different CO2 supply specification for each CO2 supplier.

- For CO2 supply that deviates from the CO2 supply specification for CStore1, dCS highlights the need for an assessment to be performed for evaluating any potential risks to CStore1.

More information
www.paceccs.com

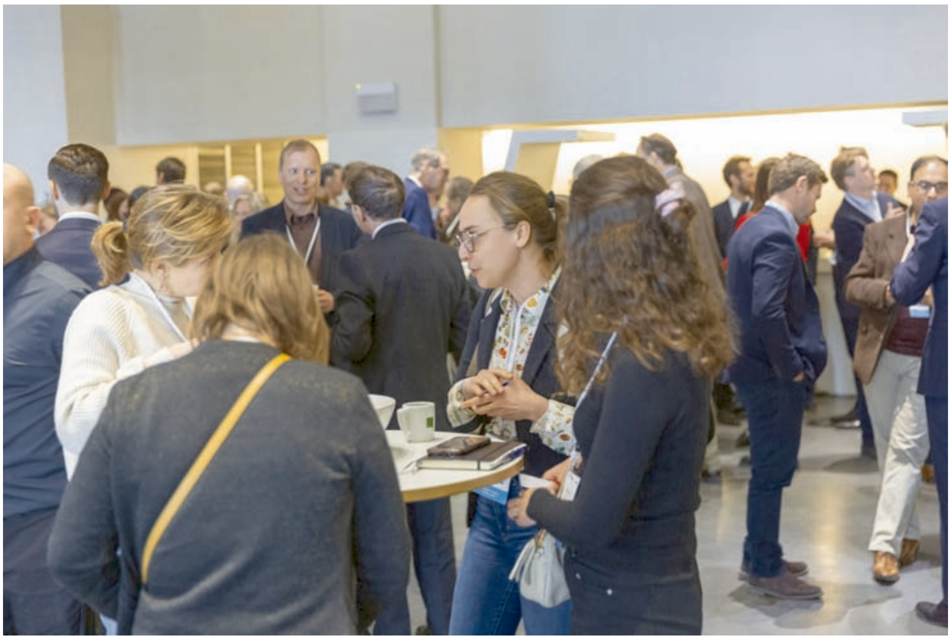
CCS – the government perspective around Europe

We heard updates on government perspectives around Europe at the ZEP forum in Brussels, including from the European Union, Norway, UK, Switzerland. The "Clean Energy Ministerial" gave updates on Japan, Nigeria, Canada. By Karl jeffery.

The European Commission's modelling shows that the European Union will need to capture and store / utilise between 300 and 640 million tonnes of carbon dioxide (CO2) every year (mtpa) by 2050 if it wants to meet its climate neutrality goal, said Eve Tamme, chair of Zero Emissions Platform (ZEP), an organisation which advises the European Union on deployment of CCS.

The European Commission put forward a "Green Deal Industrial Plan" in February 2023 and announced a "Net Zero Industry Act" in March 2023. This sets a goal for storing 50 mtpa in the EU by 2030, she said. There is also a target to capture 600 mtpa by 2050.

There have been predictions that there will be 80m mtpa sequestered by 2030 and 300 mtpa sequestered by 2040.



The Carbon Capture and Storage Association's forum in Brussels heard updates on policy, projects and financing in Europe and around the world

The approach to carbon capture in Europe has "changed quite significantly", said Chris Bolesta, CCUS policy team leader with the Directorate-General for Energy (DG ENER) at the European Commission. The focus has moved away from coal generation, and the focus has also moved away from 'one point to one sink'.

The ambitious targets need to be reached from a starting point of capturing "basically zero" today, he said.

Mr Bolesta sees the biggest challenge being the chicken-and-egg problem of no-one investing in storage if there's no-one with CO2 to store in it, and no-one investing in capture when there's no-where to store it.

The problem can be solved if there are ways to give investors in capture systems more certainty that storage will be there when they need it.

People providing storage could be given re-assurance that they can operate profitably if governments would agree to 'contracts for difference', he said. This means government will cover the difference between what the market will pay at any time, and a rate required to be profitable.

The EU also needs better ways to measure CO2 and track where it is going, he said. The lack of CO2 infrastructure across Europe "is also a problem."

There will be new elections for the European Parliament expected in June 2024, bringing in a new 'college' of parliamentarians.

"I'm convinced the next 'college' will see CCS as an important part," he said. They should recognise that the more we do today to address climate matters, the less we will need to do in future – like brushing your teeth today to avoid future dental problems, he said.

The EU is making more efforts to find out what its member states are doing. "It is time for states to communicate to us about their relationship with CCS," he said.

Mr Bolesta added that he would like to see a connection between EU and UK emission trading schemes. Once Brexit negotiations are finished, it should be the next problem in line to solve, he said.

There were questions about whether the European Union could store CO2 in locations outside Europe, such as in North Africa.

"We haven't yet seen proposals for storage in North Africa, but it would have to be ensured there is alignment with regulatory and safety standards," said Joachim Balke, head of infrastructure and regional co-operation unit, DG ENER, European Commission.

The new EU strategy

When putting together the European Union's "Green Deal, "we know we had to do a lot with the energy system," said Ruud Kempener, member of the cabinet of EU energy commissioner Kadri Simson, who takes responsibility for CCS in the European Union.

"This has become open heart surgery with the energy crisis. We have to put those elements into place while keeping the patient alive."

Mr Kempener has a PhD in chemical engineering from the University of Sydney. From October 2003 he was a researcher at Eindhoven University of Technology according to his LinkedIn page.

The European Commission plans to lay out a new strategy by the end of 2023 on CCS. It will issue a "call for evidence" very shortly, asking questions from organisations involved in the sector.

There will be questions about how to make CO2 storage more accessible, and how to regulate CO2 transport infrastructure. For example, it will consider the question of whether to regulate CO2 infrastructure similarly to gas infrastructure, which takes gas to "nearly every home in Europe," or regulated more like hydrogen, which is transported more in containers than pipelines.

Another question is the best way to organise and facilitate engagement with the public. "I think the social acceptance part of this story is important," he said.

"My commissioner really wants to get this right so your feedback will be highly appreciated."

One of the inhibitions to public acceptance with CCUS, compared to say renewables, is that it is still new for the public. "We don't have lots of projects [where local] citizens have experience in the region," he said. People can tend to form opinions once they see construction taking place.

Public perception can be unpredictable. Mr Kempener said he was once involved in seeking public support for a CO2 storage project in the South of the Netherlands, in a town where people are very proud of their mining heritage, and the football club call themselves "The Miners" (in Dutch). But they did not support CO2 storage in the mine shafts.

Norway perspective

In October 2022, Norway offered a CO2 storage permit to Wintershall Dea Norway AS and CapeOmega AS.

In March 2023, a CO2 storage licence was offered to a group consisting of Aker BP ASA and OMV (Norge) AS. A further licence was offered to a group consisting of Wintershall Dea Norge AS and Altera Infrastructure Group, through its subsidiary Stella Maris CCS AS.

A project is being planned to make ammonia directly from gas with carbon capture in the Barents Sea.

Norway is seeing "considerable interest in storage acreage in the North Sea", said William Christensen, deputy director general, Norwegian Ministry of Petroleum and Energy.

The Norwegian government is working to arrange bilateral agreements on CCS transport with other governments, to bypass the London Convention and Protocol. This states that 'waste products', including CO2, cannot be 'dumped' at sea. It has made such an agreement with Sweden, he said.

For these bilateral agreements to work, it is "important to have clarity of obligations, particularly reporting and accounting," he said. The bilateral agreements created by Norway could be a template other countries could use.

The Norwegian government is keen to get this established quickly, to give security for [its first project] Longship, he said.

The capture site for the Brevik cement plant is "over 50 per cent finished," and should be in operation in 2025, he said. This is part of Longship.

From left to right: Chris Bolesta, CCUS policy team leader with the Directorate-General for Energy, William Christensen, deputy director general, Norwegian Ministry of Petroleum and Energy, Juho Lipponen, co-ordinator of the Clean Energy Ministerial CCUS Initiative

The European Union has an Implementation Working Group (IWG) on CCS and CCU, established in 2017, to monitor progress on CCS and help advance activities to achieve the targets, he said.

Participants are Czech Republic, Germany, France, Hungary, Italy, Spain, Sweden, Turkey, Netherlands, Norway, and United Kingdom. It is chaired by Norway, Netherlands, and ZEP. The goal is 50 mtpa abated by 2030, across all participants.

UK

The UK government is talking about the country having 78 billion tonnes of CO2 storage potential, said Jonathan Briggs, chair of CCSA, and director of the Humber Zero project.

To put that number in context, the UK's Committee for Climate change set a target of 176 mtpa stored by 2050. This would fill 78bn tonnes of space in 440 years.

But UK could sell its storage space to other countries. Seeing CO2 storage as a potential 'export' can be a way to build public and political support for it, he said.

The UK is supporting the development of its CCS industry around clusters, with clusters already established in North East and North West England, Scotland, the South Coast and Wales. "If [UK] can't find a way of decarbonising the clusters you have no hope of getting to net zero by 2050," he said.

Public acceptance in the UK is perhaps easier than in some European countries because CO2 is only being stored offshore, "out of sight, out of mind". The US also has a totally different reaction to CO2 storage, he said.

The UK also has an ambition to decarbonise its electrical grid by 2035, he said.

One argument politicians can make is that CCS is a necessity not an option, if we are to reach net zero, because renewables can never supply all our electricity. For example, in the UK, gas power is increasingly a "demand response mechanism," when power plants are built so they can stand by and come in at peak times, he said.

In 2016, the UK government suddenly cancelled $1bn of funding that had been promised to the winner of a CCS competition. This has driven some scepticism in the UK that the government funding may be pulled again, said Olivia Powis, head of the UK office of CCSA.

The main difference this time is that the UK's climate ambitions have been signed into law, under the Climate Change Act of 2019, she said.

The UK has not sequestered any CO2 yet. So far the UK has proven "very good at ambition and strategy," she said, steadily increasing its targets. "We have to move to delivery and deployment".

A second difference in the UK this time around is the government's approach to funding clusters and projects within the clusters, rather than 'point-to-sink' projects, she said.

The UK's CO2 transport and storage infrastructure will become "regulated assets", like the electricity grid, with regulations about pricing and access. This will ensure that every company can have access to it at a fair price, while it can still be built and operated by private companies, she said.

Switzerland

Switzerland has a plan to reduce its CO2 emissions nationally to 12 mtpa by 2050, of which 7 mtpa will be emitted by industry and 5 mtpa emitted by agriculture, said Veronika Elgart, head of bilateral climate agreements, Swiss Federal Office for the Environment

Jonathan Briggs, chair of CCSA, and director of the Humber Zero project and Eve Tamme, chair of Zero Emissions Platform

To be net zero, this would be balanced by 5 mtpa CCS, 2 mtpa bioenergy with CCS (BECCS), and 5 mtpa of direct air capture. The CO2 sequestration is likely to be outside Switzerland, she said.

A project is exploring the transport of biogenic CO2 to Iceland for storage there. It has the name DemoUpCARMA (Demonstration and Upscaling of CARbon dioxide MAnagement solutions for a net-zero Switzerland).

The Swiss waste plant association is obliged to capture 100,000 tonnes CO2 by 2030, she said.

A stumbling block overall is the lack of recognition of 'removal credits' in legal frameworks, she said.

Ministerial meetings

The "Clean Energy Ministerial CCUS Initiative" is a group of 30 countries around the world, who send the national leaders of CCUS programmes to meet once a month to discuss CCUS policy development.

It is led by Norway, UK, US, and Saudi Arabia. Other members are Australia, Canada, Mexico, Netherlands, Nigeria, South Africa, UAE, China, and Japan. The European Commission is an 'observer'.

The group also co-ordinate involvement of CCUS in international programs such as G20, said Juho Lipponen, who co-ordinates the group. The G20 is hosted in India in 2023, and in Brazil in 2024.

It has been described as a "mutual psychotherapy group for CCUS project management," people who maintain each other's spirits after they have found that politics gets in the way of CCUS projects in their country, he joked.

There are connections with banks, the Oil and Gas Climate Initiative, and the Global Cement and Concrete Association. "Global times have never been this good for CCUS but we're not there yet," he said.

Japan is starting to get engaged, talking about 120 to 240m tonnes CO2 stored a year by 2050. ADNOC wants to store 5m tonnes a year by 2030 in the United Arab Emirates. Nigeria is looking at industrial CCS, starting with cement, working with the International Finance Corporation, part of the World Bank.

Canada has announced an investment tax credit system, with 60 per cent investment tax credit for direct air capture projects, 50 per cent tax credits for investment for post combustion CCS projects, 37.5 per cent for investment in transport, storage, and utilisation. It runs from 2022 to 2030.

In the US, consultants are forecasting 85 to 170m tonnes CO2 captured by 2030, helped along by tax credits in the Inflation Reduction Act, he said.

More information

www.zeroemissionsplatform.eu

Developments with projects and companies in Europe

An update on Norway's Northern Lights project including the energy from waste emissions; Porthos in the Netherlands; and perspectives from Heidelberg and Norske Hydro. By Karl Jeffery.

Phase 1 of Norway's Northern Lights project, with 1.5 mtpa storage, will be operational in 2024. The 50 km pipeline has been laid. "The whole project is 80 per cent ready," said Martijn Smit, business development director of Northern Lights.

Phase 2 will expand to 5.2 mtpa. It should have a final investment decision in 2023. But it "needs emitters to sign up," he said. If that happens, it will be operational in 2026. For phase 3, more technical work is needed, he said.

There have been complex negotiations to make with customers, on matters such as how the customers prove they are delivering CO2 at the required specification. Also, how compensation would be paid if Northern Lights is unable to accept CO2 for whatever reason, and so the CO2 is instead emitted to the atmosphere, and the emitter must pay for ETS allowances.

During the discussion, Northern Lights may have gone too far in trying to "move some risks to emitters," he admitted. "It didn't go down very well. We turned that one around and recognised which risks we should take as Northern lights. We are trying to bridge affordability and profitability."

There are still price challenges, including "underestimation of cost by emitters," he said.

One audience member pointed out that Northern Lights is, in theory, a "perfect project", with government funding and government even getting involved in negotiation. Yet it still has problems.

"The key players are doing everything they can do," Mr Smit replied. "There needs to be more trust. We need signatures on paper. Less lawyers and more business people in the room (may help)."

One reason for the reluctance by emitting companies to sign up may be that they think there may be a better option in the future. "The boardroom reality [is that] they can only invest money once," he said.

Haflsund Oslo Celsio

The CCS project at Oslo energy-from-waste operator Hafslund Oslo Celsio has been put on hold due to escalating costs, said Jannicke Gerner Bjerkås, director of CCS projects with Hafslund Oslo Celsio.

It had planned to be one of the two founding projects to connect to Norway's Northern Lights project, capturing 0.4 mtpa. (The other founding project, Heidelberg's Brevik cement plant, is still going ahead).

Construction of the CO2 capture facility did start in Autumn 2022. But there were problems with price inflation, including from power price increases, and the decline in value of the Norwegian Krona.

The project team found they needed more staff. The construction contractor said it needed more land. The Port of Oslo changed the location of the planned berth for CO2 ships, she said.

Another problem is that power demand in Oslo has increased, due to growth in electric cars. A new power transformer will need to be constructed. But the power capacity may not be available when it is needed to run the carbon capture plant. This added further to the uncertainty.

And it is still cheaper to put waste in landfill, than incinerate it and capture the CO2, she said.

Porthos, Netherlands

At the time of the event (April 2023), the Netherlands Porthos CCS project was awaiting a court decision relating to nitrogen emissions, expected in summer 2023.

The problem is regulations in the Netherlands regarding nitrogen emissions, stating that nitrogen emissions cannot be increased anywhere unless there is a matching decline in emissions elsewhere.

Northern Lights Phase 1 "80% ready" and operational in 2024 - Martijn Smit, business development director of Northern Lights

The nitrogen emission from Porthos would be from construction vehicles, not from the actual operation. These emissions have been estimated to be like that from six cows.

"Everybody in government understands the importance of a positive decision and will do everything in their power [to achieve it]," said Stijn Santen, senior business advisor CCS, EBN, which is one of three partners in the Porthos project. "In summer it will be concluded," he predicted.

The project plans to store 2.5 mtpa, and be operational in 2026, if the final investment decision can be made in 2023.

EBN is one of four partners in another CO2 transport and storage project, ARAMIS, along with TotalEnergies, Shell, and Nederlandse Gasunie. "We've also been looking at saline aquifer storage," he said. "We think we need to develop this and not purely rely on depleted gas fields."

Heidelberg Materials

Heidelberg Materials (formerly Heidelberg Cement) is involved in many different CCS projects at various stages of development, including in Norway, Eastern Europe, Germany, Sweden, Bulgaria, Morocco, Belgium, UK, US, and Canada, said Jan Theulen, director technologies and partnerships.

It can see a big range in the total cost of projects, from Euro 130 to Euro 200 a tonne for the full CCS chain. The big factor making a difference is the transport from emission site to storage site, he said.

The Euro 130 / tonne project has 40km onshore transport and 30km offshore, both by pipeline; the Euro 200 / tonne project involves 200km rail transport, 1000km ship transport, and 100km pipeline, he said.

Mr Theulen noted that the funding on offer by the European Union for carbon capture projects, Euro 1bn, is very low, compared to the £20bn offered by the UK government, Euro 1.1bn offered by Denmark, and Euro 2.1bn offered by the Netherlands.

The EU's Euro 1bn could help fund "4-6 serious projects", he said. But there are 98 project proposals in the EU, of which 50 could be described as viable, able to deliver CO2 storage by 2030. So about 45 projects "will have to wait".

This may not be a good economic decision, on the basis that these projects could be profitable in 2030, due to a much higher carbon price expected at that time, as free ETS allowances are taken out of the system, he said.

To illustrate, Europe's cement industry is already forecasting to have to spend Euro 5bn by 2030 on emission credits if it does not have CCS, he said.

This money could instead be spent on decarbonising the cement industry with carbon capture projects.

But some assistance would be needed making the transfer from investment today to savings in 2030, and the European Union could provide this assistance, he said.

Left to right: Nils Anders Røkke of SINTEF; Niall MacDowell of Imperial College; Jan Theulen of Heidelberg; Liv Rathe of Norske Hydro

Norske Hydro

The EU's net zero ambitions mean it will potentially send its aluminium manufacturing to other parts of the world, said Liv Rathe, director, climate office, Norsk Hydro, the largest aluminium company in Europe.

Norske Hydro already has the lowest CO2 footprint per tonne aluminium in the world. But it is also the "producer most exposed to CO2 costs," she said.

The problem is that while CO2 emissions can be reduced, they cannot be eliminated. And emission trading scheme (ETS) allowances are forecast to run out by 2039. That effectively means companies are no longer allowed to emit at all.

Even if it does CCS on all its emission streams, there will still be CO2 emissions because carbon capture does not capture 100%

There is no gain to the environment if EU's aluminium manufacturing capacity is just replaced by imports, and this is effectively what has started happening, she said.

The US, in contrast, gives companies rewards for sequestering CO2 in the form of tax credits, but does not impose costs on emissions. In other words, "they have a carrot but no sticks," she said. The US is pursuing a simple goal of getting low carbon activities to a big scale at low cost.

And in the US you do not need to compete with anyone else for the tax credit, while in Europe you are in competition for other companies for government funding. European funding typically goes to companies who have the lowest cost of decarbonisation, so aluminium producers are at the back of the queue, she said.

Europeans are also too afraid of the World Trade Organisation, which leads to reluctance to make rules requiring local content. "The US doesn't care about the WTO," she asserted.

Meanwhile, aluminium is needed as part of the energy transition, for making solar panels. Meeting EU's solar PV targets would need 4 million tonnes (MT) aluminium in 2025, and 10 MT in 2030. "Aluminium needs support as a component to net zero technologies," she said.

On the question of whether customers may pay more for a lower carbon product, Ms Rathe said the richer part of the market may be willing to pay more, as we see in the car market. "But not the whole market," she said. And around the world, so far it is "mostly Europe" that is willing to pay more.

Holcim

A representative of cement manufacturer Holcim said that the company can only consider CCU projects today based on what it knows for sure today, and there is only one operator able to provide a price for CO2 storage today, which is Northern Lights.

"You are asking us to behave on the basis of a hypothetical future," he said. It would be helpful if the European Commission could "incentivise operators to come up with projects faster."

More information

www.zeroemissionsplatform.eu

CO2 storage, transport, and public perception

The ZEP event in Brussels shared news about CO2 storage projects in Europe. There was a European Commission perspective, news on Equinor plans, transport costs, CO2 infrastructure and technical challenges with networks. By Karl Jeffery.

The European Commission recognises that Europe needs more CO2 storage sites. "There is not an abundance of storage sites to say the least," said Daniel Kitscha, investment policy officer with The Directorate-General for Climate Action (DG CLIMA) at the European Commission.

There are storage sites identified which could store 72 mtpa in the European Economic Area (EU plus Iceland, Liechtenstein, and Norway). But 37 mtpa of this is in Norway – only 35 mtpa is in the European Union, mainly Denmark and the Netherlands.

There are 12 storage operator companies across Norway, Denmark, and the Netherlands, all storing in the North Sea, and most of the projects have not yet reached final investment decisions, he said.

Mr Kitscha recognises that the oil and gas industry is in a very good position to find more storage sites, he said. One policy idea is that companies that produce oil and gas in EU will be obliged under regulations to contribute their own sites or competitors' sites, he said.

Equinor

Equinor secured a CO2 storage license for its Smeaheia CO2 storage in the North Sea, and the Polaris CO2 storage in the Barents Sea, in April 2022.

It is also a co-owner of the Northern Lights project (together with Shell and TotalEnergies) and has been storing CO2 for many years in its Sleipner and Snøvhit fields.

The company sees CO2 storage as an investment opportunity, said Torbjørg Klara Fossum, VP global CCS solutions, Equinor.

Having data from oil and gas exploration is very helpful, but more data is needed, she said.

For Smeaheia, there will be two exploration wells drilled in 2024, to gather data to help better understand the storage opportunity, to 'de-risk', she said.

Plans have been submitted to develop the storage capacity to 20 mtpa. The first phase will be 5 mtpa, and then the plan is for capacity to gradually increase.

The Smeaheia project is expected to include some kind of "shipping solution", like Northern Lights, where the CO2 is shipped to an onshore terminal which has a pipeline connection to the storage site.

A CO2 pipeline is being considered connecting to Germany (Wilhelmshaven) and Belgium (Zeebrugge). CO2 emitters along the North Europe coast could send CO2 by ship to Wilhelmshaven.

If the pipelines can be filled, that "can get the cost down by 50 per cent," she said.

If the CO2 pipelines can be filled, costs can get down by 50% - Torbjørg Klara Fossum, VP global CCS solutions, Equinor

Viking CCS

Viking CCS is a CCS project with storage in a former oilfield in the "Viking" area of the UK's Southern North Sea. Storage capacity is 300 MT. It is part of the Humber Cluster, which has UK government funding.

The CO2 storage site already has a 36-inch pipeline connecting it to the shore, formerly used for bringing in gas. The pipeline could carry 30 mtpa CO2, said project director Graeme Davis.

It will be possible to accept CO2 delivered by ship, with vessels discharging at a new jetty in the Port of Immingham, which can take very large gas carrier vessels.

For now, the key project constraint is not knowing when CO2 will be made available for the storage site, Mr Davis said.

In future, it will be possible to expand CO2 injection capacity by drilling more wells. This is analogous to how oil and gas companies increase production by drilling more wells, he said.

Europe T and S costs

The Clean Air Task Force, an environmental organisation, has mapped out the costs of CO2 transport and storage from all locations in Europe, said Eadbhard Pernot, policy manager carbon capture, Clean Air Task Force.

The study can be seen on a map at https://www.catf.us/2023/02/mapping-cost-carbon-capture-storage-europe/. It is based on planned storage sites only, and on the basis that the emitter has access to existing rail, pipeline, river barge or sea going ship.

Industrial facilities for the cement and lime industry are often placed close to quarries to get the best access to limestone, but this means that they are not necessarily near the sea. "It makes CO2 transport more expensive," he said.

Fluxys – CO2 infrastructure

Natural gas pipeline operator Fluxys, based in Belgium, has a design for a CO2 network connecting Zeebrugge, Antwerp, Liege, Charleroi in Belgium, explained Leentje Vanhamme, transformation and sustainability director, Fluxys.

The network can include a CO2 terminal in Zeebrugge connecting to storage in Norway. There could be further land connections to Germany, Netherlands, Luxembourg, and France.

There could also be marine terminals in Antwerp and Ghent for incoming CO2 from vessels. A decision to build a terminal in Antwerp could be made this year, to start commercial operations in 2026, she said. And a decision for a terminal in Ghent could be made in 2025, for commercial operations in 2027.

However, building the infrastructure would probably rely on government funding to be viable initially, she said.

CO2 transport specifications

The need for detailed specifications for CO2 is a factor commonly overlooked when planning CO2 transport networks, said Roland Span, chair of thermodynamics in the Institute of Thermodynamics and Fluid Dynamics, Ruhr Universität Bochum.

The need for standards for CO2 purity and pressure is well understood, if you have a network which multiple companies are injecting CO2 into. But there may also need to be separate specifications for the normal gas phase, higher pressure gas phase, cryogenic liquid, and CO2 in buffer storage.

And the 'dense phase' specifications can be different for CO2 in pipelines, train, or truck.

People feel CO2 storage is a "known technology," but there is much which has not been considered in detail yet, he said.

Consider if you have two batches of CO2, one with 1 per cent nitrogen and another with 0.05 per cent nitrogen. The different batches will have different properties, including density, at different temperatures.

So if you mix them together in a tank, there can be complex flows, as the batches change density as they change temperature at different rates, he said.

Public perception in Denmark

Jacob Ladenburg, professor in the Department of Technology, Management and Economics at the Technical University of Denmark (DTU) has conducted a survey about public views on CCS, with 3900 responses.

People were asked to what extent Denmark should use CCS technology in different locations: onshore urban, onshore rural, nearshore, offshore. Some people were presented with CCS in different ways, being told that it is "not a new technology in Denmark" or that the technology has been "used abroad for 40 years".

The results show, as might be expected, that people want to live as far from a CCS storage site as possible. There were some differences to results based on the information provided, but not linking to any clear conclusion as to what information would do most to persuade people.

The detailed survey response analysis can be found online if you search for "Jacob Ladenburg acceptance of CCS".

More information
www.zeroemissionsplatform.eu

Accelerating CCS in the ARRRA-cluster

Ariane Giraneza, Climate Policy Manager at Industrial Decarbonisation NL-BE-NRW, sheds light on her instrumental work and role in decarbonising heavy industry in the ARRRA-cluster (or Antwerp, Rotterdam, Rhine, Rhur Area). www.bellona.org

There is no doubt that this year will be crucial for the development of CO2 transport and storage infrastructure in the industrial cluster spanning the Netherlands, Belgium, and North Rhine-Westphalia. Bellona's Climate Policy Manager responsible for the region, Ariane Giraneza, took the time as part of Bellona's ongoing CCS Campaign #CCS4NetZeroIndustry to outline recent updates, challenges and opportunities for the ARRRA-cluster for the months ahead.

As projects move from planning to deployment, in part with the aid of EU funds, policy support at the European level is crucial. Firstly, to further de-risk investments in CCS, and secondly to ensure that the deployment of CO2 transport and storage infrastructure happens in a coordinated way across the borders in the region.

The 50 Mtpa injection capacity target for CO2 in the Net-Zero Industry Act already sends a strong signal to the market on the importance of CCS deployment to facilitate industrial decarbonisation and the EU's commitment and real action to reach this aim.

However, in order to accelerate the development in the ARRRA cluster, the EU will have to also publish their Strategic Vision on CCUS to provide the necessary guidance for Member states and ensure consistency is maintained on CCS deployment in the EU.

These are crucial steps to further the development of the ARRRA-cluster, spanning three EU Member States, with different particular challenges and opportunities .

Decarbonising Europe's industry is crucial to achieve the goal of becoming the first climate neutral continent on earth. The ARRRA-cluster offers great opportunities to showcase the effective provision and use of interregional climate technologies and infrastructures for the decarbonisation of heavy industry. But to achieve this, the EU must now capitalise on present momentum and take the lead on developing a framework for CCS that avoids windfalls and maximises climate outcomes.

Advanced Materials for CO2 Capture and Separation

The report from the Carbon Dioxide Capture and Conversion (CO2CC) Program evaluates and discusses recent developments related to the challenges and use of CO2 capture technologies, in particular the absorption using liquid solvents, adsorption using solid adsorbents, and advanced membrane-based CO2 separation.

The report covers materials development, reaction mechanisms, the optimization of process parameters, reactor design, system integration, economic performance, the innovative configuration of system units as well as other CO2 capture technologies including oxyfuel combustion, chemical looping, direct air capture (DAC) and cryogenic carbon capture.

The objectives of the report include:

• Review the modification of solvents for CO2 absorption and address the challenges of the current use of solvents.

• Provide recent development in terms of the optimization of process parameters including temperature, CO2 concentration, pressure, and flow rate.

• Report current development of reactor design and improvement for CO2 absorption and adsorption.

• Provide recent technology developments for membrane-based CO2 capture related to the development of new membranes.

• Report recent developments on other CO2 capture technologies including pre-combustion CO2 capture (e.g., sorption enhanced H2 production), oxyfuel combustion, chemical looping, and cryogenic carbon capture.

The report begins with a background discussion of issues relating to climate change and CCUS for decarbonisation of energy and industrial sectors, noting some recent policy achievements.

Chapter 2 covers ‘Materials for Post-combustion and Pre-combustion CO2 Capture’, discussing different solvents including strong and weak alkaline as well as aqueous amine solutions. This chapter also includes an economic analysis, which highlights the different measures of carbon capture cost.

Key takeaways from the report

• Catalyst development for hydrogen production is a key challenge for pre-combustion CO2 capture. To overcome high temperature requirements for hydrogen production, non-thermal plasma-assisted processes could be interesting, as it also favours hydrogen production from a thermodynamics perspective.

• Another key future research area for pre-combustion CO2 capture can be related to dual or multifunctional materials development. The dual functional materials could capture CO2 and convert the captured CO2 simultaneously during the regeneration of materials. This technology can reduce the energy requirement, intensify CO2 capture and utilisation, and thus reduce the overall process costs.

• Silica-based materials are promising for CO2 capture due to their controllable pore structure and high thermal stability. These materials show interesting results related to the influence of water, which is normally undesirable. The presence of water during material preparation could enhance the polymerization of SBA-15 sorbents and amine loading.

• Porous carbon is another type of solid adsorbent for CO2 capture. Excellent CO2 capture capacity could be achieved ascribed to high surface area, crystallinity, and high micro- and mesopore volumes, when a novel graphitization method was applied through activation using potassium acetate and iron acetate with simultaneous graphitization.

• For a higher CO2 recovery, a multi-stage cascade design is mandatory. Enriching and stripping cascades are both suitable for 90% CO2 recovery, provided that sophisticated recycling streams are designed in the processes to enhance the CO2 flux. In order to achieve a >95% CO2 purity, a CO2/N2 selectivity greater than 50 is needed to make the process feasible.

• The addition of amine groups to solid adsorbents has been proven to enhance CO2 capture capacity and lower regeneration energy. However, the stability of amine grafted sorbents needs to be further studied, related to the leaching and evaporation of amine groups.

Chapter 3 covers ‘Materials for CO2 Capture by Adsorption Methods’ and introduces the different and common adsorbents that exist in the field. The chapter covers mesoporous, MgO-, CaO- and biochar-based materials as well as metal organic frameworks (MOFs).

Chapter 4 covers ‘Materials for CO2 Separation by Membrane Technology’ and discusses CO2/N2 separation from flue gases, CO2/H2 separation in syngas processing, and CO2/CH4 separation in natural gas and biogas sweetening. An overview of current pilot plant results is also included.

Chapter 5 covers ‘Other CO2 Capture and Separation Technologies,’ including discussions on oxy-fuel combustion carbon capture, chemical looping, DAC, and cryogenic carbon capture.

Next articles

This is a series of articles summarising recent key reports from The Catalyst Group Resources Carbon Dioxide Capture and Conversion (CO2CC) Program. Look out for “CO2 Reduction via Biomass Conversion in Energy and Chemicals” in the next issue.

More information

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

www.catalystgrp.com/tcg-resources/member-programs/co2-capture-conversion-co2cc-program/

Achieving emissions reduction targets in the iron and steel industry using CCUS

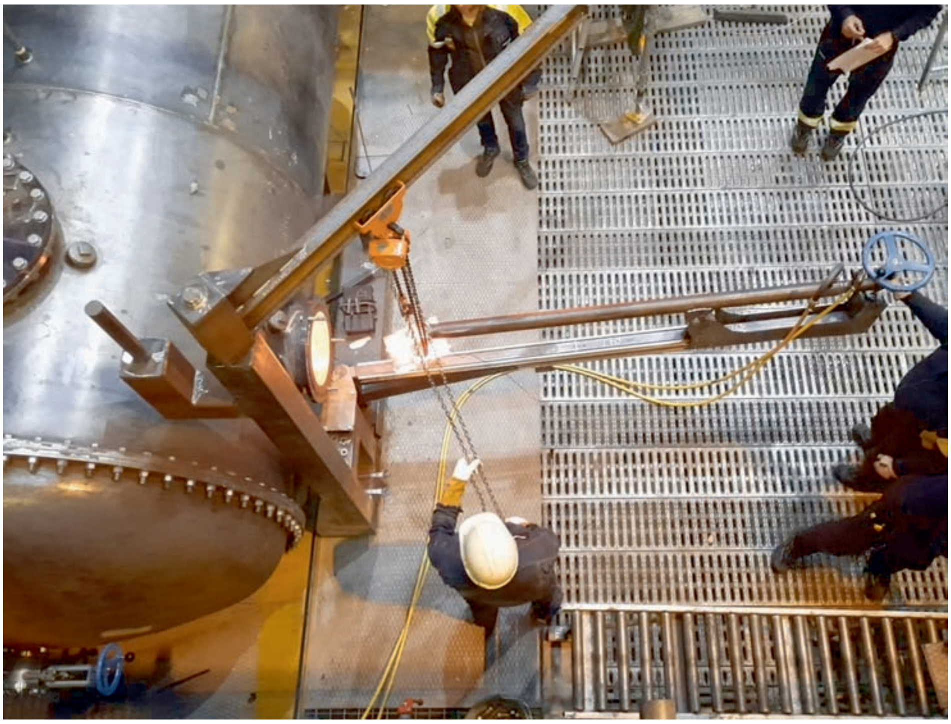
The EU-funded research and innovation project called C4U (Advanced Carbon Capture for steel industries integrated in CCUS Clusters) tackles some of the key challenges of deploying the technologies in the iron and steel industry at commercial scale.

The iron and steel industry is responsible for 7-9% of global greenhouse gas emissions. According to the International Energy Agency (IEA), the sector is currently off-track to reach net-zero emissions by 2050.[1] This means it needs to accelerate efforts to reduce its carbon footprint and scale up both proven and developing decarbonisation technologies.

As one of these key technologies, recognised by both the Intergovernmental Panel on Climate Change and the IEA, CCUS is essential for achieving the Paris Agreement ambitions, particularly in curtailing CO2 emissions from the main energy intensive industries such as iron and steel production. Policymakers and investors have become increasingly confident about the prospects of CCUS with project developers announcing ambitions for over 200 new CCUS facilities worldwide by 2030 according to the IEA[2] and the technology is improving.

The EU-funded research and innovation project called C4U (Advanced Carbon Capture for steel industries integrated in CCUS Clusters) tackles some of the key challenges of deploying the technologies in the iron and steel industry at commercial scale. This is done by advancing processes to make them more cost and energy efficient, and identifying optimal industrial integration solutions while analysing the economic, environmental and business impacts.

The combined use of the C4U technologies can tackle up to 94% of the sources of CO2 in a steel mill, resulting in an overall CO2 emission reduction of 89%. The project is also developing and testing approaches with stakeholders and businesses to assess and advance societal readiness for CCUS. A team led by Professor Haroun Mahgerefteh of University College London's Department of Chemical Engineering coordinates the project.



At a pilot facility in Luleå, Sweden, C4U project partners TNO and Swerim demonstrated reheating of steel products with carbon-free hydrogen

CCUS and hydrogen in the steel industry

There is no one-size-fits-all solution for decarbonising the iron and steel sector and a mixture of technologies are likely to be needed in the future. CCUS offers certain advantages – it can be retrofitted to existing industrial plants and offers new ways of integrating iron and steel production with other industries by using co-products of the CO2 capture process.

Recent research[3] has shown that in the absence of large amounts of renewable electricity being made available to the iron and steel sector, CCUS offers the most energy efficient way to reduce the CO2 emissions. CCUS therefore offers the opportunity of drastic emissions reduction in the near-term.

Alternatives to advance carbon-neutral steelmaking in Europe, particularly hydrogen based methods, have also been in the spotlight. Recently, major European steel companies have announced initiatives to push forward hydrogen-based steel production technologies. The first sites for these are being built for example in Sweden and Germany. Nevertheless, the commercial competitiveness of these technologies in relation to CCUS is still unclear, especially when considering the current and future availability of green hydrogen, produced by water electrolysis using renewable electricity.

1. https://www.iea.org/reports/iron-and-steel
2. https://www.iea.org/fuels-and-technologies/carbon-capture-utilisation-and-storage
3. M. Flores-Granobles, M. Saeys. Energy Environ. Sci., 2020, 13, 1923

In a transitional period while awaiting for green hydrogen infrastructure to come on line, blue hydrogen produced via the steam methane reforming route using fossil natural gas may fill the shortfall, but this also necessitates CCS as a means of mitigating the co-produced CO2 through geological storage. These issues are compounded by the associated fuel and energy costs, which are significant. Both CCUS and hydrogen based technologies are needed to accelerate the net-zero transition in the iron and steel industry.

Still, there are key challenges for CCUS deployment in the industry that must be overcome - costs remain high and the technology still has not yet been implemented at large-scale. Nevertheless, the greatest barriers to CCUS deployment are considered to be commercial, regulatory, and societal rather than technological issues. To overcome these, novel business models must be developed to promote take-up of the technology within industrial CCUS clusters. This includes building a sustainable business case by working with key stakeholders and identifying best case scenarios to reduce financial risks.

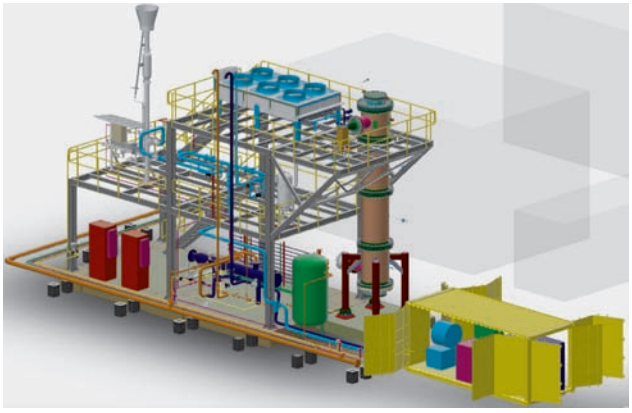
Bringing down the costs and creating infrastructure to boost adoption

Given the urgency of emission reductions in the steel sector, a portfolio of promising CO2 capture technologies must be developed and practically tested to a high Technology Readiness Level (TRL) while identifying optimal integration solutions that deliver minimum cost and energy consumption. The C4U research project develops carbon capture processes that address this challenge.

Central to the C4U project's value proposition to businesses are two key chemical carbon capture processes – DISPLACE (high-temperature sorption-displacement process for CO2 recovery) and CASOH (Calcium Assisted Steel mill Off-gas Hydrogen production). While capturing CO2, they can recover heat at very high temperatures and produce decarbonised fuels which can be used to reheat furnaces or generate clean energy, as well as be used in a variety of other steel plant operations or industries.

C4U is elevating the DISPLACE and CASOH capture technologies from TRL5 to TRL7 through pilot testing at inspiring scales in real world operational environments and then designing them for full-scale optimal integration in the iron and steel industry.

The integration of CCUS in existing industrial clusters is also key to optimising adoption across the value chain. The North Sea Port industrial cluster, a 60-kilometre-long cross-border port area that stretches from Vlissingen on the North Sea coast in the Netherlands, to Ghent in Belgium, for example, is pushing forward with building an integrated CO2 transport network and is home to a steel mill using carbon capture and utilisation technology. The "Ghent Carbon Hub" aims to build a CO2 pipeline network and liquefaction terminal for shipping liquefied CO2 to permanent storage sites under the North Sea.



3D layout of the CASOH pilot in Gijón, Spain

The hub is expected to be able to process around 6 million tonnes of CO2 each year, representing about 15% of Belgium's emissions. In the C4U project, detailed modelling approaches are developed and applied to investigate the operation and safety of CO2 pipeline transport and storage infrastructure whilst exploring opportunities to integrate CCUS technologies into the North Sea Port industrial cluster. This involves developing a pipeline network flow model that predicts CO2 flow conditions and chemical composition at any time and point along the network, including for delivery to a geological storage site.

A rapidly evolving policy and business environment

Societal readiness and political acceptance for CCUS will also be critical for achieving industrial decarbonisation. An urgent mix of policy instruments, environmentally-sound and transparent narratives and approaches, and innovative business models can deliver effective incentives that are in-line with business and stakeholder needs.

While researchers help prepare CCUS for large-scale adoption, policymakers play their part in creating an enabling environment for the sector; for instance, by championing clear narratives on the role of CCUS in achieving national decarbonisation targets, encouraging innovation and recognising the need for ongoing operational support for industry. Globally, policy support for CCUS is growing. The last few months saw the announcement of a number key policy packages to drive the scale up of CCUS:

In the USA, the Inflation Reduction Act provides significant tax benefits to CCUS developers to encourage investment. It is estimated that the incentives could see the CCUS industry grow in the USA 13-fold by 2035;

Similarly, the EU has bolstered its financial support for CCUS and identified it as a strategic net-zero technology that will benefit from new measures under the proposed Net-Zero Industry Act. The Act aims to scale net-zero industry technology manufacturing in the EU to meet at least 40% of its demand by 2030;

Additionally, the UK has announced to earmark £20 billion to boost CCUS projects across the country.

With advances in research and increasing policy support and investments, CCUS has the potential to play a leading role in decarbonising the iron and steel industry. In combination with hydrogen and other technologies, CCUS offers the sector the opportunity to meet its climate targets, helping to build a cleaner future.

Acknowledgement

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More information

c4u-project.eu

How US carbon tax credits are accelerating global CCS commerciality

Recent shifts in policy and regulatory frameworks in the US are accelerating the deployment of carbon capture, utilization, and storage (CCUS) both within and beyond its country borders. With CCUS increasingly acknowledged as a critical tool to address climate change, are there sufficient policies and economic incentives in place to ensure the technology is commercially competitive enough to unlock its full potential? Adam Green, Carbon Policy Advisor, Worley discusses.

In the last year, CCUS has been a hot topic with frequent project updates, technology developments and funding announcements reflecting how this technology is now a key consideration for hard-to-abate sectors that need to rapidly decarbonize. Demand for CCUS, particularly in North America, Europe and Asia-Pacific is rising rapidly, with over 200 facilities expected to be operational by 2030, capturing over 220 million tons of CO_2 a year. But what role will CCUS have to play in our decarbonization journey?

Since the Petra Nova CCS retrofit project failed, President Biden's Inflation Reduction Act has brought a new level of investor confidence to the CCUS market

The US is leading the pack

Some of this recent increase in activity is, in part, thanks to shifts in policy and regulatory frameworks, particularly in the US. While tax credits have been available for US-based CCUS projects for some time, President Biden's Inflation Reduction Act (IRA) boosts the 45Q Tax Credit for point sources from USD$50 to $85 per ton of CO_2 sequestered. The goal of this tax credit is to incentivize hard-to-abate industries such as gas-fired power plants, cement, steel, hydrogen, and petrochemicals to retrofit or incorporate CCUS into their facilities. Given that 49% of CCUS projects were cancelled because of financial and economic challenges (according to Rystad Energy) the 45Q expansion is a major catalyst in revitalizing and accelerating the CCUS industry.

The IRA also lowers the carbon emissions threshold that facilities must meet to qualify, creating the potential for many more projects to come forward in the US. For power generation, the capture threshold for credit-eligible facilities will fall from 500,000 tons per year of CO_2 emitted to 18,750 ton per year. Further, the introduction of an option for direct payment ensures that participants will benefit from CCUS, not just those with high cash tax liabilities, although non-tax exempt entities will only benefit for 5 of the 12 year crediting period. These changes create more certainty for investors, which will ultimately unlock more investment options and stimulate the market in a way that tax liability limited credits do not. In fact, a study by the Bipartisan Policy Center found that "one dollar in cash has nearly double the value of a dollar in tax credits to a project developer."

More certainty equals more attractiveness

From the failure of the Kemper County facility in Mississippi to the cancellation of the Petro Nova CCS retrofit unit in Texas, previously interrupted and delayed projects across the US had cast doubt over the viability of CCUS technologies. However, the changes instigated by the IRA are a welcome departure from this uncertainty and bring a new level of investor confidence to the CCUS market. This is particularly welcome news for those investors that had previously invested hundreds of thousands of dollars in feasibility studies, development plans and community engagement, only to fail to meet the criteria for government funding or lose in the competitive application process.

The investor attractiveness of the US's newly enhanced 45Q Tax Credit has not been lost on the governments of international CCUS hotspots such as Canada, the UK, the European Union, and Australia. As with the impact of the IRA more broadly, governments are concerned about the extent to which these announcements will redirect investment from their jurisdictions and are beginning to respond in turn, accelerating the commercial viability of CCUS as they do.

Canada's 2023 Budget, for example, expanded the investment tax credits available for CCUS and hydrogen production, and clean technology projects designed to stimulate investment to support the country's energy transition. Similarly, the European Union's Green Deal Industrial Plan and its Net Zero Industry Act (NZIA) look to address Europe's main bottleneck to a successful CCUS industry.

The need to measure carbon dioxide flows accurately for CCUS

The article examines some issues associated with the underpinning measurements of CO2 that will be required to address IPCC requirements. By Dr. Edris Joonaki, Consultant and Technical Lead, TÜV SÜD National Engineering Laboratory.

Implementation of large-scale CCUS will require accurately knowing how much CO2 has flowed through pipelines and then been used or sequestered, much the same as custody transfer metering in the oil and gas industry today. Both the IPCC and IEF reports mention the use of CCUS hubs to reduce transportation costs, with multiple sources of CO2 feeding into shared infrastructure and pipelines for delivery to utilisation or storage facilities.

Under the EU Emissions Trading System there is a requirement for uncertainties of ±2.5 % or less on mass flow measurements of CO2. With currently available flow metering technology, single phase flow meters will be required for CCUS applications, especially for transportation through pipelines, where the CO2 will be in the liquid or dense supercritical phases.

Depending on the flow metering technology used there will be a requirement to know the values of key thermophysical properties of the flowing fluid. For example, density is required for conversion from volumetric to mass flow rate whilst both density and viscosity are required to convert the transit time measured by an ultrasonic flow meter to volumetric flow rate.

CO2 streams will never be pure but will have varying degrees of contaminants depending on the process from which the CO2 is being captured and the capture technology employed. Hence, it will be necessary to measure the composition of the process streams in real-time, especially where CO2 from multiple sources is fed into shared infrastructure.

The phase diagram of pure CO2 has several phase transition boundaries close to the temperature and pressure regions relevant for pipeline transport, for example the critical point of pure CO2 is 31 ˚C and 74 bar. Furthermore, even low levels of impurities significantly perturb the fluid properties and open up two-phase region boundaries.

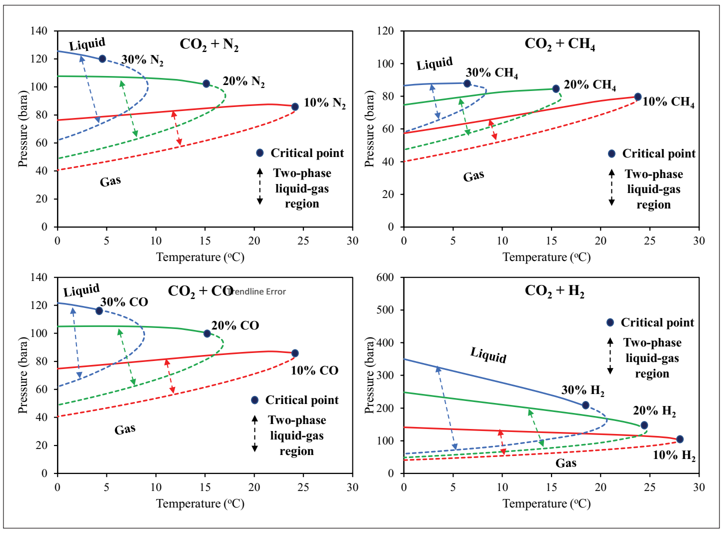


Figure 1 - Phase diagrams of CO2-rich streams in presence of some common industrial impurities: N2, CH4, CO, and H2 at various concentrations from 10 to 30 mol%. Solid lines are bubble lines, and Square Dot lines are dew lines

These factors impact flow measurement in several ways.

Firstly, given the use of single-phase flow meters, it is important to understand the fluid properties of the process stream in real-time to ensure that the stream stays in the intended phase, e.g., gaseous, supercritical or liquid phase. If the prevailing phase changes from the condition for which the meter is intended, or if multiphase flow develops, the accuracy of the flow meter will deteriorate significantly to the point where fiscal measurements would not be possible.

Secondly, unless a Coriolis flow meter is used, a conversion from volume to mass flow rate is required which relies upon detailed knowledge of fluid properties pressure and temperature conditions, to determine the instantaneous density of the process stream.

In practice, a mixture of flow metering technologies is likely to be used within any individual CCUS hub. Coriolis flow meters are likely to be the preferred technology for lower flow rate applications, for example for captured streams from small-scale CO2 sources or for injection into geological storage facilities. But the use of full-bore ultrasonic flow meters is preferred for higher flow rates in large-diameter pipelines.

Therefore, at a high level, the composition of the process stream (one of the primary measurements) will feed into determination of the fluid properties, which in turn will feed back into the primary flow rate measurement.

A further complication is that there are many different impurities in the flue gas, initial capture product, or in the final CO2 product ready for transportation as explained earlier. Some impurities originate from the combustion air or the fuel, whilst others are combustion products. Also, some impurities in the fuel, for example, sulphur, react in the combustion process, generating new compounds that were not present in the initial CCUS mixture.

The effects of the impurities are to both alter the phase boundary and create a two-phase region as well as change physical properties such as density and viscosity. Three categories can be identified for the impurities, based on their amount in CCUS fluids:

1) major impurities,

2) minor impurities, and

3) trace impurities

Although some of the major, minor and trace impurities are considered for their health, safety, and environment (HSE) repercussions, they might not be essential to be factored into modelling. They may not be a vital term for fluid modelling conceptually, especially compared to much larger concentrations of components such as hydrogen, nitrogen, and oxygen.

It is worth noting that the concentration magnitude does not indicate the level of importance. Some components such as mercury (Hg), nitrogen (N_2), and ammonia (NH_3) often exist in low concentrations in CCUS fluids, but they can strongly influence the overall fluid properties; and it is considered as one of the potential challenges of transportation of CCUS fluids.

Equally, monoethylene Glycol (MEG) and triethylene glycol (TEG) are listed as minor impurities, but are considered of greater importance because of their harmful effects on the CCUS system (e.g., damage to elastomers and liquid dropout in lines). Therefore, balanced decision-making is needed to account for impurities based on their effects on thermodynamic properties and the modelling task load. Since the type and concentration of minor and trace impurities is process-specific it would be ideal to consider different types and concentrations of impurities according to the source process.

Based on the current research on the physical characteristics of CO_2 blends, a review/gap analysis was conducted at TÜV SÜD. The assessment was performed to determine the lowest and highest pressure and temperature ranges at which fluid property measurements have been previously conducted. The study's findings pointed out a general lack of experimental data and specific areas where there are few or no relevant research studies.

The review's main goal was to collect information on physical properties, including density, and vapour-liquid equilibrium (VLE). Although data on ternary and other multicomponent blends were collected wherever available, the focus was primarily on binary mixtures and blends with minor/trace contaminants.

The results showed that there were insufficient data available for CO_2 blends with minor or trace contaminants. Only solubility data for CO_2/Hg, CO_2/MEG, CO_2/NH_3, and CO_2/TEG mixtures were acquired. Since minor/trace components are present in such low concentrations in CO_2-rich streams, solubility data is readily available. Mercury, for example, is rarely present in quantities large enough to have a significant impact on total fluid density or phase equilibria. These components are considerably more significant in determining the solubility of the bulk phase in order to analyse dropout across the system at various pressures and temperatures.

To conclude, the ability to accurately measure the amount of CO_2 captured, transported and used or stored will be a fundamental foundation of large-scale CCUS. But this presents some interesting technical challenges that require an integrated approach to real-time determination of process stream composition, bulk flow rate and fluid properties. The essential technologies exist, but the challenge of integrating these and making them economically viable, should not be underestimated.

TÜV SÜD National Engineering Laboratory is a global centre of excellence for flow measurement and fluid flow systems and is the National Designated Institute responsible for the UK's National Flow Measurement Standards.

More information

www.tuv-sud.co.uk/nel

Carbon capture technology for buildings

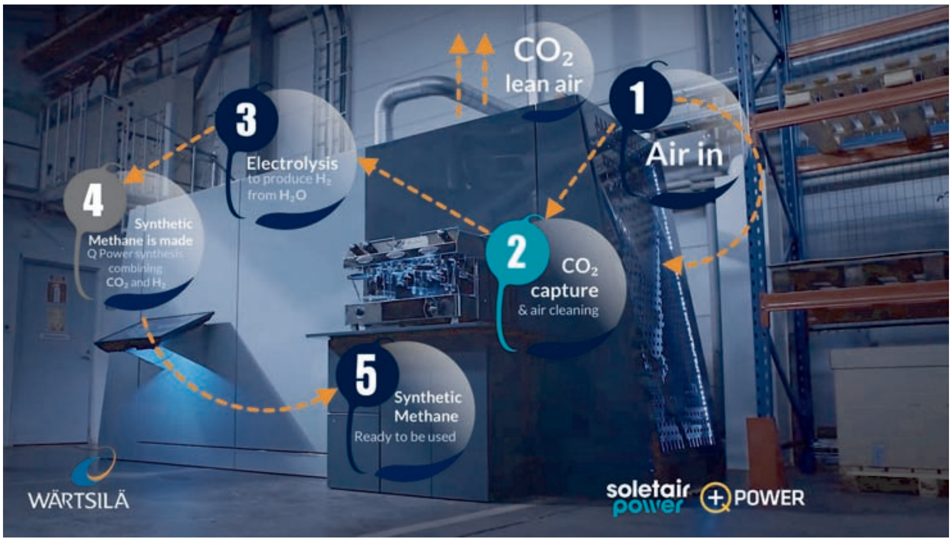
Soletair Power (Finland) has developed a unique solution for extracting carbon dioxide (CO2) from building ventilation systems to help achieve carbon net zero and even carbon negative building projects.

The company employs temperature vacuum swing adsorption (TVSA) to segregate CO2, before regenerating the adsorbent by 'swinging' to a vacuum. Soletair's TVSA is able to capture CO2 with 99.9% purity, using less than 100 Deg C as the regeneration temperature. The process is reliant on accurate, reliable measurement of temperature, humidity, and CO2 using Vaisala technology.

Buildings and construction are responsible for 37% of the world's CO2 emissions, so ambitious goals have been established to lower this figure during both construction and operation – the ultimate aim is to achieve carbon net zero buildings.

There is also pressure from local and industry-specific regulations as well as broader, global requirements like the Paris Agreement, which requires a 50% reduction in CO2 emissions by 2030.

Soletair Power, founded in 2016, uncovered the potential for technology to reduce a building's carbon emissions by capturing CO2 from its ventilation system and using it in the production of fuel or concrete, for example.



How the Soletair Power-to-X Unit works. Image courtesy of Soletair Power and Wärtsilä

Why capture CO2 from buildings?

CEO Petri Laakso explains the multiple benefits of Soletair Power's solutions. "Capturing CO2 from a building's air, whether that be its inlet, exhaust, or circulated air, reduces its overall CO2 emissions. Our system also delivers cost-reduction, employee well-being, and sustainability benefits.

For example, with CO2-lean air coming into the building you can reduce ventilation levels – which saves on heating, cooling, and energy, further reducing operational CO2 emissions. Lower CO2 levels inside offices and residential buildings also contribute to better health, well-being, and employee performance.

"To capture CO2, the air needs to be moving and ventilation systems do this work for us, and the air in buildings also tends to be around 20 °C, which is the optimum temperature for our process."

In addition to capturing CO2 from the air passing through heating, ventilation, and air conditioning (HVAC) systems, Soletair Power has also developed an indoor CO2-filtering air purifier for meeting rooms and smaller office spaces, and an outdoor CO2 capture system.

"Our outdoor device is very similar to the HVAC-integrated one, but with a housing around the unit," says Petri. "We have one such unit in Duisburg, Germany, which is installed outdoors to capture as much CO2 as possible. The CO2 is then used by the company as a raw material for various industrial processes."

Are carbon-negative buildings possible?

A major additional benefit of Soletair Power's solution is that the captured CO2 can be used for other applications, including concrete production. "For concrete, the captured CO2 is used to create calcium carbonate, so you have the potential to achieve negative emissions when the CO2 is locked away from the atmosphere. This is one way we can help building owners to achieve net-zero emissions for the building's lifetime by compensating for construction-related and operational emissions," says Petri.

"Carbon-negative buildings will also offer significant cost savings, meaning our systems can provide a return on investment within just a few years."

Achieving net zero is no mean feat though, and the ability to do so can depend on various local factors, including how the power and heating for the building is generated. "To make a building into a carbon sink you need its electricity to be renewable and the heating from a source that minimises emissions," Petri explains.

Soletair Power is currently working on several projects to create carbon net zero buildings. "These projects are using various advanced measures to reduce CO2 emissions during building construction and operation; in some cases, our solution is the final touch that tips the emissions over onto the negative side, and we should have some exciting results to share in the coming years," Petri states.

Converting captured CO2 into sustainable fuel

In autumn 2018, Wärtsilä, a global leader in innovative technologies and solutions for the marine and energy industries, approached Soletair Power about using extracted CO2 to produce fuels, before coming aboard the project with a seed investment in April 2019. The collaboration produced the world's most compact device that uses air to create fuel.

The Power-to-X demonstration unit, which was showcased at the Finland Pavilion at Expo 2020 in Dubai, used renewable power and CO2 from the surrounding air along with hydrogen from water to produce synthetic methane, which was then used to power a coffee machine for tradeshow guests.

Soletair Power Power-to-X unit demonstrating fuel out of thin air. Photo courtesy of Soletair Power and Wärtsilä

The companies have also collaborated on the development of an HVAC-integrated unit that captures CO2 from the inlet air at Wärtsilä's Sustainable Technology Hub in Vaasa and supplies CO2-lean air to the building.

Accurate sensors are a key building block

The goal of the CO2 capture system is to reduce a building's energy consumption while maintaining the same level of air quality inside.

"Our system keeps the CO2 in the building at a low level, so that the ventilation can operate at very low levels in a demand-controlled mode. We need to be able to accurately measure the CO2 data to determine how much the system is capturing, which is where Vaisala's sensors come into play. As well as CO2 sensors, our technology also uses sensors for humidity and temperature at various points in the process."

Soletair Power uses the duct humidity and temperature transmitter HMD60, the CARBOCAP® carbon dioxide transmitter series GMD20, the CARBOCAP® carbon dioxide, temperature, and humidity transmitter series GMW90, and Vaisala's handheld CO2 meter GM70 to take these readings.

Petri explains the reasons behind choosing Vaisala: "It was important for us to use top-notch equipment in all of our units. We previously used cheaper sensors from elsewhere, but we found that the long-term stability of the equipment was lacking, which meant that we couldn't guarantee accurate data as the equipment aged. Conscious of Vaisala's reputation for customer service and accurate reliable measurement solutions, we therefore moved to Vaisala."

Petri also highlights the importance of reliable equipment in gaining insights from measurement data: "The performance of our chemistry-based solution is affected by various factors including ambient conditions, so if you don't have reliable data, it's hard to judge why those changes have occurred."

Soletair Power's future plans include developing the TVSA technology to make the CO2 capture systems more compact and improve the sustainability of their operation. "We expect to continue our cooperation with Vaisala, and as our solution develops, we will likely need the support of their experts on which sensors to choose and how to calibrate them to work optimally in changing atmospheric conditions," Petri explains.

With global urbanisation continuing apace and emissions regulations becoming ever stricter, the need for innovative solutions in buildings and construction is set to grow – and with disruptive pioneers like Soletair Power leveraging Vaisala's stable and reliable measurement technologies to take big steps forward, the future is bright.

More information

www.vaisala.com
EMEA.media@vaisala.com

Projects and policy news

RWE plans to develop three new UK carbon capture projects

www.rwe.com/carbon-capture

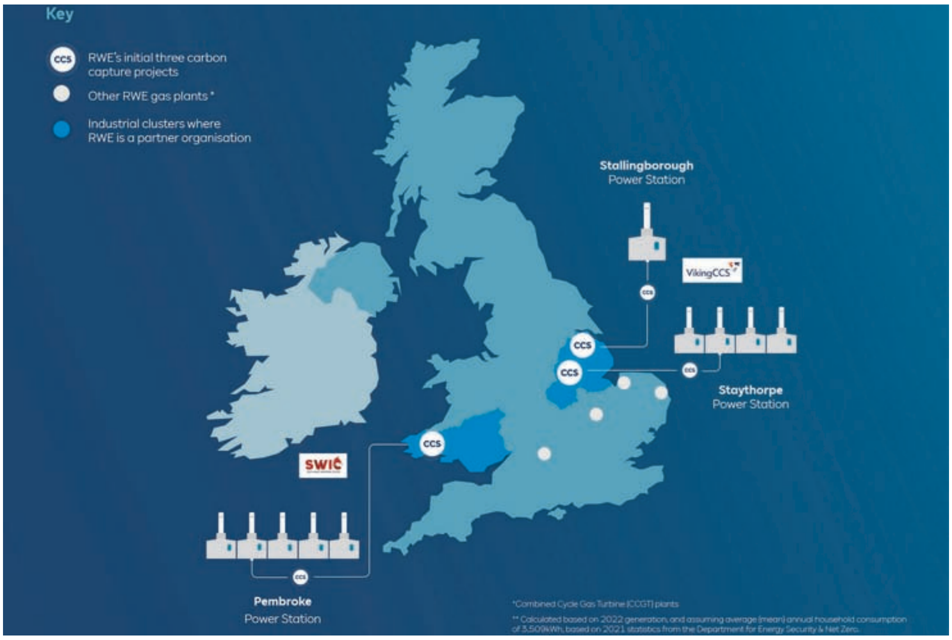
RWE has announced plans to progress three new carbon capture projects as it leads the way towards helping decarbonise UK power.

The company is testing the feasibility of options to retrofit carbon capture technology at its existing combined cycle gas power stations at Pembroke and Staythorpe. It is also developing proposals for a new carbon-capture, gas-fired power station at Stallingborough, close to the Humber Estuary. The proposed development would be up to 800 megawatts enough to power one million homes.

As operators of the largest fleet of gas fired power stations in the UK and a leading renewables generator, RWE considers CCS to be a viable solution for delivering decarbonised, reliable, and dispatchable power generation, whilst supporting the UK's target of decarbonising its power system by 2035. As well as being key to the UK's long term energy security, the three proposed CCS projects will play a key part in helping RWE achieve its own global ambition to be carbon neutral by 2040 – targets aligned with the Paris Agreement.

Tom Glover, UK Country Chair for RWE, commented, "In order to decarbonise the power sector, support security of supply and enable large scale industrial decarbonisation, it is important that clean gas generation projects are developed. Carbon capture can support the expansion of the other renewable and low carbon technologies that RWE is a leader in deploying, by providing energy security through firm and flexible provision of electricity that is not reliant on weather. I am pleased to announce our plans for three UK carbon capture projects, representing an important step in our progression towards decarbonising our existing gas fleet."

The development of these projects would form an important part of a robust and comprehensive energy network that ensures the UK has stable and secure generation whenever it is needed. If all three projects are progressed, they would collectively be capable of securing up to 4.7 gigawatts (GW) of flexible, decarbonised generation capacity – enough to produce electricity to power the equivalent of 8.1 million typical UK homes, while capturing 11 million tonnes of CO2 per year. The projects would also represent a significant investment into UK energy infrastructure, and would play a key role in helping decarbonise neighbouring industrial clusters.



The carbon capture projects could secure up to 4.7 GW of generation and capture 11 million tonnes of CO2 per year

All three projects are close to proposed CO2 networks or will have access to shipping facilities, which would enable the CO2 to be safely transported and stored by third parties. RWE has developed partnerships with industrial clusters South Wales Industrial Cluster (SWIC) and Viking CCS in order to develop these transportation and storage options. Where possible, utilisation options for the captured CO2 will be targeted.

The projects are now preparing to apply to the Department for Energy Security and Net Zero's Track 2 Phase 2 cluster sequencing funding application process, which is dedicated to carbon capture projects in close proximity to carbon capture storage or transport facilities. The application will ensure that RWE can demonstrate that carbon capture is a viable solution and an essential tool in the race to net zero.

A Policy Blueprint for Responsible BECCS Development in the United States

www.efifoundation.org

The summary report from the Energy Futures Initiative details a holistic federal policy blueprint to accelerate responsible BECCS deployment in the United States.

Taking Root: A Policy Blueprint for Responsible BECCS Development in the United States – Summary Report (June 2023) synthesizes the final policy findings and recommendations from the Energy Futures Initiative/EFI Foundation multi-year study entitled Bioenergy with Carbon Capture and Storage: Sowing the Seeds of a Negative-Carbon Future. The wide-ranging scope of bioenergy with carbon capture and storage (BECCS) intersects with federal policies for sustainable agriculture and forestry, clean energy, and climate change.

Bioenergy in the United States is currently the largest single source of renewable energy and a major component of domestic energy production through ethanol used in transportation. Combining bioenergy with carbon capture, however, is in the early stages of deployment. Various analyses identify a large role for BECCS to provide net-negative carbon dioxide emissions as part of a portfolio of measures to achieve net-zero greenhouse gas emissions by midcentury.

BECCS deployment in parallel with greenhouse gas mitigation measures can help achieve climate goals more quickly, as well as counterbalance residual emissions from difficult-to-decarbonize sectors of the economy.

Researchers develop a new method for the sustainable use of carbon dioxide

A new study from the Max Planck Institute demonstrates a process that can turn carbon dioxide into a valuable material for the biochemical industry via formic acid.

New synthetic metabolic pathways for fixation of CO2 could not only help to reduce the CO2 content of the atmosphere, but also replace conventional chemical manufacturing processes for pharmaceuticals and active ingredients with carbon-neutral, biological processes.

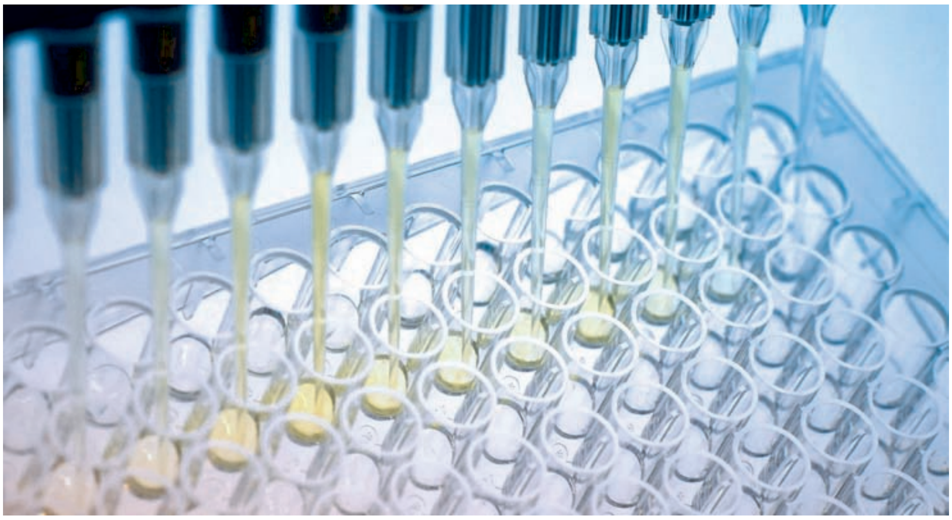
Researchers led by Tobias Erb at the Max Planck Institute for Terrestrial Microbiology are using nature's toolbox to develop new ways of carbon dioxide fixation. They have now succeeded in developing an artificial metabolic pathway that produces the highly reactive formaldehyde from formic acid, a possible intermediate product of artificial photosynthesis.

Formaldehyde could be fed directly into several metabolic pathways to form other valuable substances without any toxic effects. As in the natural process, two primary components are required: Energy and carbon. The former can be provided not only by direct sunlight but also by electricity - for example from solar modules.

Within the added-value chain, the carbon source is variable. carbon dioxide is not the only option here, all monocarbons (C1 building blocks) come into question: carbon monoxide, formic acid, formaldehyde, methanol and methane. However, almost all of these substances are highly toxic - either to living organisms (carbon monoxide, formaldehyde, methanol) or to the planet (methane as a greenhouse gas). Only formic acid, when neutralised to its base formate, is tolerated by many microorganisms in high concentrations.

"Formic acid is a very promising carbon source," emphasizes Maren Nattermann, first author of the study. "But converting it to formaldehyde in the test tube is quite energy-intensive." This is because the salt of formic acid, formate, cannot be converted easily into formaldehyde. "There's a serious chemical barrier between the two molecules that we have to bridge with biochemical energy - ATP - before we can perform the actual reaction."

The researcher's goal was to find a more economical way. After all, the less energy it takes to feed carbon into metabolism, the more energy remains to drive growth or production. But such a path does not exist in nature. "It takes some creativity to discover so-called promiscuous enzymes with multiple functions," says Tobias Erb. "However, the discovery of candidate enzymes is only the beginning. We're talking about reactions that you can count along with since they're so slow - in some cases, less than one reaction per second per enzyme. Natural reactions can happen a thousand times faster."



A key step in expanding synthetic formate assimilation is its thermodynamically challenging reduction to formaldehyde, visible here as a yellow color change.. © Max Planck Institute for Terrestrial Microbiology/Geisel

This is where synthetic biochemistry comes in, says Maren Nattermann: "If you know an enzyme's structure and mechanism, you know where to intervene. Here, we benefit significantly from the preliminary work of our colleagues in basic research."

The optimization of the enzymes comprised of several approaches: building blocks were specifically exchanged, and random mutations were generated and selected for capability. "Formate and formaldehyde are both wonderfully suited because they penetrate cell walls. We can put formate into the culture medium of cells that produce our enzymes, and after a few hours convert the formaldehyde produced into a non-toxic yellow dye," explains Maren.

The result would not have been possible in such a short time without the use of high-throughput methods. To achieve this, the researchers cooperated with their industrial partner Festo, based in Esslingen, Germany. "After about 4000 variants, we achieved a fourfold improvement in production," says Maren.

With collaboration partner Sebastian Wenk at the Max Planck Institute of Molecular Plant Physiology, the researchers are currently developing a strain that can take up the intermediates and introduce them into the central metabolism. In parallel, the team is conducting research with a working group at the Max Planck Institute for Chemical Energy Conversion headed by Walter Leitner on the electrochemical conversion of carbon dioxide to formic acid.

The long-term goal is an "all-in-one platform" - from carbon dioxide via an electrobiochemical process to products like insulin or biodiesel.

More information

www.mpg.de

Surrey researchers unravel the workings of unique carbon capture tech

The UK can lead the way in technologies that effectively capture carbon dioxide and convert them into useful products such as hydrogen, says Dr Melis Duyar, a CCS expert from the University of Surrey.

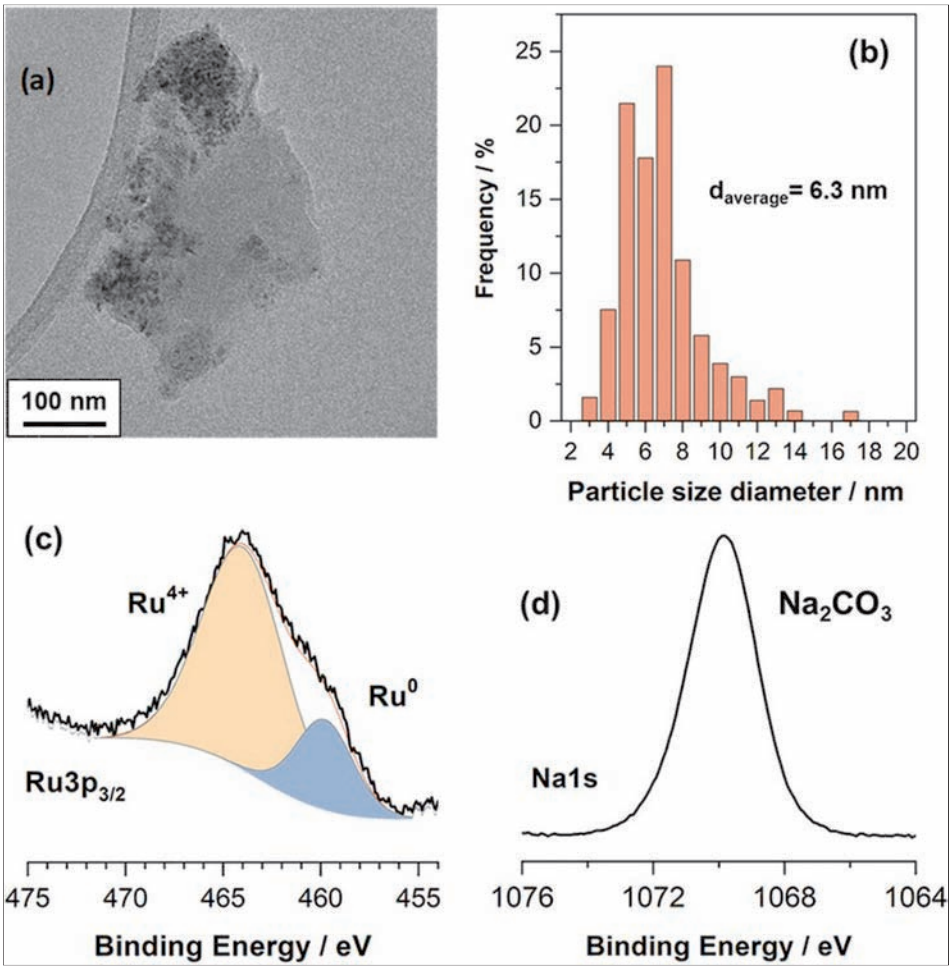
Surrey's research team conducted a first-of-its-kind experiment to understand how their new technology, which uses a switchable dual-function material (DFM), captures and converts carbon dioxide into green fuels or useful industrial chemicals.

The Surrey team's switchable DFM, "NiRuNa/CeAl ", consists of nanoparticles of a bimetallic alloy, in combination with a dispersed Na-based adsorbent. These elements are combined to create a unique material for capturing and converting CO2 in not just one, but three chemical reactions, offering versatility in an ever-changing energy landscape.

Dr Melis Duyar, lead author of the study from the University of Surrey, said, "Pursuing advanced carbon capture technology is more than just the right thing to do for our planet—it's an exceptional opportunity for the UK to emerge as a global front-runner, leveraging the vast potential of green energy products born from this process."

"We'll continue to apply the lessons learnt from this study and work with others in the higher education sector and industry to continue to mature this process."

Surrey researchers found that NiRuNa/CeAl can be used to capture CO2 in three important chemical reactions:



Ex situ characterization of NiRuNa sample (a) representative TEM image. (b) Particle size distribution based on TEM images. (c) Ru 3p XPS region. (d) Na 1s XPS region. Credit: Journal of Materials Chemistry A (2023)

• CO2 methanation (converting CO2 into methane) – a process where CO2 is converted into methane*. It combines CO2 with hydrogen (H2) to produce methane (also called "synthetic natural gas") and water.

• Reverse water-gas shift – a chemical process that involves the conversion of CO2 and H2 into carbon monoxide (CO) and water (H2O). This reaction can be used to make sustainable "synthesis gas" which is a mixture of CO and H2, that can be converted to a vast variety of chemicals using techniques that already exist within the chemical industry, moving us closer to a circular economy.

• Dry reforming of methane (DRM) – a chemical process that involves the conversion of methane and CO2 into "synthesis gas", taking advantage of underutilised hydrocarbon resources such as biogas and offering opportunities for decarbonisation and CO2 recycling in the absence of green hydrogen.

By using a technique called operando-DRIFTS-MS, the team were able to observe interactions of molecules with the surface of these unique dual-function materials while carbon dioxide was being captured and while it was further converted to products via these 3 reactions. This allows researchers to determine what makes a DFM work, greatly advancing their ability to design high-performance materials.

"Capturing and using CO2 is key to reaching the ultimate goal of net zero by 2050. We now have a clearer understanding of how switchable DFMs are able to perform a multitude of reactions directly from captured CO2, which will help us improve the performance of these materials even more via rational design."

More information

www.surrey.ac.uk

Compact Syngas Solutions wins £4M funding to test CO2 capture

Full-scale rollout could see 50 UK modules built to convert waste to liquid fuel while capturing 29,000 tonnes of CO2 a year.

The company that turns waste wood and unrecyclable materials into clean hydrogen fuel has secured almost £4 million in government funding to make its biomass and waste-to-hydrogen plants even greener by using carbon capture.

Compact Syngas Solutions (CSS) has won £3,979,113 from the Bioenergy with Carbon Capture and Storage (H2BECCS) Innovation Programme, run by the Department for Energy Security and Net Zero (DESNZ). CSS, based in Deeside, Wales, previously won a first round of funding of £246,568.

CSS has developed an advanced gasification process that generates hydrogen gas from waste products, including biomass like waste wood and other selected non-recyclable materials. This waste is often sent to landfill, where it decomposes and emits harmful gases including carbon dioxide and methane into the atmosphere.

The technology harnesses this waste by converting it into syngas, a valuable gas that can be used to produce hydrogen for use as a cleaner fuel.

The new funding will help CSS build a full-scale rig to show that water can be used to separate and store carbon dioxide during the process. This has previously been achieved with amines, a potentially harmful compound derived from ammonia.

Removing the carbon dioxide reduces the carbon footprint of the hydrogen produced and makes the process more efficient. The syngas, once separated from the hydrogen, is also used in a gas engine that generates energy to power the process and export surplus to the grid, maximising outputs from the system.

During the project, the rig will run continuously for 1,000 hours, reliability testing the technology and getting it ready for commercialisation. Every day, a single module will produce 750kg of hydrogen – enough to fuel a fleet of HGVs – and capture around 1,600kg of carbon dioxide.

CSS plans to build more than 50 hydrogen modules at around 15 sites, ranging from a single module to six per site offering the flexibility to suit local demand. These 50 modules will annually produce 11,000 tonnes of hydrogen, and capture 29,000 tonnes of carbon dioxide

CSS plans to build more than 50 hydrogen modules at around 15 sites, ranging from a single module to six per site offering the flexibility to suit local demand. These 50 modules will annually produce 11,000 tonnes of hydrogen, and capture 29,000 tonnes of carbon dioxide.

The technology will be key to helping the UK reach its Net Zero 2050 target. The production of low carbon hydrogen from waste materials stops it reaching landfill and creates a fuel that has no greenhouse gas by-products. Hydrogen has many uses in transport and industry.

Paul Willacy, managing director of Compact Syngas Solutions, said, “Winning a second round of funding is an incredible achievement for the team, as we were up against some stiff competition. “We are delighted that we can now scale up technology into a commercial-scale demo plant, and we are actively looking for further investment to support rollout in the next couple of years."

“Capturing and storing the carbon from our gasification process and the hydrogen we produce will support the drive to Net Zero and lower the environmental impact of producing this green fuel at scale.”

“Hydrogen has a very low environmental impact, but this project will help deal efficiently with the CO2 that emerges during its production.”

More information

www.syngas-solutions.co.uk

Capture & utilisation news

ArcelorMittal and LanzaTech first ethanol samples from CCS in Ghent

www.arcelormittal.com
www.lanzatech.com

The €200 million 'Steelanol' facility is a first of its kind for the European steel industry, deploying technology developed by leading carbon utilization company LanzaTech.

The project has taken the first step toward full operation of a commercial scale facility that will capture carbon-rich waste gases from steelmaking and biologically convert them into ethanol through LanzaTech's bio-based process. Unlike traditional fermentation, the process ferments gases instead of sugars and uses a biocatalyst instead of yeast.

The Steelanol facility was inaugurated in December 2022, with cold commissioning taking place thereafter. The biocatalyst has now been introduced into the facility (a process called inoculation) to begin growth and verify production of new molecules.The facility is expected to reach full operational capacity before the end of the year.

"ArcelorMittal has a passion for sustainability and circularity and has found the right partner in LanzaTech to realize that today. The beauty of the Steelanol facility is that we are enabling a new form of industrial symbiosis, connecting industries together by using gases from steel production as a feedstock for other sectors," said Manfred Van Vlierberghe, CEO ArcelorMittal Belgium. "This is part of the Smart Carbon Strategy we are developing. By coming together and sharing these resources between sectors, we are not only furthering our circular, Smart Carbon mission, but also helping to solve climate, CO2 and waste challenges."

In May 2023, the first gases from the steel mill's blast furnace were safely introduced to LanzaTech's biocatalyst. After a successful inoculation, initial samples that contained ethanol were produced this week, demonstrating that the carbon in the gases is being converted into new chemical products. Commercial-scale ethanol production from the bioreactors will follow, with expected ramp up of production in the coming months.

The ethanol can then be used as a building block to produce a variety of products, including sustainable transport fuels, packaging materials, apparel, and even cosmetic fragrances, hence helping to advance the decarbonization efforts of the global chemical sector. The ethanol will be jointly marketed by ArcelorMittal and LanzaTech under the Carbalyst® brand name.

The Steelanol plant has the annual capacity to produce 80 million litres of advanced ethanol, around half of the total current demand in Belgium. It expects to reduce carbon emissions from the Ghent plant by 125,000 tonnes annually, thereby advancing the EU's 2030 Climate Target Plan to reduce greenhouse gas emissions by 55% by the end of the decade. Project partners include Primetals Technologies and E4tech with support from CINEA, the European Climate, Infrastructure and Environment Executive Agency.

The product samples from the facility this week mark an important step toward the circular use of carbon and the end of single-use carbon, whereby gases are no longer regarded as waste but as raw materials. In addition, the recycling of carbon means Steelanol's process of Carbalyst® ethanol production does not compete in any way with food crops, as is the case for traditional methods of ethanol production.

The LanzaTech process implemented at the site is fully flexible: not only can it use industrial gases from today's steel production methods but also it can adapt as industry transitions to future steel production technologies with increased green hydrogen input. This versatility enables the carbon recycling application to evolve with available residue, waste streams, and green H2. LanzaTech's process is already employed by three operational commercial facilities, and LanzaTech anticipates the launch of two additional commercial facilities, in Asia, before the end of the year.

SigmaRoc's first carbon capture facility launched at Nordkalk's Köping site

www.sigmaroc.com
www.aqualung-cc.com

SigmaRoc plc, the specialist quarried materials group, has installed its first carbon capture unit using Aqualung's novel membrane technology.

The fully scalable carbon capture system is the first implementation of its kind in the industry. The carbon capture system has been developed by Aqualung Carbon Capture AS, a leading provider of membrane-based carbon capture and separation technology based in Norway.

Over the course of the last year, SigmaRoc have reviewed an array of technologies including amine absorption, solid absorption, membrane and cryogenic. The Aqualung membrane technology was considered as best suited for the Group's operations based on the following factors:

- Small footprint
- Low capital expenditure
- Low operating expenditure
- Low complexity and environmentally friendly
- Highly efficient - Highly favourable energy balance
- Fully scalable and modular

The Aqualung module installed in Köping can capture up to 25% of the process emissions emitted from a standard kiln process at Nordkalk and was initially designed as a 'capture and release' system to demonstrate the durability and efficiency of the membranes.

The unit will also be connected to a pilot purification module to simulate settings required to produce higher purities of CO2 for different end use applications that go beyond sequestration requirements.

The Group is working with various businesses and solution providers with regards to the end use of CO2 including being involved with NICE (Norvik Infrastructure CCS East Sweden) project to explore CO2 utilisation options with various partners.

Nordkalk also secured part-funding from the Swedish Energy Agency for the implementation and scaling of the Köping carbon system with the intention to capitalise on the learning from the engineering, commissioning, and operation phase of the initial module.

Klara Helstad, Head of Sustainable industry at the Swedish Energy Agency commented, "This project, funded via the Industrial Leap, is an important step towards the realisation of a full-scale value chain for carbon dioxide capture and storage (CCS) - or utilisation (CCU) - at the Nordkalk Köping site. The results can then be of use in future implementations at other industrial sites"

CCS Europe calls on EU leaders to back CO2 storage and transport

CCS Europe, a coalition of companies from the carbon value chain and campaign groups, has sent a letter to all 27 EU leaders asking them to support the European Commission's proposal for a Net Zero Industry Act.

The letter calls on EU leaders to back the Commission's provisions for carbon storage and urges them to back the development of transport infrastructure for CO2 to benefit the whole of European industry. It also asks EU governments to develop national strategies for CCS to complement the EU-wide measures in the NZIA proposal.

The letter says that EU climate policy has a major weakness which must be addressed if it is to be credible and government support is needed to achieve this:

"Regardless of how much renewable electricity or hydrogen may become available in future, some carbon emissions from industrial processes cannot be avoided. The use of carbon capture and storage (CCS) technologies is essential if the release of CO2 into the atmosphere is to be prevented from many hard-to-abate industrial sectors. These include the manufacture of lime, cement, chemicals and some steel production, together with various other energy- intensive manufacturing and waste-to-energy plants."

"The EU's net-zero ambition recognises that it will not be possible to avoid the release of all greenhouse gases by 2050. to, as well as curbing emissions, the capture and permanent removal of CO2 from biogenic sources has an essential role to play in reducing the concentration of CO2 already in the atmosphere."

"Put simply, without widespread deployment of CCS the EU cannot achieve its net-zero goal."

"Development of the entire CCS value chain, including CO2 capture technologies, transport and storage, will be needed to acheve the EU's climate goals and to support Europe's technological leadership. Sites for permanent CO2 storage, and the associated infrastructure, must be made available as soon as possible to encourage emitters to invest in capture facilities."

"CCS Europe, the coalition on whose behalf I am writing, includes industrial companies, business associations and environmental NGOs amongst its members. It is clear to us that too few Member States recognise the need to develop national CCS deployment strategies. The President of the European Commission, Ursula von der Leyen, has said that the EU will need to be storing 300 million tonnes of CO2 annually by 2050. At present, no commercial storage sites in operation, but the Commission has proposed in its Net-Zero Industry Act that storage capacity of 50 million tonnes annually should be made available by 2030."

"The increase in the cost of ETS allowances, the pending withdrawal of free allowances, and access to EU funding programmes and national support schemes will all help to develop the business case for investment in CO2 capture. The provision of sites for permanent CO2 storage on a non-discriminatory and competitive basis is technically realistic and will remove the greatest obstruction to CCS deployment."

"However, additional arrangements must also be made for CO2 transportation. CCS Europe urges all Member States to promote the development of a CO2 transport infrastructure that in time will grow to serve European industry on an extensive basis."

"It is essential that every Member State identifies the requirements of its industry in order to secure emission reductions on the scale needed. Widespread deployment of CCS technologies will prove essential to the achievement of the net-zero ambition."

"The Commission's proposals within the Net-Zero Industry Act deserve the support of your government. We strongly encourage you to complement a Europe-wide approach with the promotion of national strategies to secure the capture and permanent storage of CO2 from industries that will have no choice but to release it into the atmosphere."

CCS Europe is an advocacy and communications body supported by technology providers, project developers, industry and environmental NGOs, who share a commitment to achieve significant reductions in CO2 emissions.

The focus of CCS Europe will be energy-intensive and hard to abate industry that cannot eliminate CO2 emissions other than by capture and permanent storage of CO2 in geological formations or in materials where CO2 is permanently chemically bound under normal use and disposal.

More information

www.ccs-europe.eu

Transport and storage news

TotalEnergies partners with Petronas and Mitsui on a Carbon Storage hub in Malaysia

www.totalenergies.com
www.petronas.com
www.mitsui.com

The partners will evaluate several CO_2 storage sites in the Malay Basin, including both saline aquifers and depleted offshore fields.

The partnership agreement, which was signed on the opening day of the inaugural Energy Asia event in Kuala Lumpur, aims to develop a CO_2 merchant storage service to decarbonize industrial customers in Asia.

"TotalEnergies is pleased to join forces with Petronas and Mitsui on a Carbon Storage hub in Malaysia to support decarbonization in Asia. We will bring to the partnership our strong CCS expertise, anchored in Europe with a first integrated project in Norway due to start next year and several other projects that will contribute to meeting our carbon storage capacity target of 10 million tons per year by 2030", said Patrick Pouyanné, Chairman and CEO of TotalEnergies.

In Asia, where countries such as South Korea and Japan have pledged for Net Zero Commitment in 2050, the development of a CCS value chain for hard-to-abate industrial emissions will require a specific regulatory framework and significant investment. Through this agreement, the partnership will study several potential storage sites, determine the best technical means to deliver CO_2 to Malaysia from industrial clusters in the region and develop the most appropriate business framework for commercialization of a carbon storage service in Malaysia.

"Petronas is proud to collaborate with forward-looking partners such as TotalEnergies and Mitsui in developing solutions through CCS to move us closer towards a lower-carbon future. The strategic partnership demonstrates Petronas' commitment to position Malaysia as a regional CCS hub to capture opportunities in the energy transition with a focus on reducing the carbon footprint of our operations to continue delivering the energy needs of today", said Tan Sri Tengku Muhammad Taufik, President and Group CEO of Petronas.

Bureau Veritas awards Approval in Principle for ship retrofitting tech

www.bureauveritas.com
www.wahkwong.com.hk

Wah Kwong Maritime Transport Holdings and Qiyao Environmental Technology received the AiP that confirms feasibility of retrofitting CCS technology on existing ships.

The AiP follows a joint study led by BV, Wah Kwong and Qiyao Environ Tec, which validated the technical feasibility of using CCS technology onboard two Wah Kwong vessels.

Hing Chao, Executive Chairman of Wah Kwong, said, "With regulations such as the IMO's CII and the EU ETS coming into force for shipping, it is essential to ensure compliance and to reduce the carbon footprint of existing vessels for years to come. Carbon capture and storage technology is one of the net-zero solutions currently available. Wah Kwong takes a holistic approach to sustainability and is proud to work with Bureau Veritas and Qiyao Environmental Technology on this pioneering application of CCS for the maritime sector, which is now validated with the issuance of an AiP. We hope this would encourage further studies or advance implementation of the CCS technology."

Based on the specific design parameters of the vessels, Qiyao Environ Tec developed a customized design of a CCS unit, which passed laboratory tests, achieving over 85% CO_2 capture from the exhaust gas flow, and is being continuously optimised and upgraded. The system is based on an organic amine solution which extracts CO_2 from exhaust gas, before it is cooled into liquid form and stored in a low temperature storage tank.

The study showed that CCS would enable the two vessels to remain compliant by upgrading and maintaining their CII rating at a C level until 2030. It considered all aspects of retrofit space, operational impact, CAPEX and OPEX, as well as the upcoming EU ETS, to assess the future investment and revenue expectations for each vessel.

BV provided comprehensive support for the project, from vessel selection in the early stages of the project, to the design layout of the CCS system on board, certification and cost analysis. BV reviewed the plans according to existing regulations and rules to ensure the safety of the vessels and equipment, and validate that the carbon emission reduction targets are effectively achieved during the operation of the vessels.

The project aims to support the future commercial application of CCS technology in the maritime sector, providing a clear analysis to guide decision-making by ship owners and related parties, especially for older vessels in operation.

Navigator and Bumi Armada join for CO2 shipping and injection

navigatorgas.com
www.bumiarmada.com

The Bluestreak CO_2 Joint Venture aims to provide an end-to-end CCS solution for carbon emitters in line with the United Kingdom's Industrial Decarbonisation Strategy.

Navigator Holdings, the owner and operator of the world's largest fleet of handysize liquefied gas carriers, and Bumi Armada Berhad, one of the world's largest floating infrastructure operators, will each own 50% of the new venture.

Mads Peter Zacho, Navigator's Chief Executive Officer, commented, "The Bluestreak CO_2 Joint Venture marks the first shipping partnership into the carbon capture sector in the UK. I'm incredibly pleased to have the opportunity to offer an end-to-end solution for customers, particularly those not served by the large "mega-cluster" projects."

It is anticipated that the Bluestreak CO_2 Joint Venture will design and implement a value chain of shuttle tankers delivering to a floating carbon storage & injection unit. The complete value chain is expected to safely and reliably transport and provide buffer storage of liquid carbon dioxide.

The CO_2 is intended to be subsequently injected into offshore storage aquifers and/or depleted oil and gas reservoirs in a controlled manner, with full surveillance and management of the permanent storage location. This approach is anticipated to allow the Bluestreak CO_2 Joint Venture to serve emitters with no access to pipeline infrastructure, to effectively manage their CO_2 emissions.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