Carbon Capture Journal

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Recycling CO2 for oil recovery – an economic and climate conundrum

Bellona: the EU Green Deal Industrial Plan - welcome but not enough

While the intentions behind the Communication are welcome, the announced measures mostly summarise existing support mechanisms. More importantly, it doesn't underline the critical condition for receiving any additional support – significant emission reductions.

On 1 February, the European Commission announced a Green Deal Industrial Plan to enhance the competitiveness of Europe's net-zero industry and support the fast transition to climate neutrality. The plan, aimed at scaling up of the EU's manufacturing capacity for net-zero technologies and products, consists of four pillars: a simpler regulatory framework, faster access to funding, enhancing skills and open trade. The Commission also aims to propose a Net-Zero Industry Act to identify goals for net-zero industrial capacity and provide a regulatory framework suited for its quick deployment.

The suggested measures announce more simplification and flexibility for accessing funds. However, flexibility should not come at the expense of a beneficial climate impact; if taxpayers are footing the bill, the investments for industry need to deliver significant emissions reductions.

CO2 infrastructure: general support present, but specific needs missing from the picture

The development of CO2 infrastructure is needed in industries where other options, such as direct electrification, have a limited deployment potential. The Communication touches upon several regulatory and financial aspects that would benefit the uptake of an EU wide CCS value chain.

The pillars of simple regulatory environment, faster permitting promoting strategic cross-border projects (transportation and CO2 infrastructure) are welcome and helpful to overcome bottlenecks standing in the way of deployment. Such a simplified regulatory framework would need to be harmonised across industries to incentivise a confident EU-wide CCS value chain development. The Communication also allows greater Member State flexibility when it comes to dispersing State Aid towards decarbonisation technologies such as CCS, potentially opening up much needed financing.

However, the lack of specific support mechanisms for CCS is a cause for concern since the technology will play a key part in the decarbonisation of industries such as the cement sector. In comparison, other technologies such as hydrogen are mentioned numerous times as a focus area. Although hydrogen is sure to play a role in EU decarbonisation, the specific focus on it creates a risk of syphoning funds away from CCS, direct electrification measures, and other necessary technologies jeopardises the realisation of an effective industrial climate action plan. For example, the Hydrogen Bank uses funds from the Innovation Fund, making fewer funds available for capital expenditure-heavy activities like CCS.

Embodied Carbon: the recognition of full climate impact of materials is key

A predictable regulatory environment, such as the Commission proposal aims to establish, is crucial to effectively decarbonise the building sector. The proposal does indeed refer to the construction and manufacturing sectors as "key to the green transition", but it fails to address building materials altogether, which are traditionally manufactured via CO2-intensive processes. Thus, we urge the Commission to explicitly include crucial materials such as cement in the scope of "products that are key to meet our climate neutrality goals" .

We welcome the Commission's acknowledgement of the role that European standards have in rolling out new industrial value chains. Establishing clear standards that set thresholds for embodied carbon content in construction materials, together with mandatory green public procurement criteria, will send a clear signal for the creation of lead markets for low-carbon materials, whose uptake will help accelerate the decarbonisation of the building stock. Specific support mechanisms such as carbon contracts for difference are also needed for various low-carbon products, such as cement and steel.

In addition, a harmonised approach at EU level for embodied carbon requirements will ease the burden on industry players that are having to deal with different legislation to that end, as some Member States already include embodied carbon provisions in national legislation (e.g., Denmark). The Net-Zero Industry Act must not only ensure the highest level of harmonisation across Member States, but also that the rapid deployment of clean technologies promotes standardised LCA data collection in buildings.

Conclusions: What's missing?

Overall, the Communication identifies the correct challenges for industrial decarbonisation, but falls short on a few key elements. Going forward, the Net-Zero Industry Act must demonstrate a strong commitment to supporting projects which deliver real emissions reductions. All additional support, financial or regulatory, should only be provided under the condition that the receiving projects and products are climate compatible.

In addition to the needed conditionality, the support aimed at clean technologies should have a stronger focus on the specific infrastructure needed to decarbonise industry. Renewable energy generation and targeted use, the development of grids and CO2 infrastructure are all important elements that will need to be supported in order to create a thriving carbon neutral industry in the EU.

More information
www.bellona.org

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Front cover: Illustration of Removr's planned million-ton facility, to start operations in 2029. The location has yet to be determined, but it could be in Norway or Iceland.
Back cover: The Carbon Storage Assurance Facility Enterprise (CarbonSAFE) Initiative

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Leaders - CCUS in the United States

Projects and policy

Capture and utilisation

Transport and storage

Report: Powering toward 100% clean power by 2035

A report by Evergreen Action and Natural Resources Defense Council finds ambitious carbon standards are critical for U.S. to achieve an 80% clean grid by the end of this decade and keep Biden's climate targets within reach.

The report, "Powering Toward 100 Percent Clean Power by 2035," details how President Biden can build on the clean energy investments in the Inflation Reduction Act (IRA) and close the remaining pollution gap to get on track to achieve his climate commitments.

New modeling in the report finds that the most effective action the administration can take to tackle power sector carbon pollution is to set ambitious carbon pollution standards for new and existing power plants under the Clean Air Act. Specifically, the modeling shows that advancing strong limits on power plant carbon pollution, along with the IRA, could cut power-sector carbon emissions 77 percent below 2005 levels by the end of this decade.

"The IRA was a pivotal moment for climate action in the United States, but it is not mission accomplished for the Biden climate agenda," said Evergreen Action Power Sector Policy Lead Charles Harper. "President Biden committed to the most ambitious set of climate goals in American history—including getting us to 100 percent clean power by 2035 and slashing 2005 climate pollution levels in half by 2030."

"Important progress has been made, but President Biden must take bold action this year in order to deliver on those commitments. By ramping up its work to transition the U.S. economy toward 100 percent clean energy, the Biden administration and state leaders can reduce toxic pollution, cut energy costs, create good jobs, and advance environmental justice. Let's get to work."

The report provides a roadmap to build on the historic climate progress made by the IRA and get on the path to achieve Biden's targets of 100 percent clean electricity by 2035 and a 50-52 percent reduction of economy-wide emissions from 2005 levels by 2030.

In addition to strong power sector standards, NRDC's modeling shows that effective implementation of the IRA, improvements in electricity transmission and stepped-up action by states can put the U.S. on track to a safer, clean energy future.

Recommendations from the report

- Setting ambitious carbon pollution standards for new and existing power plants under the Clean Air Act, through the Environmental Protection Agency (EPA), and setting EPA pollution standards that reduce traditional air and water pollutants and improve public health;
- Expanding transmission capacity, speeding up interconnections, and creating market parity for clean energy at the Federal Energy Regulatory Commission (FERC);
- Implementing the Inflation Reduction Act effectively, with timely federal guidance on the IRA's tax credits and grant programs and the distribution of funds in a way that maximizes carbon reductions and equitable economic opportunity; and
- Advancing climate action at the state level, including accelerated 100 percent clean electricity and pollution standards that align with 80 percent clean power by 2030 and heightened oversight of polluting utilities.

The report assesses the steps the Biden administration must take to stay within reach of 100 percent clean electricity by 2035 and address harmful pollution from fossil generation.

"This new report not only shows that President Biden's climate goals for the power sector are achievable—but it is among the first to lay out how we can actually get there," said Manish Bapna, President and CEO of NRDC.

"We don't need magic bullets or new technologies. We already have the tools—and now we have a roadmap. If the Biden administration, Congress, and state leaders follow it, we will build the better future we all deserve. There is no time for half measures or delay."

The biggest opportunity: EPA carbon standards for new and existing fossil power plants

"Setting stringent carbon pollution standards is the most significant action the federal administration needs to take now to clean up the grid this decade," says Lissa Lynch, Director, Federal Legal Group, Climate & Clean Energy Program at NRDC in a blog post.

"And fortunately, the IRA directs EPA to issue new carbon pollution standards for power plants, and the law's incentives dramatically reduce the cost of such standards for power companies and their customers."

"Based on new NRDC modeling presented in the report, setting strong carbon pollution standards for both existing and new coal and gas plants is estimated to have an equal impact on power sector pollution as the IRA clean electricity tax credits themselves."

"Pairing the IRA with strong EPA carbon standards for power plants, the Biden Administration could cut power sector carbon pollution 77 percent below 2005 levels and achieve a 76 percent clean grid by the end of this decade. However, setting weak standards, or failing to set standards for existing gas plants, would leave potential emission reductions on the table—more than half of the standards' potential carbon reductions would be lost if existing gas plants' carbon pollution is left unregulated."

"We are at a pivotal moment in the clean energy transition. Congress took an enormous step by enacting the IRA's historic clean energy and climate investments. But those investments alone will not achieve our national climate and clean power targets—the Biden administration and state policymakers must take bold actions to reduce power sector pollution and facilitate the buildout of clean energy."

"Decisive and immediate action is required to achieve 80 percent emission reductions by 2030 and keep 100 percent clean power by 2035 within reach. Our new paper lays out the roadmap to reach that essential destination."

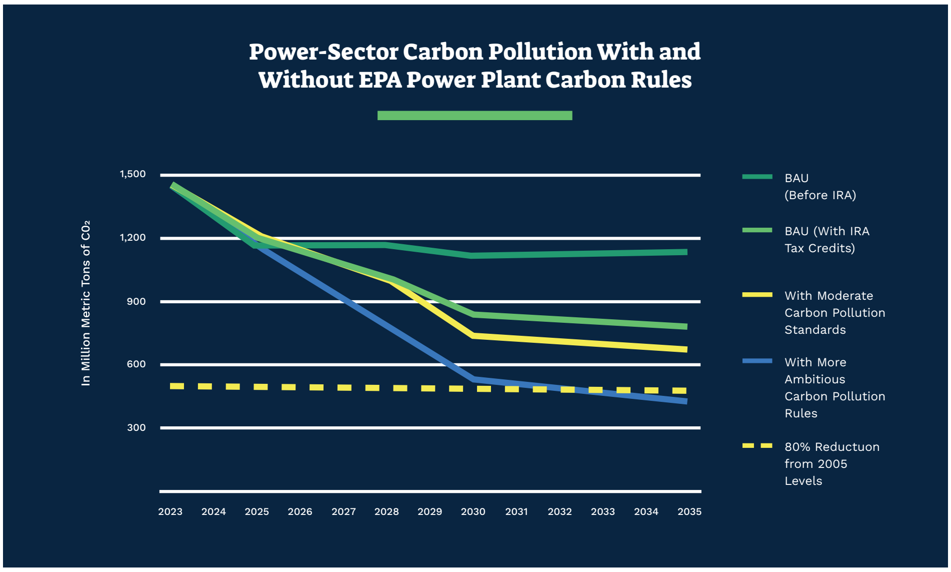

Figure 1 - Power sector emissions under "Business-as-Usual" (BAU) with and without IRA and two regulatory scenarios: the IRA plus moderate carbon pollution standards (covering new gas and existing coal) or with more ambitious standards (also covering existing gas)

Carbon pollution standards for new and existing power plants - background

The Clean Air Act, as amended by the IRA, directs EPA to establish limits on CO2 from new and existing fossil fuel-fired power plants. Under CAA Section 111(b), EPA sets New Source Performance Standards (NSPS) for new plants.

These standards limit the amount of air pollution that can be emitted by a newly built plant. Existing sources are regulated under Section 111(d)—for those, EPA must issue Emission Guidelines, which set emission limits for existing plants and direct states to develop plans for the existing power plants in their state to meet EPA's emission limits.

For both new and existing plants, standards must be based on the emission reductions achievable by the "best system of emission reduction" (BSER) that is available to the plants, as evaluated by EPA on a technical basis. EPA's considerations for new plants, which are designed with the latest technology, may be somewhat different from those for existing plants, which are already in operation and must reduce their current emissions.

EPA first issued power plant CO2 Section 111 rules in 2015 under the Obama administration. The 2015 Section 111(b) NSPS for new coal plants is based on a BSER that includes partial carbon capture and sequestration (CCS); the standard for new gas plants is based on efficient combined cycle technology. Although the NSPS was challenged in court, the litigation has yet to be completed and the standard remains in effect. While the Trump EPA proposed to amend the NSPS in 2018, it never finalized the proposal, leaving the 2015 standard in place.

The 2015 Section 111(d) rule for existing fossil plants, known as the Clean Power Plan (CPP), was based on the emission reductions achievable through the replacement of dirtier generation with cleaner generation, for example through building zero-emitting renewable generation to replace a retiring coal plant. The CPP was challenged in court and stayed by the Supreme Court before it could be implemented.

In 2019, the Trump administration repealed the CPP and replaced it with a new rule based on minor improvements to coal plants' operating efficiency. Litigation challenging the CPP repeal culminated in the Supreme Court's recent decision in West Virginia v. EPA, which constrained—but did not eliminate— EPA's Section 111(d) authority. The Court held that EPA may not base Section 111(d) emission limits on the reductions that could be achieved by replacing dirtier fossil generation with cleaner generation, as EPA had done in the CPP.

Now, EPA must proceed with new rulemakings that conform to West Virginia v. EPA's constraints, by setting standards based on technology that causes individual plants to "operate more cleanly." Such standards could be based on the emission reductions achievable through improvements to the operating efficiency of the plant; co-firing with a cleaner fuel, such as co-firing coal with gas, or gas with hydrogen; or installing CCS.

Although EPA must set the level of the standard based on pollution-control measures that can be installed at the plant itself (sometimes called "inside-thefenceline" measures), states and companies will have flexibility to determine how best to meet the standard—which may include other measures such as ramping down fossil plant generation and investing in zero-emitting generation.

EPA has said that new proposed rules under both 111(b) and 111(d) will be released by April 2023.

NRDC's modeling projects that rules reflecting just partial application of such measures could reduce power sector carbon emissions to 77 percent below 2005 levels by 2030 (see Figure 1).

Relying on adequately demonstrated and cost reasonable technologies that conform to the mandates of West Virginia v. EPA, such as CCS, emission reductions of 90 percent are achievable for both coal-fired and gas fired power plants. Since significant carbon abatement is possible using inside-thefenceline measures, EPA's 111(b) NSPS for new gas plants and 111(d) Emission Guidelines for existing coal and gas plants can and must require substantial carbon pollution reductions.

More information

www.nrdc.org

www.evergreenaction.com

The Texas Solution to Net-Zero

While the overall US clean energy transition has been analyzed, the state of Texas's specific energy transition has not been studied. The combination of the state's large cluster of high carbon emitters, proximal capacity to geologic carbon storage capacity, and an existing backbone of pipeline infrastructure places it in a unique position to directly provide clean energy to the Texas grid using carbon capture and storage (CCS).
By Cynthia L. Taylor, doctoral candidate at Southern Methodist University.

Given solar and wind renewable energy is only available to the grid when the sun shines and the wind blows, fossil fuel generated energy is needed to keep the grid running with reliable power capacity. By decarbonizing fossil power through carbon capture and storage, it will enable the Texas grid to provide clean energy 24/7.

Texas could lead the US in the energy transition to net-zero. Testing the effect of a procurement premium on demand for carbon-free electricity in Texas, as well as its impact on demand for natural gas with CCS is a key factor in my current Texas case study dissertation research.

The Texas Gulf region is one of the largest emitters of carbon in the country with a significant concentration of fossil-fuel and petrochemical operations. Given its close proximity to geologic saline and fossil storage, as well as an established oil and gas transport infrastructure, this region is well positioned for industrial decarbonization using CCS.

Two coal power plants and 24 gas power plants in the region, emitting 15 million and 31.2 million tons of carbon per year respectively, are capable of being retrofitted for carbon capture over the next 10 to 15 years. They are also eligible for the 45Q tax credit.[1] The Gulf region has a skilled workforce in place capable of implementing the transition, allowing it to maintain its leadership position in energy through decarbonization.

The Texas Comptroller's Fiscal Notes discuss how renewable energy sources suppling energy to the Texas grid, which provides 90% of the state's electric load, have been growing due to the Renewable Energy Credit program that was expanded in 2005, increasing the goal to 10,000 MW by 2025.[2]

A NET Power-led consortium aims to accelerate commercialization of its technology by building the first utility scale gas-fired power plant with carbon capture near Odessa, Texas. The project targets approximately 300 megawatts of carbon-free power and will transport captured CO2 to a permanent underground sequestration location through Occidental's existing Permian CO2 handling infrastructure and operations

According to ERCOT, in 2022, 44% of the generating capacity of the grid was derived from natural gas, 29% from wind, 12% from coal, 9% from solar, 4% from nuclear, and the balance from storage, hydro, and biomass sources.[3] Using CCS, significant levels of clean energy supplied by Houston area power plants could be put on the grid. Decarbonized fossil energy together with renewable energy would provide clean energy 24/7 to Texas consumers. Retrofitting these facilities has also become significantly more economically viable with the increased 45Q tax credit provided in the Inflation Reduction Act (IRA).

The IRA is the most comprehensive legislation ever enacted by Congress and the US government to fight climate change. Provisions in the IRA lower the cost of commercial clean technology, including wind and solar energy generation and electric vehicles, as well as improve building efficiency. To stimulate private sector investment in decarbonized power generation, the IRA increased the section 45Q carbon capture tax credit for point source CCS from $50/ton to $85/ton for permanently stored carbon in geologic saline formations.

The tax credit for carbon captured and stored as a tertiary injectant for use in enhanced oil recovery was increased from $35/ton to $60/ton. Both rates are subject to prevailing wage and apprenticeship requirements to ensure CCS projects provide well-paying jobs and training opportunities. The credit will now be paid out during the first 12 years of project operations. The direct pay option in

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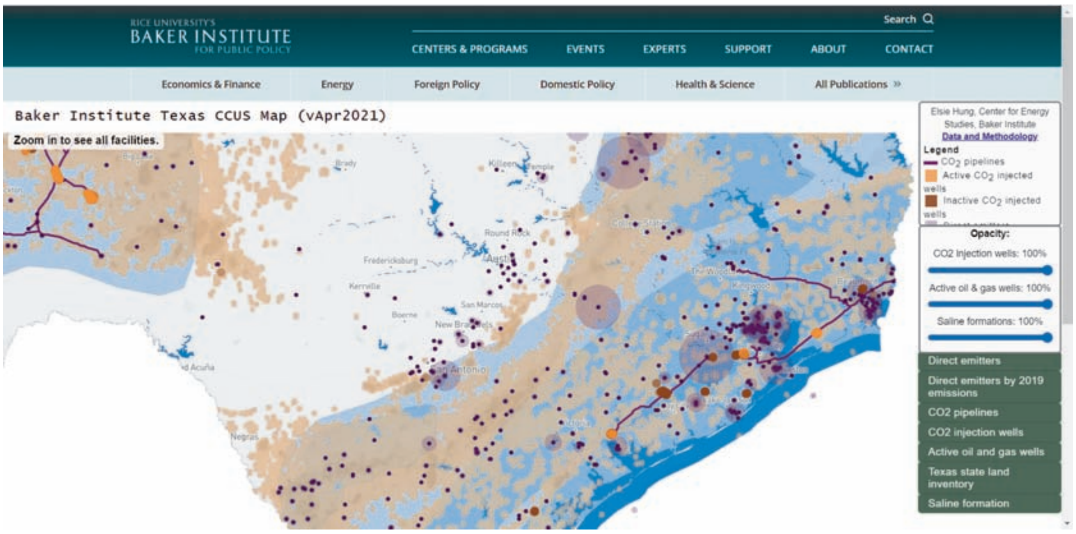
2. Lisa Minton, Texas Electricity Resources: Where Power Comes From – and How it Gets to You, (Austin: Texas Comptroller, 2020), https://comptroller.texas.gov/economy/fiscal-notes/2020/august/ercot.php
3. ERCOT Fact Sheet (Austin: ERCOT, 2022), https://www.ercot.com/files/docs/2022/02/08/ERCOT_Fact_Sheet.pdf

which the tax credit is fully refundable, as well as the eligibility to transfer it to other taxable entities with corporate tax liability, have made CCS projects imminently more attractive for investors.



The interactive Texas CCUS map from the Baker Institute at Rice University visualizes the state's carbon capture landscape with key layers, including existing CO2 pipeline infrastructure, CO2 injections, oil and gas production activities, and sources of CO2 emissions

The provisions of the IRA also relaxed the annual carbon capture threshold for electricity generating facilities from 500,000 tons of carbon per year to 18,750 tons per year. The annual carbon capture threshold for all other industrial facilities, such as ethanol, steel, cement, and petrochemicals, was reduced to 12,500 tons per year. Clean generation in the electricity sector is expected to increase by around 40% to 60-81% by 2030 due to provisions in the IRA. These increases will help to secure the Biden Administration's goal of reaching 100% clean electricity generation by 2035.[4]

Private sector investment in point source CCS used in power generation has become more economically viable with increased and monetizable 45Q tax benefits, plus potential revenue streams from the utilization of carbon in plastics, fuels, and chemical feedstocks, as well as voluntary carbon credit sales. The use of securitization funding to level out the cost of electricity to consumers in the energy transition could also increase the likelihood of a viable revenue stream from sales of clean fossil power on the grid. Reducing the clean energy procurement premium to electricity consumers could fill the revenue stream gap to boost returns needed to spur private sector investment.

Securitization funding was used to finance the unprecedented cost of damage caused to Texas electric utilities by winter storm Uri in February 2021. The Texas legislature authorized the issuance of securitization funding by electric utilities to fund costs that would otherwise have been passed on to ratepayers immediately. $2.1 billion of bonds issued by Texas Electric Market Stabilization Funding in June 2022 enabled the cost of damages to be spread over the term of the bonds of up to 28 years.

As the bonds were awarded the strongest credit rating possible by Moody's Investors Service, the average borrowing rate was exceptionally low. An average interest rate of around 4.9% was passed on to ratepayers in the form of a separate monthly charge on their electricity bill. Bonds with the exact same structure and provisions could be issued to finance the energy transition in Texas to provide clean energy 24/7 to Texas consumers.[5]

State statues such as HB 200 in Wyoming, which promotes the transition to clean energy through retrofitting existing fossil fuel power plants with CCS by allowing cost recovery of investment in CCS from ratepayers, also help to stimulate investment. This statue is meant to provide dispatchable, low-carbon electricity that is available for use on demand through CCS technology.

This is precisely the power needed for peaking capacity on the grid when renewable energy is not accessible. State policies that allow for investment in CCS through rate recovery, securitization funding for the clean energy transition, as well as possible modifications to renewable portfolio standards to incorporate energy produced using CCS, are all key drivers to spur further investment in point source CCS.

Given the natural advantage in the Texas Gulf region of scaling up the deployment of CCS, as well as the recent amendments to the Section 45Q tax credit in the IRA, private sector investment in CCS projects in Texas is likely to increase. Enabling securitization funding to flatten the cost of decarbonization for ratepayers will be strategic in the implementation of Texas's energy transition. Enacting state policy similar to that in Wyoming, which allows cost recovery of investment in CCS for retrofitting existing fossil fuel power plants, would accelerate the process.

Given the long-established oil and gas infrastructure in the Texas Gulf region, the significant geologic fossil and saline storage capacity, as well as Texas's unique independent electricity grid, Texas is well positioned to lead the country is the energy transition using CCS technology for decarbonization.

My current dissertation research is focused on investigating private sector CCS investment drivers, federal and state policy, as well as electricity prices required to achieve 24/7 clean energy on the Texas grid.

More information

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4. John Larsen, Ben King, Hannah Kolus, Naveen Dasari, Galen Hiltbrand, and Whitney Herndon, A Turning Point for US Climate Progress: Assessing the Climate and Clean Energy Provisions in the Inflation Reduction Act (Washington DC: Rhodium Group, 2022), https://rhg.com/research/climate-clean-energy-inflationreduction- act/
5. $2,115,700,000, Texas Electric Market Stabilization Funding Offering Memorandum (Austin: ERCOT, 2022), https://www.ercot.com/files/docs/2022/06/17/Offering%20Memorandum.pdf

NETL project partner demonstrates over 2.8 million tonnes of CO2 capture

Food processing company Archer Daniels Midland (ADM), with support from NETL, demonstrated an integrated system of processing carbon dioxide and transporting it from an ethanol plant to the Mt. Simon Sandstone saline reservoir for permanent geologic storage.

This is the largest demonstration of its kind in the United States and marks a crucial step forward in efforts to decarbonize the U.S. economy and power sector by 2050.

The system demonstrated by ADM at the company's Agricultural Processing and Biofuels Plant, located in Decatur, Illinois, collected CO2 produced as a byproduct of processing corn into fuel-grade ethanol. ADM carbon capture and storage (CCS) is the first geologic storage project to operate with the U.S. Environmental Protection Agency's Class VI injection well permit. Under this Class VI permit, the cumulative amount of CO2 injection into the Mt. Simon Sandstone saline reservoir was over 2.8 million tonnes.

"Widespread deployment of large-scale CCS technologies at sites like ADM's ethanol plant could offer insight into reducing CO2 emissions at industrial operations throughout the country," said Sai Gollakota, NETL federal project manager.

Injection start-up day at the Illinois Basin - Decatur Project. Pictured are project principal investigator Sallie Greenberg, second from right, and other project partners

Saline reservoirs are layers of porous rock that are saturated with brine, a concentrated salt solution. Mt. Simon Sandstone could potentially store billions of tons of CO2 and is a clean sedimentary rock dominated by silicate minerals and lacking significant amounts of clay minerals, which typically clog pores and reduce porosity.

This composition results in highly favorable porosity and permeability features for CO2 storage. Supercritical CO2 fluid is injected into the saline reservoir at a depth of approximately 6,800 feet at a site adjacent to the ADM ethanol plant. Nearly 50 years of successful natural gas storage in the Mt. Simon Sandstone indicates that this saline reservoir and overlying seals should effectively contain sequestered CO2.

The ADM project, conducted in partnership with the Illinois State Geological Survey, Schlumberger Carbon Services and Richland Community College, will continue to monitor CO2 migration and protect groundwater sources in the area. The success of this project could also facilitate exploration of long-term CO2 utilization options in the Southern Illinois Basin.

"The work in Illinois is a prime example of collaboration between private industry, academia and government and shows what NETL can help achieve." Gollakota said. Even after the end of DOE agreement in September 2022, ADM has been continuing CCS operations in Decatur, and is actively working on commercializing the geologic storage technologies it has developed in this project. Working with other industry partners, ADM has plans for expanding the scale of CCS in Illinois by developing CO2 pipeline infrastructure.

Advanced CCS technologies offer significant potential for reducing CO2 emissions, while minimizing the economic impacts of the solution.

NETL is a U.S. Department of Energy national laboratory that drives innovation and delivers technological solutions for an environmentally sustainable and prosperous energy future. By leveraging its world-class talent and research facilities, NETL is ensuring affordable, abundant and reliable energy that drives a robust economy and national security, while developing technologies to manage carbon across the full life cycle, enabling environmental sustainability for all Americans.

More information

netl.doe.gov

www.adm.com

NETL Pittsburgh site to host DAC centre

A new facility will be established with the goal of jumpstarting the development of direct air capture (DAC) technologies that can provide new economic opportunities while lowering CO2.

Last year, the U.S. Congress authorized $25 million for the new NETL Direct Air Capture Center. Scheduled to come online during the summer of 2024, the new facility will accelerate the commercialization of DAC technologies beyond the conceptual stage. The facility will provide developers with the ability to operate over a wide range of conditions, which will enable better understanding of how various DAC technologies respond in different climates.

"DAC technology is still early in its evolution, and a wide variety of technologies are being explored," said David Luebke, technical director of the NETL Direct Air Capture Center. "The new facility will be designed with substantial flexibility to accommodate the rapidly evolving technological landscape. The Center will feature dedicated engineering, scientific and logistical support for experimental system design, installation, execution of experiments, and interpretation of results."

Testing systems at three scales will be included at the DAC Center: lab-scale systems designed to examine the long-term stability of DAC materials, bench-scale module testing systems capable of probing flow dynamics, and small pilot-scale skid rooms able to test prototype DAC units under a broad range of climate conditions.

NETL is well-positioned to lead the development of DAC technology. The Lab has been instrumental in advancing research to capture CO2 from the flue gas streams produced by power plants and other industries and store it permanently and safely in deep underground complexes and geologic reservoirs or use it as a feedstock to produce higher-value products such as chemicals and plastics.

Projects at the DAC Center will have access to a plethora of dedicated NETL process modeling and analysis resources to evaluate the technoeconomic aspects of new technologies, a step toward commercialization and widespread adoption. Data generated by the DAC Center will also play a major role in enabling life cycle analysis (LCA) of emerging capture technologies.

"DAC will be a cornerstone of decarbonizing the nation's economy," Luebke said. "The NETL DAC Center will become the gold standard in technology performance characterization as we collaborate with our partners to explore the potential of their diverse direct air capture concepts."

PNNL reveals 'cheapest' CO2 capture at $39 per metric ton

Researchers at the Department of Energy's Pacific Northwest National Laboratory have created a new system that efficiently captures CO2 - the least costly to date - and converts it into one of the world's most widely used chemicals: methanol.

Snaring CO2 before it floats into the atmosphere is a key component in slowing global warming. Creating incentives for the largest emitters to adopt carbon capture technology, however, is an important precursor. The high cost of commercial capture technology is a longstanding barrier to its widespread use.

PNNL scientists believe methanol can provide that incentive. It holds many uses as a fuel, solvent, and an important ingredient in plastics, paint, construction materials and car parts. Converting CO2 into useful substances like methanol offers a path for industrial entities to capture and repurpose their carbon.

PNNL chemist David Heldebrant, who leads the research team behind the new technology, compares the system to recycling. Just as one can choose between single-use and recyclable materials, so too can one recycle carbon.

"That's essentially what we're trying to do here," said Heldebrant. "Instead of extracting oil from the ground to make these chemicals, we're trying to do it from CO2 captured from the atmosphere or from coal plants, so it can be reconstituted into useful things.

You're keeping carbon alive, so to speak, so it's not just 'pull it out of the ground, use it once, and throw it away.' We're trying to recycle the CO2, much like we try to recycle other things like glass, aluminum and plastics."

As described in the journal Advanced Energy Materials, the new system is designed to fit into coal-, gas-, or biomass-fired power plants, as well as cement kilns and steel plants. Using a PNNL-developed capture solvent, the system snatches CO2 molecules before they're emitted, then converts them into useful, sellable substances.

A long line of dominoes must fall before carbon can be completely removed or entirely prevented from entering Earth's atmosphere. This effort—getting capture and conversion technology out into the world—represents some of the first few crucial tiles.

Taking up only as much space as a walk-in closet, a new carbon capture and conversion system is simple and efficient at removing carbon dioxide from gas that's rich with carbon dioxide. On the left of this walk-in fume hood, "smoke" moves through a cylindrical container where it makes contact with a carbon-capturing solvent. That solvent chemically binds to carbon dioxide and, on the right, is converted to methanol. (Photo by Eric Francavilla | Pacific Northwest National Laboratory)

Deploying this technology will reduce emissions, said Heldebrant. But it could also help stir the development of other carbon capture technology and establish a market for CO2-containing materials. With such a market in place, carbon seized by anticipated direct air capture technologies could be better reconstituted into longer-lived materials.

The call for cheaper carbon capture

In April 2022, the Intergovernmental Panel on Climate Change issued its Working Group III report focused on mitigating climate change. Among the emissions-limiting measures outlined, carbon capture and storage was named as a necessary element in achieving net zero emissions, especially in sectors that are difficult to decarbonize, like steel and chemical production.

"Reducing emissions in industry will involve using materials more efficiently, reusing and recycling products and minimizing waste," the IPCC stated in a news release issued alongside one of the report's 2022 installments.

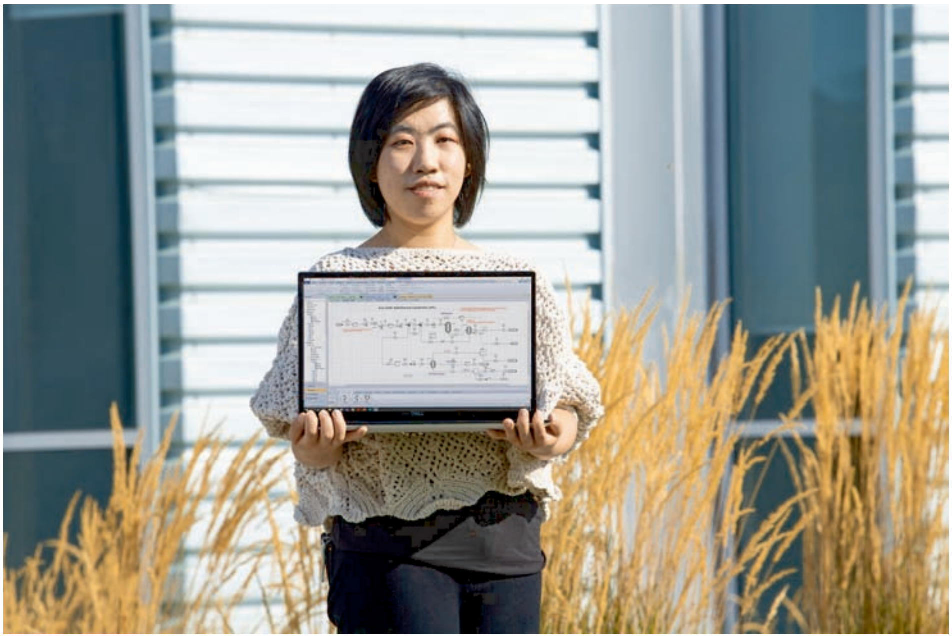
"In order to reach net zero CO2 emissions for the carbon needed in society (e.g., plastics, wood, aviation fuels, solvents, etc.)," the report reads, "it is important to close the use loops for carbon and carbon dioxide through increased circularity with mechanical and chemical recycling."

PNNL's research is focused on doing just that—in alignment with DOE's Carbon Negative Shot. By using renewably sourced hydrogen in the conversion, the team can produce methanol with a lower carbon footprint than conventional methods that use natural gas as a feedstock. Methanol produced via CO2 conversion could qualify for policy and market incentives intended to drive adoption of carbon reduction technologies.

Methanol is among the most highly produced chemicals in existence by volume. Known as a "platform material," its uses are wide ranging. In addition to methanol, the team can convert CO2 into formate (another commodity chemical), methane and other substances.

A significant amount of work remains to optimize and scale this process, and it may be several years before it is ready for commercial deployment. But, said Casie Davidson, manager for PNNL's Carbon Management and Fossil Energy market sector, displacing conventional chemical commodities is only the beginning.

"The team's integrated approach opens up a world of new CO2 conversion chemistry. There's a sense that we're standing on the threshold of an entirely new field of scalable, cost-effective carbon tech. It's a very exciting time."



Chemical engineer Yuan Jiang analyzed the operating costs of a new carbon capture and conversion system, finding it could do the job for about $39 per metric ton of carbon dioxide. (Photo by Andrea Starr | Pacific Northwest National Laboratory)

Crumbling costs

Commercial systems soak up carbon from flue gas at roughly $46 per metric ton of CO2, according to a DOE analysis. The PNNL team's goal is to continually chip away at costs by making the capture process more efficient and economically competitive.

The team brought the cost of capture down to $47.10 per metric ton of CO2 in 2021. A new study described in the Journal of Cleaner Production explores the cost of running the methanol system using different PNNL-developed capture solvents, and that figure has now dropped to just below $39 per metric ton of CO2.

"We looked at three CO2-binding solvents in this new study," said chemical engineer Yuan Jiang, who led the assessment. "We found that they capture over 90 percent of the carbon that passes through them, and they do so for roughly 75 percent of the cost of traditional capture technology."

Different systems can be used depending on the nature of the plant or kiln. But, no matter the setup, solvents are central. In these systems, solvents wash over CO2-rich flue gas before it's emitted, leaving behind CO2 molecules now bound within that liquid.

Creating methanol from CO2 is not new. But the ability to both capture carbon and then convert it into methanol in one continuously flowing system is. Capture and conversion has traditionally occurred as two distinct steps, separated by each process's unique, often non-complementary chemistry.

"We're finally making sure that one technology can do both steps and do them well," said Heldebrant, adding that traditional conversion technology typically requires highly purified CO2. The new system is the first to create methanol from "dirty" CO2.

Dialing down tomorrow's emissions

The process of capturing CO2 and converting it to methanol is not CO2-negative. The carbon in methanol is released when burned or sequestered when methanol is converted to substances with longer lifespans. But this technology does "set the stage," Heldebrant said, for the important work of keeping carbon bound inside material and out of the atmosphere.

Other target materials include polyurethanes, which are found in adhesives, coatings, and foam insulation, and polyesters, which are widely used in fabrics for textiles. Once researchers finalize the chemistry behind converting CO2 into materials that keep it out of the atmosphere for climate-relevant timescales, a wide web of capture systems could be poised to run such reactions.

In lieu of today's smokestacks, Heldebrant envisions CO2 refineries built into or alongside power plants, where CO2-containing products can be made on site. "We are at a turning point," Heldebrant and his coauthors wrote in a recent article published in the journal Chemical Science, "where we can continue to use 20th century, monolithic capture and conversion infrastructure or we can begin the transition to a new 21st century paradigm of integrated solvent-based carbon capture and conversion technologies."

The technology is available for licensing. Please contact Sara Hunt, PNNL commercialization manager, to learn more.

This work was supported by the Department of Energy's Technology Commercialization Fund, the Office of Fossil Energy and Carbon Management, and Southern California Gas. Part of the work was performed at EMSL, the Environmental Molecular Sciences Laboratory, a DOE Office of Science user facility at PNNL.

More information

www.pnnl.gov

Can clay capture carbon dioxide?

Led by Sandia chemical engineer Tuan Ho, a team has been using computer models combined with laboratory experiments to study how a kind of clay can soak up carbon dioxide and store it.

The scientists shared their initial findings in a paper published in The Journal of Physical Chemistry Letters.

"These fundamental findings have potential for direct-air capture; that is what we're working toward," said Ho, lead author on the paper. "Clay is really inexpensive and abundant in nature. That should allow us to reduce the cost of direct-air carbon capture significantly, if this high-risk, high-reward project ultimately leads to a technology."

Ho imagines that clay-based devices could be used like sponges to soak up carbon dioxide, and then the carbon dioxide could be "squeezed" out of the sponge and pumped deep underground. Or the clay could be used more like a filter to capture carbon dioxide from the air for storage.

In addition to being cheap and widely available, clay is also stable and has a high surface area — it is comprised of many microscopic particles that in turn have cracks and crevasses about a hundred thousand times smaller than the diameter of a human hair. These tiny cavities are called nanopores, and chemical properties can change within these nanoscale pores, Rempe said.

This is not the first time Rempe has studied nanostructured materials for capturing carbon dioxide. In fact, she is part of a team that studied a biological catalyst for converting carbon dioxide into water-stable bicarbonate, tailored a thin, nanostructured membrane to protect the biological catalyst and received a patent for their bio-inspired, carbon-catching membrane. Of course, this membrane is not made out of inexpensive clay, and was initially designed to work at fossil-fuel-burning power plants or other industrial facilities, Rempe said.

"These are two complementary possible solutions to the same problem," she said.

How to simulate the nanoscale?

Molecular dynamics is a kind of computer simulation that looks at the movements and interactions of atoms and molecules at the nanoscale. By looking at these interactions, scientists can calculate how stable a molecule is in a particular environment — such as in clay nanopores filled with water.

CAUGHT IN CLAY — Sandia bioengineer Susan Rempe, left, and chemical engineer Tuan Ho peer through an artistic representation of the chemical structure of a kind of clay. Their team is studying how clay could be used to capture carbon dioxide. (Photo by Craig Fritz)

"Molecular simulation is really a powerful tool to study interactions at the molecular scale," Ho said. "It allows us to fully understand what is going on among the carbon dioxide, water and clay, and the goal is to use this information to engineer a clay material for carbon-capture applications."

In this case, the molecular dynamics simulations conducted by Ho showed that carbon dioxide can be much more stable in the wet clay nanopores than in plain water, Ho said. This is because the atoms in water do not share their electrons evenly, making one end slightly positively charged and the other end slightly negatively charged. On the other hand, the atoms in carbon dioxide do share their electrons evenly and, like oil mixed with water, the carbon dioxide is more stable near similar molecules, such as the silicon-oxygen regions of the clay, Rempe said.

Collaborators from Purdue University led by Professor Cliff Johnston recently used experiments to confirm that water confined in clay nanopores absorbs more carbon dioxide than plain water does, Ho said.

Sandia postdoctoral researcher Nabankur Dasgupta also found that inside the oil-like regions of the nanopores, it takes less energy to convert carbon dioxide into carbonic acid and makes the reaction more favorable compared to the same conversion in plain water, Ho said. By making this conversion favorable and require less energy, ultimately the oil-like regions of clay nanopores make it possible to capture more carbon dioxide and store it more easily, he added.

"So far, this tells us clay is a good material for capturing carbon dioxide and converting it into another molecule," Rempe said. "And we understand why this is, so that the synthesis people and the engineers can modify the material to enhance the oil-like surface chemistry. The simulations can also guide the experiments to test new hypotheses about how to promote the conversion of carbon dioxide into other valuable molecules."

The next steps for the project will be to use molecular dynamics simulations and experiments to figure out how to get carbon dioxide back out of the nanopore, Ho said. By the end of the three-year project, they plan to conceptualize a clay-based direct-air carbon capture device.

The project is funded by Sandia's Laboratory Directed Research and Development program. The research was performed, in part, at the Center for Integrated Nanotechnologies, an Office of Science user facility operated for the Department of Energy by Sandia and Los Alamos national laboratories.

More information

www.sandia.gov
www.lanl.gov

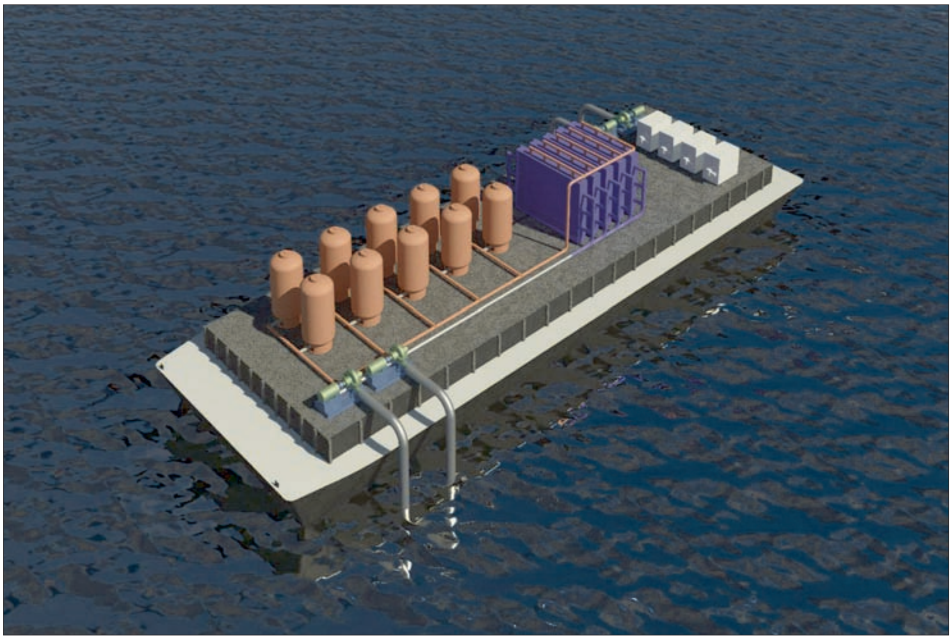
Cheap method for pulling CO2 out of seawater offers new approach

A team of researchers at MIT have found a new method for removing carbon dioxide from the ocean that could be far more efficient than existing systems for removing it from the air.

As carbon dioxide continues to build up in the Earth's atmosphere, research teams around the world have spent years seeking ways to remove the gas efficiently from the air. Meanwhile, the world's number one "sink" for carbon dioxide from the atmosphere is the ocean, which soaks up some 30 to 40 percent of all of the gas produced by human activities.

Recently, the possibility of removing carbon dioxide directly from ocean water has emerged as another promising possibility for mitigating CO2 emissions, one that could potentially someday even lead to overall net negative emissions. But, like air capture systems, the idea has not yet led to any widespread use, though there are a few companies attempting to enter this area.

Now, a team of researchers at MIT says they may have found the key to a truly efficient and inexpensive removal mechanism. The findings were reported in the journal Energy and Environmental Science, in a paper by MIT professors T. Alan Hatton and Kripa Varanasi, postdoc Seoni Kim, and graduate students Michael Nitzsche, Simon Rufer, and Jack Lake.



Researchers have found an effective new method for removing carbon dioxide from the ocean. It could be implemented by ships that would process seawater as they travel, or at offshore drilling platforms or aquaculture fish farms. Images courtesy of the researchers

The existing methods for removing carbon dioxide from seawater apply a voltage across a stack of membranes to acidify a feed stream by water splitting. This converts bicarbonates in the water to molecules of CO2, which can then be removed under vacuum. Hatton, who is the Ralph Landau Professor of Chemical Engineering, notes that the membranes are expensive, and chemicals are required to drive the overall electrode reactions at either end of the stack, adding further to the expense and complexity of the processes. "We wanted to avoid the need for introducing chemicals to the anode and cathode half cells and to avoid the use of membranes if at all possible," he says.

The team came up with a reversible process consisting of membrane-free electrochemical cells. Reactive electrodes are used to release protons to the seawater fed to the cells, driving the release of the dissolved carbon dioxide from the water. The process is cyclic: It first acidifies the water to convert dissolved inorganic bicarbonates to molecular carbon dioxide, which is collected as a gas under vacuum. Then, the water is fed to a second set of cells with a reversed voltage, to recover the protons and turn the acidic water back to alkaline before releasing it back to the sea. Periodically, the roles of the two cells are reversed once one set of electrodes is depleted of protons (during acidification) and the other has been regenerated during alkalization.

This removal of carbon dioxide and reinjection of alkaline water could slowly start to reverse, at least locally, the acidification of the oceans that has been caused by carbon dioxide buildup, which in turn has threatened coral reefs and shellfish, says Varanasi, a professor of mechanical engineering. The reinjection of alkaline water could be done through dispersed outlets or far offshore to avoid a local spike of alkalinity that could disrupt ecosystems, they say.

"We're not going to be able to treat the entire planet's emissions," Varanasi says. But the reinjection might be done in some cases in places such as fish farms, which tend to acidify the water, so this could be a way of helping to counter that effect.

Once the carbon dioxide is removed from the water, it still needs to be disposed of, as with other carbon removal processes. For example, it can be buried in deep geologic formations under the sea floor, or it can be chemically converted into a compound like ethanol, which can be used as a transportation fuel, or into other specialty chemicals. "You can certainly consider using the captured CO2 as a feedstock for chemicals or materials production, but you're not going to be able to use all of it as a feedstock," says Hatton. "You'll run out of markets for all the products you produce, so no matter what, a significant amount of the captured CO2 will need to be buried underground."

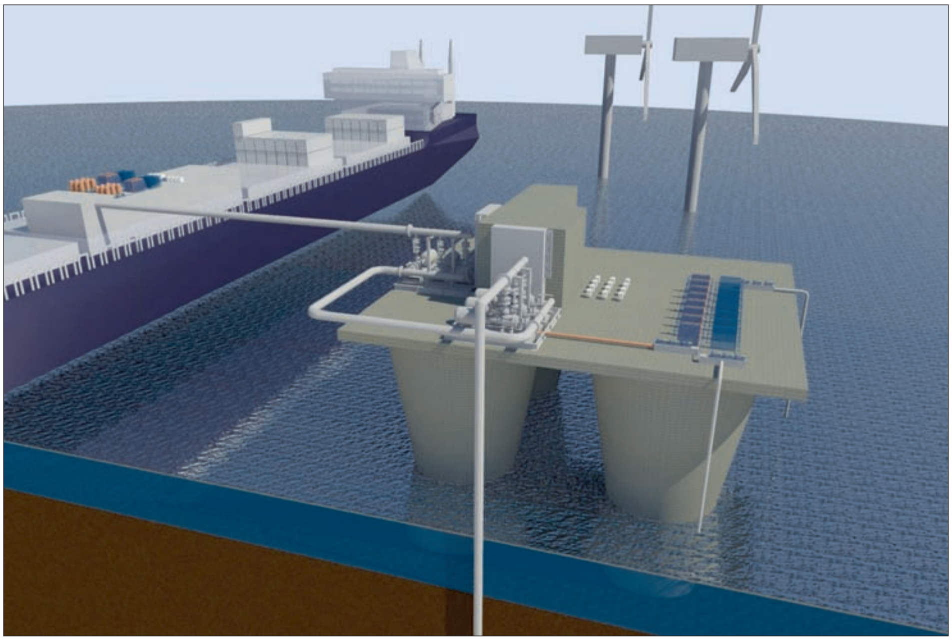
Initially at least, the idea would be to couple such systems with existing or planned infrastructure that already processes seawater, such as desalination plants. "This system is scalable so that we could integrate it potentially into existing processes that are already processing ocean water or in contact with ocean water," Varanasi says. There, the carbon dioxide removal could be a simple add-on to existing processes, which already return vast amounts of water to the sea, and it would not require consumables like chemical additives or membranes.

"With desalination plants, you're already pumping all the water, so why not co-locate there?" Varanasi says. "A bunch of capital costs associated with the way you move the water, and the permitting, all that could already be taken care of."

The system could also be implemented by ships that would process water as they travel, in order to help mitigate the significant contribution of ship traffic to overall emissions. There are already international mandates to lower shipping's emissions, and "this could help shipping companies offset some of their emissions, and turn ships into ocean scrubbers," Varanasi says.

The system could also be implemented at locations such as offshore drilling platforms, or at aquaculture farms. Eventually, it could lead to a deployment of free-standing carbon removal plants distributed globally.

The process could be more efficient than air-capture systems, Hatton says, because the concentration of carbon dioxide in seawater is more than 100 times greater than it is in air. In direct air-capture systems it is first necessary to capture and concentrate the gas before recovering it. "The oceans are large carbon sinks, however, so the capture step has already kind of been done for you," he says. "There's no capture step, only release." That means the volumes of material that need to be handled are much smaller, potentially simplifying the whole process and reducing the footprint requirements.



Initially, the system can use existing or planned infrastructure that already processes seawater, such as desalination plants, but the system is scalable. This rendering shows how the new method could also be used by ships and offshore platforms

The research is continuing, with one goal being to find an alternative to the present step that requires a vacuum to remove the separated carbon dioxide from the water. Another need is to identify operating strategies to prevent precipitation of minerals that can foul the electrodes in the alkalinization cell, an inherent issue that reduces the overall efficiency in all reported approaches. Hatton notes that significant progress has been made on these issues, but that it is still too early to report on them. The team expects that the system could be ready for a practical demonstration project within about two years.

"The carbon dioxide problem is the defining problem of our life, of our existence," Varanasi says. "So clearly, we need all the help we can get."

More information

www.mit.edu

U.S. CCS news

U.S. DOE awards $2.52 Billion for commercial CCS demonstrations

www.energy.gov

The Biden-Harris Administration announced $2.52 billion in funding for two carbon management programs to catalyze investments in transformative carbon capture systems and carbon transport and storage technologies.

Funded by President Biden's Bipartisan Infrastructure Law, the two programs—Carbon Capture Large-Scale Pilots and Carbon Capture Demonstration Projects Program—aim to significantly reduce carbon dioxide emissions from electricity generation and hard-to-abate industrial operations, an effort critical to addressing the climate crisis and meeting the President's goal of a net-zero emissions economy by 2050.

The new programs will help accelerate the demonstration and deployment of carbon management technologies, supporting the Biden-Harris Administration's efforts to create good-paying manufacturing jobs, reduce pollution to deliver healthier communities, and reinforce America's global competitiveness in the clean energy technologies of the future.

"Drastically cutting emissions across our economy through next-generation carbon management technologies is a critical component of President Biden's strategy to combat the climate crisis and achieve our ambitious clean energy goals," said U.S. Secretary of Energy Jennifer M. Granholm. "By focusing on some of the most challenging, carbon intensive sectors and heavy industrial processes, today's investment will ensure America is on a path to reach net-zero emissions by 2050 and at the forefront of the global clean energy revolution."

The electricity generation and industrial sectors account for a large portion of U.S. carbon emissions. Successfully scaling carbon management technology—especially in hard to decarbonize sectors and heavy industries such as steel and cement production— is a key component of President Biden's plan to combat the climate crisis and achieve a net-zero carbon economy by 2050. In addition to reducing harmful greenhouse gas emissions, these technologies will also help deliver clean air and other environmental benefits to communities across the country while revitalizing local economies.

One Carbon Partnership formed for ethanol CCS project

www.cardinalethanol.com

www.vault4401.com

Cardinal Ethanol and Vault 44.01 Ltd. have formed a joint venture to design, implement, and operate a CCS project at Cardinal's ethanol production facility near Union City, Indiana.

Cardinal's facility produces approximately 135 million gallons of ethanol per year, which generates approximately 400,000 metric tons of CO_2 as a by-product of the corn fermentation process.

"We are committed to enhancing shareholder value through employing the latest technology in the production of clean, low carbon intensity and environmentally friendly bioethanol. Partnering with Vault 44.01 on this CCS project is another step in Cardinal Ethanol's commitment to further lower our carbon impact and protect our environment. This partnership aligns with Cardinal Ethanol's goals and keeps us on a path to zero emission liquid fuels," said Jeff Painter, Chief Executive Officer, Cardinal ethanol, LLC.

One Carbon Partnership plans to construct a facility to capture the CO_2 generated from the ethanol production process and safely and permanently store such emissions deep underground in a secure geologic reservoir, thereby substantially reducing the CO_2 emissions from the ethanol production process.

While the project is still in its early stages and subject to customary variables that could influence the project, the partnership has submitted a Class VI permit application to EPA Region 5 in support of the project and has received a completeness determination from the EPA. The partners have engaged with local landowners and communities about the potential project and are very pleased with the support they have received.

"We are pleased to be working with the excellent team at Cardinal and are excited to have reached several important milestones in the development of this high quality, early-to-market CCS project. This project with Cardinal exemplifies our view that the lowest cost option for CCS is often to find a local solution, where that's possible," said Scott Rennie, Chief Executive Officer, Vault 44.01.

CF Industries and LOTTE CHEMICAL explore clean ammonia project

www.cfindustries.com

www.lottechem.com

The companies have signed an MoU for a joint exploration of clean ammonia production based in the U.S. and long-term clean ammonia offtake into South Korea.

The MOU establishes a framework for the companies to assess the joint development of and investment in a greenfield clean ammonia production facility in the U.S., including at CF Industries' Blue Point Complex in Louisiana. The companies believe that the U.S. offers considerable advantages for clean ammonia production, including access to plentiful and low-cost natural gas, the regulatory and legal framework in place, and the geology suitable for permanent carbon sequestration.

The prospective ammonia facility would use CCS technologies to reduce CO_2 emissions from the ammonia production process to a level that meets or exceeds South Korea's clean ammonia requirements.

Additionally, the companies will quantify expected clean ammonia demand in South Korea for power generation, bunkering and other sectors, taking into account regulatory and policy requirements, as well as safety and environmental considerations. This workstream will confirm the scale of long-term offtake volume expectations for a potential clean ammonia facility.

"We are pleased to advance our relationship with LOTTE and leverage the world class expertise of both companies to meet the substantial emerging demand for clean ammonia in South Korea," said Tony Will, president and chief executive officer, CF Industries Holdings, Inc. "We look forward to helping LOTTE and South Korea meet their clean ammonia requirements as we continue to accelerate the world's transition to clean energy."

The MOU is part of LOTTE's efforts to develop a global clean ammonia supply chain to support its hydrogen energy business for global clean energy supply and carbon reduction growth. LOTTE has established a plan to produce and sell 1.2 million tons of clean hydrogen by 2030. Clean ammonia is seen as a safe and efficient hydrogen carrier and storage mechanism.

CarbonFree and bp collaborate on CCS for industrial sites

carbonfree.cc

The development agreement focuses on deploying CarbonFree's proprietary SkyCycle™ technology at hard-to-abate industrial sites.

bp ventures has been an investor in CarbonFree for nearly 10 years. bp and CarbonFree will work to identify and pursue potential SkyCycle development projects at industrial facilities.

"CarbonFree has been a bp ventures portfolio company for nearly 10 years and during this period we have worked together to help make carbon capture a commercial reality for industrial companies looking to decarbonize. As bp looks to become a net zero company by 2050 or sooner, and help the world get to net zero, CarbonFree's SkyCycle technology can play a role in helping heavy industry make progress toward their net zero goals. This agreement is an important milestone in our relationship with CarbonFree and we look forward to our ongoing collaboration," said Orlando Alvarez, SVP, gas and power trading Americas at bp.

CarbonFree's SkyCycle captures and uses carbon emissions from hard-to-abate industrial sources by converting CO_2 into specialty chemicals, including calcium carbonate. Calcium carbonate comprises more than 4% of the earth's crust and is found throughout the world as chalk, limestone and marble.

CarbonFree has been developing and refining the technology for more than 15 years and the company's ambition is to capture 10% of the world's industrial carbon, thereby helping industries and companies reach their net zero goals.

"We are working with bp to accelerate the introduction of SkyCycle to the market," said CarbonFree CEO Martin Keighley. "As a valued supporter for nearly a decade, bp understands our technology and the potential impact it can have on helping decarbonize hard-to-abate industrial sites. SkyCycle is an innovative solution in this space, with already-proven technology and a compelling business proposition for customers."

SkyCycle is a modular, scalable and patented technology designed to directly capture CO_2 emissions from a wide variety of hard-to-abate industrial emitters. The technology produces precipitated calcium carbonate (PCC). PCC is a high-value product used for a variety of industrial purposes, including in the manufacturing of paper, plastics, ceramics, paints, coating, adhesives, sealants, rubber and cleaning products.

CarbonFree's SkyCycle™ technology demonstration plant in San Antonio, Texas

SK Inc. and ION Clean Energy enter commercialisation partnership

ioncleanenergy.com

eng.sk.com

The companies have formed a new licensing partnership for the exclusive deployment of ION's industry-leading carbon capture technology in Asia and Australia.

SK Inc., the strategic investment arm of South Korea's SK Group, has also completed a strategic minority equity investment in ION. The collaboration between SK and ION will focus on evaluating global opportunities in the areas of R&D, technology enhancements, supply chain management and commercial project development.

"Our partnership with ION comes at a perfect time, as commercial demand for carbon capture, utilization and storage (CCUS) technologies continues to grow exponentially," said Youngwook Lee, CEO of SK Inc. Materials. "We believe ION's industry leading technology will become a catalyst for faster development of the entire CCUS industry, and this investment strengthens our ability to provide holistic CCUS solutions to industrial carbon emitters across the globe."

SK Inc. has been expanding its investments in green businesses and technologies to support SK Group's overarching goal of achieving net-zero greenhouse gas emissions to mitigate the effects of climate change. The investment in ION underscores SK Inc.'s commitment to this endeavor and supports ION's goal of eliminating 1 billion tonnes of CO_2 emissions by 2050 from utility and industrial sources.

"We're honored and excited to partner with SK to continue the development and commercial deployment of ION's products" said Buz Brown, CEO of ION Clean Energy. "Their belief in our technology validates the work and dedication of our team over the last decade. SK's commitment to our partnership has us feeling very bullish about the positive impact we can make together on commercial projects around the world. This is a big step in our growth and will accelerate ION's momentum to match the market demand."

ION is commercializing its proprietary liquid absorbent process and enabling technologies for use by large point sources, including natural gas and coal-fired power plants, as well other industrial CO_2 emitters such as hydrogen, cement, petrochemical, steel, and mining operations.

Its solvent-based capture technology for post-combustion utility and industrial source applications has a direct impact on reducing CapEx and OpEx, while capturing at least 95% of CO_2 from stack emissions and flue gases. Additionally, ION's energy efficiency, robust performance, and environmentally advantageous features can help drive down the lifetime cost of technology and greatly contribute to reducing the overall cost of CO_2 capture.

Recycling CO2 for oil recovery – an economic and climate conundrum

Balancing increasing demand for oil while lowering greenhouse gas (GHG) emissions is the greatest challenge facing the industry today: global consumption is currently around 100 million barrels per day (mb/d), despite a ramp up in renewables.

By Ole Gunnar Tveiten, Advisor Geology, AGR

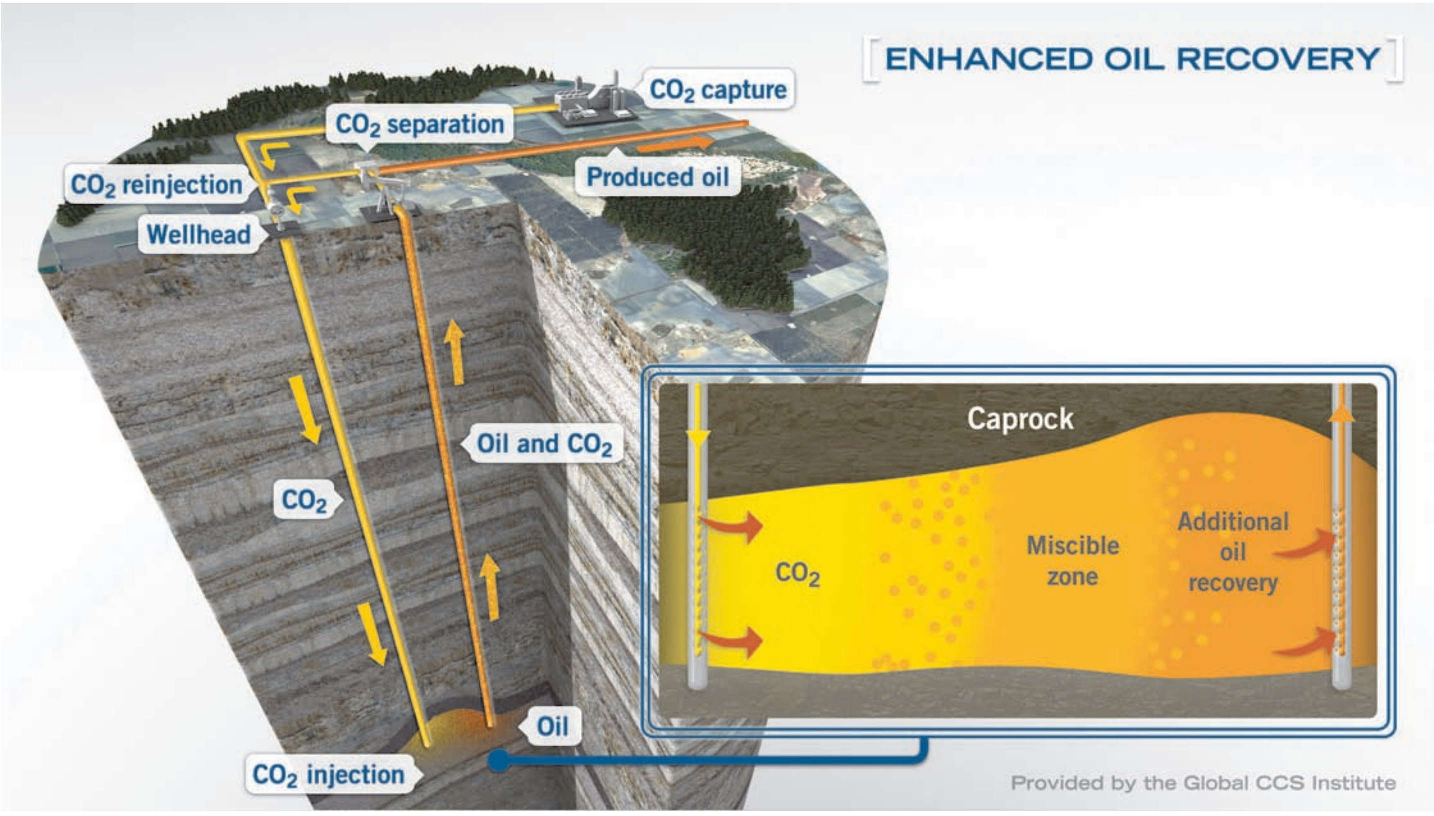


Figure 1 – a schematic of enhanced oil recovery provided by the Global CCS Institute

If the world is to meet the targets of the Paris Agreement, Carbon Capture and Storage (CCS) needs to capture at least a fifth of CO2 emitted by the fossil fuel industry by 2050. Currently, this stands at less than 4%.[1] While we transition to cleaner, greener energy, fossil fuels will be necessary for some time to come to meet this insatiable energy demand.

So, why not use the carbon emitted to enhance oil recovery (EOR) and fast track intentions to safely trap and lock away carbon deep in oil and gas reservoirs and aquifers? (Figure 1)

Recycling CO2 for EOR alongside CCS will not only make a positive contribution to reducing emissions; it can radically overhaul the future of the oil and gas sector as it deals with its decline and transition to lower carbon technologies. Extending the recovery and lifetime of depleting fields, with minimal impact on the environment and climate will:

• Reduce the need for new exploration

• Allow existing pipelines and installations to be reused

• Enable financing and the creation of infrastructure of permanent CO2 injection facilities

• Depending on the nature of reservoir and oil in a given field, the economics can be substantial

• Avoid developing new oil and gas plays in the most controversial areas.

Exploiting hydrocarbons heritage for climate gain

EOR is the process by which CO2 is injected as a gas into the subsurface of active oil reservoirs. When it reaches below 800m it transforms into a liquid where it can be used to displace remaining resources and boost ulti-

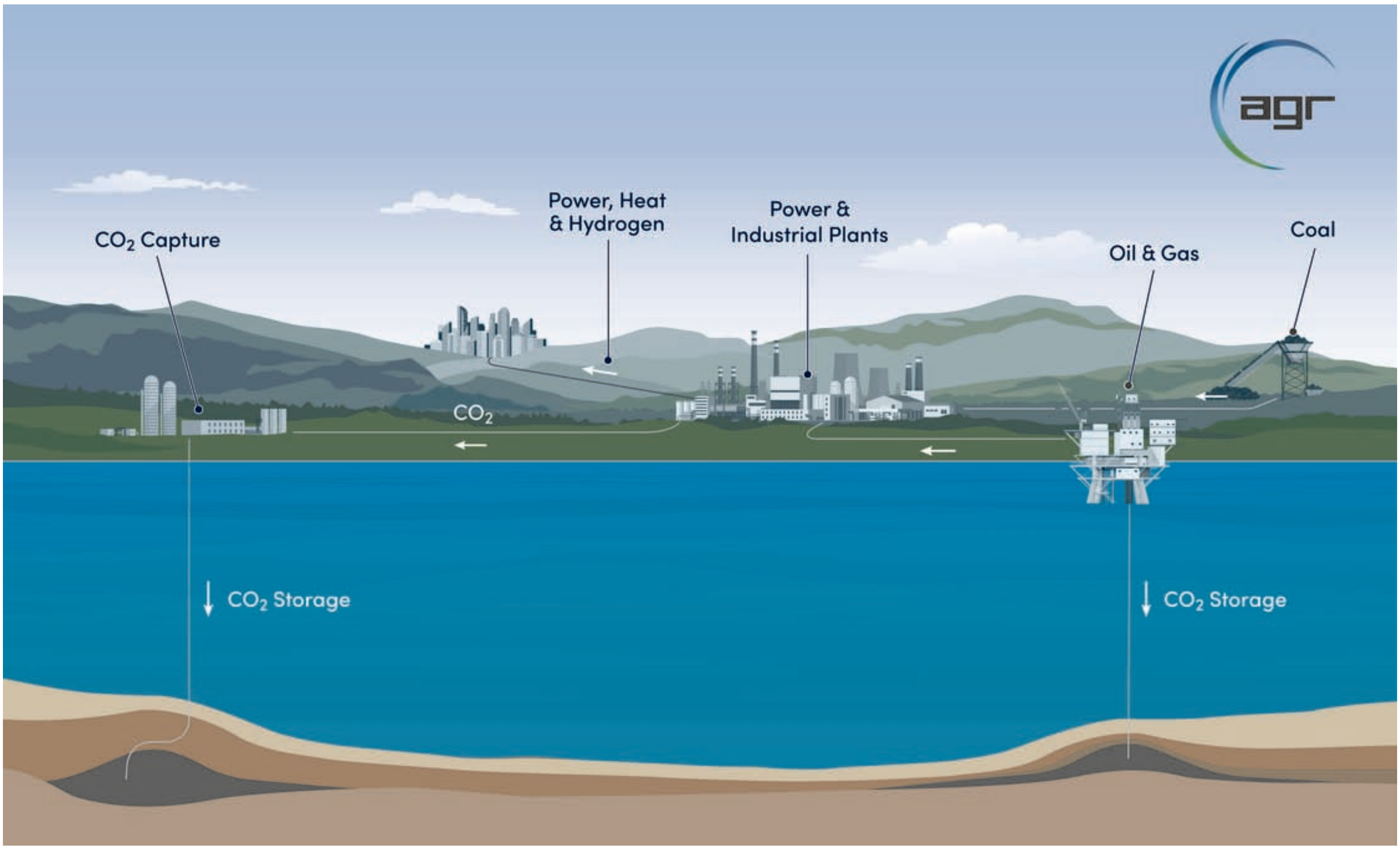


Figure 2: Illustrative graph of carbon capture, use and storage

mate oil recovery. As the most prominent use of carbon today, EOR is the driver for a host of CCUS (Carbon Capture, Utilization and Storage) deployment strategies (Figure 2).

Pioneered in Texas in the early 1970s, both the USA and Canada have been actively and successfully utilizing the technique ever since, without government subsidies.

The production stages of a conventional crude project are often split into three stages: primary, secondary and tertiary. It is at the tertiary, or tail-end stage when typically only around 30-50% of the oil in the reservoir has been recovered with the rest remaining in the ground. This is when facilities are dismantled, wells are permanently plugged and abandoned, and infrastructure is removed from the seabed. CO2 for EOR can reverse the decline of mature fields and increase the overall percentage recovered through several methods including CO2 injection, steam or use of chemicals like surfactants.

CO2 as a fluid has the ability to mobilize remaining oil towards production wells and has a long history in the USA. For example, carbon injection has been used in The Kelly-Snyder oilfield since 1972[2]. Located on the eastern edge of the Permian Basin in Texas, the operator, Kinder Morgan, has ramped up CO2 injection on the giant oil-producing area which has seen production increase from 9,600 bbl/d to more than 30,000 bbl/d.

The CO2 mixes miscible with oil, improving its mobility, and so allowing it to flow more easily. Most notably, a considerable amount of the injected CO2 is retained in the pore space or dissolved in water. Some CO2 will return to the surface and will be separated and reinjected.

Hesitancy in Europe

At present, EOR is the only form of large-scale, permanent carbon sequestration that is profitable. In order to store huge amounts of CO2 and reach Paris Accord, financing CO2 storage will be very difficult.

The discussions to replicate this technique in the North Sea are proving to be divisive despite its success across the Atlantic and with major developments underway in Africa and Australia. It is the ethics and the logic around "carbon-negative" oil which is contentious and viewed by many as counterproductive.

While it could help reduce emissions from hard-to-decarbonize sectors such as aviation and transport, this very much depends on the source of the CO2 and its eventual consumer. However, it is important to emphasize that the amount of stored CO2, as a function of EOR, will be greater than carbon emissions created from extra oil extraction[3]. In essence, CO2 can be used to access more oil for short-term use as renewables upscale, while concurrently storing it in the reservoir. Also, EOR may prevent new field developments, a benefit for the environment and climate. Finally, if gas to power with carbon capture is used, then the measure of kgCO2/bbl produced will be abated.

In a report on advanced extraction methods, the Norwegian Petroleum Directorate (NPD) stated that the remaining oil resources on the Norwegian Continental Shelf that are technically recoverable require advanced EOR methods to be fully exploited. The three-part study showed an average potential of 7% of oil initially in place (STOIIP) in improved recovery and a permanent storage effect for

CO_2 in the reservoir of 70-100%[4]. Several studies have also been carried out by operators, with support from the Directorate, which show encouraging results and potentially valuable opportunities to store CO_2.

An in-house quick calculation of how 7% EOR looks in certain oilfields in NCS is shown in Table 1 (The required CO_2 is estimated to 0.5 ton CO_2 per barrel extra oil).

By producing 941 million barrels, we store 24 million tonnes CO_2 per year over 20 years - in total 480 million tonnes. Will it be possible to get the necessary CO_2 to realize these values (941*80 USD=75 billion USD)?

Despite the fact that the NPD, academia and major oil companies have carried out studies that indicate increased recovery through the use of CO_2, no decisions have been made either in Norway or in other European oil-producing countries to invest in the establishment of CO_2 storage in combination with EOR. There are several reasons for this:

• Mammoth investment in infrastructure which will be required if support from government subsidies are limited

• Availability of sufficient CO_2 - CO_2 has not been available in the North Sea basin

• Reluctance around the perception of safety, environmental and economic risk associated with introducing CO_2 into existing wells and facilities.

Moreover, this averseness is largely due to EU taxonomy guidelines forcing through a phase-out of fossil energy and not classifying EOR as a climate mitigating action. Companies and investors will have to prepare for reporting under a number of new and complex sustainability disclosure standards and adapt as they continue to evolve: ESG (Environmental, Social and Governance) has become really important.

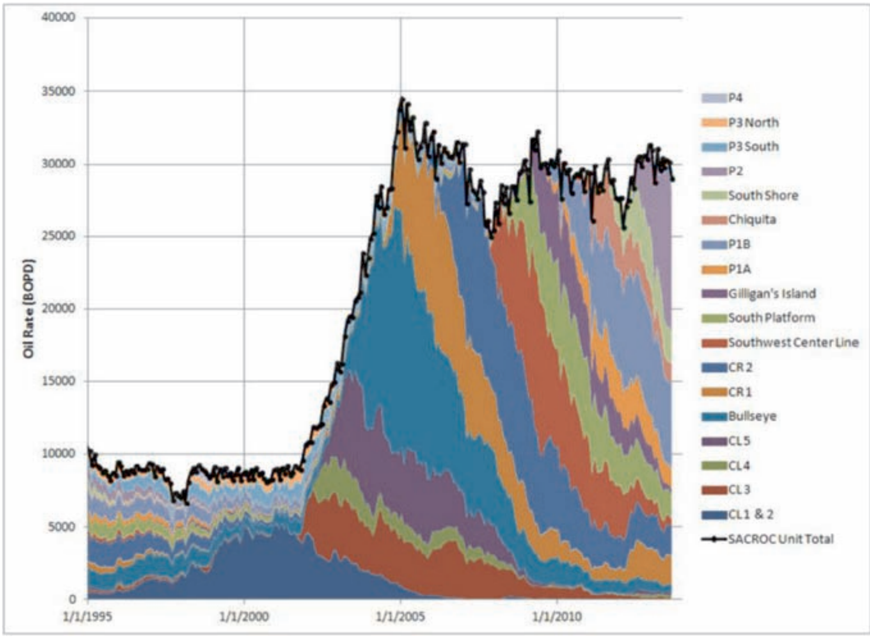


Figure 3: 1996-2013 CO_2 flood project area contribution to total SACROC unit production[2]

The interest and appetite for CCS endeavors, however, is gaining momentum in Europe in particular.

The surge for CCS

Modelling by the European Commission shows that the EU will need to capture, utilize or store between 300 and 640 million tonnes of CO_2 every year over the next three decades if climate neutrality goals are to be achieved[5]. However, financing of CCS is a huge challenge.

Norway has been injecting captured CO_2 in saline aquifers since the mid-1990s and is currently spearheading the prolific Northern

Field	STOIIP (million bbl)	EUR (million bbl)	RF @ EUR	CO_2 for EOR 7% of STOIIP (million bbl)	Required CO_2/year (million tonne) for a 20 year campaign
Ekofisk	6725	3372	50 %	471	11,8
Eldfisk	2832	872	31 %	198	5,0
Tor	951	199	21 %	67	1,7
Valhall	2737	974	36 %	192	4,8
Hod	342	96	29 %	24	0,6
Total	13390	5670		**941**	**24**

STOIIP – stock tank oil initially in place

EUR – estimated ultimate recovery

RF – recovery factor

Table 1: An in-house estimate of how 7% EOR potential looks in a range of NCS oilfields

Lights project - Norway's first licence for CO_2 storage on the NCS and a major part of the initiative that the Norwegian government calls Longship: the first ever cross-border, open source CO_2 transport and storage infrastructure network.

From two emission points in Southern Norway - HeidelbergCement in Brevik and Hafslund Oslo Celsio waste-to-heat plant - a total of 0.8 tonnes of liquid CO_2 will be captured annually for transport to Øygarden to its end destination in a subsea sandstone aquifer 2,000m under the North Sea seabed. Phase one of the project will be completed in mid-2024 with a capacity of up to 1.5 million tonnes of carbon each year[6]. The project received substantial funding of USD 2 billion from the Norwegian Authorities (taxpayers).

Large-scale CCS is a critical part of Denmark's ambition to reach net zero carbon emissions by 2045. It recently awarded its first license to inject carbon into depleted oil and gas fields in the North Sea[7].

By 2025, in the Greensand project, Wintershall Dea and INEOS Energy plan to inject up to 1.5 million tonnes per annum (Mtpa) of CO_2 with plans to increase capacity to 8 Mtpa by 2030. By 2027, TotalEnergies' Bifrost project aims to inject up to 3 Mtpa and reach 5 Mtpa by 2030. Full funding is not yet decided.

In the UK, the North Sea Transition Authority has established a new team dedicated to carbon transportation and storage ahead of announcing awards for the first ever CCS licensing round.

Adopting CO_2 for EOR technologies and upscaling CCS infrastructure could help finance energy demand and lower emissions before more expensive green energy claims the largest stake of the energy mix by mid-century. According to the latest projections by the IEA, to deliver deep emissions reductions and limit global temperature increases to 2°C by 2060, 14% of cumulative emission reductions must be derived from CCS technologies[8].

Enduring ingenuity and innovation

A positive legacy of oil and gas towards impactful climate change is the use of its ingenuity and experience to convert deep, largely empty offshore reservoirs as safe and secure sanctums for CO_2.

AGR is participating in The LinCCS project to deliver support and advice on geoscience, reservoir and drilling engineering, storage monitoring, facilities, and cost engineering to create an 'atlas' of the design and re-design possibilities across different scenarios.

It's a win-win solution for the sector eager to shrink its carbon footprint and seek more efficient and economical prospects. As operators are looking for ways to reduce their own emissions, offshore CCS is emerging as a competitive alternative. The green shift is underway with the industry taking a solid step-by-step approach to adapt operations and adopt innovation.

Putting carbon to work for climate change

In 2023, the European Commission will table a 'strategic vision' for CCS and carbon usage technologies, with the aim of clarifying rules and giving certainty to investors. New legal frameworks and funding streams are already bouncing off the back of a compelling sense of urgency.

Finally, it should be mentioned that the long term perspective of safe CO_2 storage is very long, AGR simulates 1,000 years forward modelling of CO_2 through absorption, dispersion and transition into calcite minerals.

If the Paris climate accord is to be fulfilled, storing huge amounts of CO_2. Without CO_2 for EOR, the cost will be outside most governments funding abilities and/or political support.

As many oilfields are in the process of being depleted, time is of the essence as the conversion of existing infrastructure to function as EOR and CO_2 storage will take several years to upscale. The window is now open to plan and implement increased extraction with CO_2 and accelerate storage efforts.

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About the author

As an Advisor Geology with AGR, Ole Gunnar Tveiten brings more than 40 years knowledge and experience of the complex geology of North Sea. His track record in operational geology, pore pressure evaluation and geomechanics covers advising some of the most historical discoveries and field development projects in the basin.

Recently, he has been involved in tasks ranging from screening and characterising prospective CO_2 storage sites to risk assessment and certification of international CCS projects.

More information

www.agr.com

Carbon Capture and Transportation with Cryogenic Technologies

Moving large amounts of CO_2 cost effectively can be achieved through liquefaction of the CO_2. Cryogenic CO_2 capture is ideally suited to capture post-combustion CO_2 emissions generated from burning coal, waste, or heavy fuel oil.
By Stephen B. Harrison, sbh4 consulting.

Cryogenic liquid CO2 storage tanks

Cryogenics makes CO_2 compact for transportation and storage. Gaseous CO_2 at atmospheric pressure and ambient temperature requires 588 times more volume than liquid CO_2.

Cryogenic CO_2 capture technologies are ideal where liquid CO_2 distribution will be required to the utilisation or sequestration location. This will be the case where the CO_2 is destined to be used in food, beverage, or other industrial gases applications.

It is likely that liquid CO_2 distribution for carbon capture and sequestration (CCS) projects will be required for many years, since almost no CO_2 pipeline infrastructure exists today. For example, the Northern Lights CCS project (which will permanently store CO_2 emissions from a waste to energy plant and Norcem's Brevik cement plant in Norway) will use liquid CO_2 distribution.

Gas-phase CO_2 capture technologies may be more suitable if CO_2 compression and pipeline transmission is required, or if onsite gaseous CO_2 utilisation is possible.

CO2 liquefaction

CO_2 can be captured in the gas phase using conventional technologies such as amine solvent absorption. CO_2 liquefaction is achieved using a cryogenic heat exchanger to condense CO_2 gas. Electrical power is required to operate the refrigeration equipment, so the process can be decarbonised using renewable electricity.

As an alternative to mechanical refrigeration, ammonia absorption refrigeration can be used. This process avoids the mechanical compression of a refrigerant gas and derives the cold energy instead from the absorption and desorption of ammonia in water. If waste heat is available, this process can be more efficient than mechanical refrigeration.

After liquefaction, CO_2 is stored and transported in tanks which are insulated to minimise boil off. Typically, liquid CO_2 storage tanks are constructed of carbon steel and insulated with polyurethane foam. Often, a refrigeration unit is used to re-liquefy boiled off CO_2. This avoids CO_2 losses and over-pressurisation of the CO_2 storage tank.

CO2 capture through direct liquefaction

Direct liquefaction of mixed gases is difficult. For example, when CO_2 is present in a mixture with nitrogen, the nitrogen is incondensable at the temperature at which the CO_2 can be liquefied. This means that the CO_2 liquefier heat exchanger becomes shrouded with nitrogen gas and there is no longer any contact with the CO_2 gas to be liquefied.

On the other hand, direct liquefaction of very pure CO_2 is viable. In this context, 'very pure' would typically a purity greater than 98%. Biogenic CO_2 released from bioethanol fermentation or brewing produces CO_2 at this purity.

Direct liquefaction of CO_2 from fermentation broths requires drying of the CO_2 prior to liquefaction. This is essential to avoid formation of solid ice particles within the CO_2 liquefier. It also ensures that the CO_2 product is suitable for commercial applications in the food and beverage sector or for metallurgical welding applications.

Cryogenic CO2 distribution by road

Cryogenic Carbon Capture

It is only recently that technology has been developed for the direct liquefaction of CO_2 from lower concentration CO_2 streams.

The US start-up Sustainable Energy Solutions, now part of Chart Industries, has developed the Cryogenic Carbon Capture (CCC) process during the past decade.

CCC relies on direct sublimation of CO_2 gas to solid CO_2. Hence it can capture CO_2 from dilute flue gas streams. After the solid CO_2 has been formed, it is dissolved into liquid CO_2. The product is high purity liquid CO_2.

The CCC process relies only on electrical power for gas blowers and compressors for its operation. The implication is that it is aligned to operation with renewable electricity, meaning that no CO_2 emissions are created from capturing the CO_2.

The CCC technology is that it sufficiently robust to treat 'dirty' post-combustion flue gases that contain oxides of sulphur or nitrogen.

This means that it is ideally suited to capture post-combustion CO_2 emissions generated from burning coal, waste, or heavy fuel oil. In contrast, amine solvent processes for CO_2 capture are sensitive to sulphur impurities.

Cryogenic CO2 capture from SMRs

CO_2 capture from steam methane reformers (SMRs) is often regarded as a 'quick-win' in the decarbonisation of industrial processes. The CO_2 concentration, pressure, and partial pressure in the SMR process gas is high. This leads to cost-effective CO_2 capture. CO_2 has been captured from SMRs for decades so that the CO_2 can be used to make urea fertilizer.

The use of cryogenics to capture and purify CO_2 from SMRs is likely to be the next milestone in the development of CO_2 capture from these units. The Cryocap™ H2 process from Air Liquide combines cryogenic separation of CO_2 from the SMR process gas stream with membrane separation of hydrogen.

A demonstration project at an SMR in Port Jérôme, on the river Seine in France, showed that an additional 12% hydrogen yield from the SMR is achievable using the Cryocap™ H2 process. This can have a tremendous positive impact on operational economics and can help to fund the investment in the Cryocap™ H2 equipment.

More information

www.sbh4.de

Permanent sequestration of CO2 in industrial wastes

The report from the Carbon Dioxide Capture and Conversion (CO2CC) Program gives an overview of the potential for capturing and converting CO2 into valuable products using different kinds of wastes or byproducts from industrial processes.

The report, "Permanent sequestration of CO2 in industrial wastes/byproducts" looks at the economic feasibility, technical performance and life cycle of various processes for mineral carbonation (MC) and assesses the industrial applications of CO2 capture using solid wastes as a feedstock.

It then outlines the main challenges for MC research and development, such as increasing the CO2 uptake and decreasing the energy requirements and cost, and how the processes could be scaled up to meet the requirements of CO2 reduction for climate goals.

First an overview of the technology is presented discussing the fundamental principles of mineral carbonation from natural processes to engineering systems. The report then introduces the use of industrial wastes/byproducts as a viable and effective feedstock for the mineral carbonation process.

A detailed techno-economic analysis of numerous carbonation techniques that use a variety of industrial wastes then assesses each in terms of their technical performance, economic feasibility, and life cycle. The report concludes with a presentation and discussion of current and potential industrial applications of CO2 sequestration using solid wastes.

Key takeaways from the report

- Life cycle assessment of steel slag in the US showed that it can sequester 7.5 million tons of CO2 annually of which 7 million tons are from direct CO2 capture from the mineralization process and 0.5 million tons from the avoided emissions by using the MC products
- Although studies on life cycle assessments of solid waste utilization are rather limited and often restricted to case studies on a specific waste, all assessments seem to confirm the economic feasibility and profitability of utilizing solid wastes for MC
- Despite the growing interest in MC, most recent studies are still in the bench scale stage and only a few studies have evaluated industrial demonstration units of MC process using industrial wastes
- This could be attributed to the limited research funding for pilot scale applications as well as lack of regulatory policies for the application of the solid products
- It could also be attributed to the fact that experts often discuss carbon capture and sequestration in terms of geological storage, which pushes CO2 mineralization to the margins making it less likely to be included in policymaking
- In general, the main challenges for MC research and development are increasing the CO2 uptake and decreasing the energy requirements and cost
- This can be addressed through effective optimization of the process by identifying the most influential parameters that can mainly affect the overall efficiency
- Hence, taking a holistic approach towards the MC process optimization can be very insightful and set the future direction for MC research
- In addition, more studies on lifecycle and technoeconomic assessments are needed to pave the way for technically and economically viable large-scale applications

Overview of mineral carbonation

MC is a process that involves the reaction of CO2 with alkaline compounds such as calcium and magnesium oxides and has the potential to sequester considerable amounts of CO2 with a capacity that can be scaled to match the amount of CO2 emissions released from several industries.

MC is also one of the most sustainable approaches for CO2 sequestration. It ensures leakage-free fixation of carbon dioxide and generates valuable products such as calcium and magnesium carbonates, which can be used in different applications, such as adsorbent materials and cement additives.

The MC process can be carried out through direct and indirect carbonation techniques, and it is often controlled by several parameters, such as alkalinity, pretreatment method, particle size, solid to liquid ratio, temperature, and pressure. These parameters directly influence the CO2 uptake capacity by changing the kinetics and mass transfer of the process. Different process parameters and feedstocks can lead to wide array of uptake capacities.

Alkaline solid wastes, such as steel dusts and slags, cement and construction materials waste, fly ash, and red mud can be used for mineral carbonation to permanently sequester CO2, stabilize these solid wastes and produce valuable products. Collectively, the overall CO2 emissions reduction potential by direct MC using industrial byproducts has been estimated to be 310 million tons globally.

Sources of industrial waste

The steel industry produces different types of wastes such as blast furnace slag and basic oxygen, electric arc and ladle furnaces waste. It is estimated that producing one ton of steel generates 250 kg of alkaline waste. Life cycle assessment of steel slag in the US showed that it can sequester 7.5 million tons of CO2 annually.

Cement manufacturing generates between 15 to 20 tons of cement kiln dust (CKD) per 100 tons of produced cement, and the global amount of CKD generated annually is estimated to be 30 million tons. The annual production of CKD in the US is 1.67 million tons.

Mineral carbonation of fly ash can be regarded as one of the most cost-effective ways to sequester carbon dioxide, as large amounts of fly ashes are being continuously generated from the combustion of coal and oil shale power plants. Fly ashes are also generated during the incineration of municipal solid wastes. Globally, around 750-1000 million tons of fly ash is generated every year.

Red mud (RM) is another industrial waste that is often generated during the processing of bauxite into aluminum. The global reserves of bauxite, which is a sedimentary rock with very high aluminum content, are estimated to be around 55-75 billion tons. Globally, alumina production from bauxite resulted in more than 2 billion tons of RM.

Over the last few years, there has been increasing interest in studying the tailings generated during the extraction of Nickel from ores. Nickel tailings typically contain very high concentrations of magnesium oxides along with other alkaline oxides. Several studies have investigated the techno-economics of mineral carbonation of mine tailings in Canada.

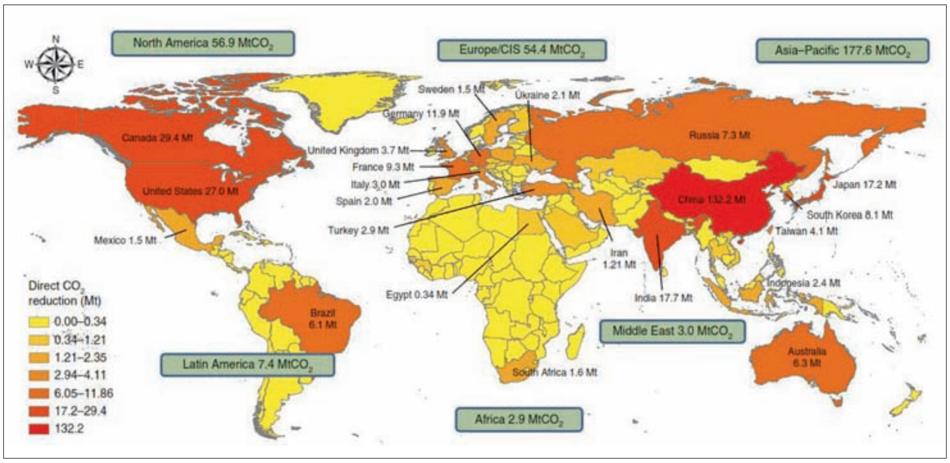


Figure 1- Estimates of the regional CO2 reduction potential using industrial alkaline waste (Pan et al., 2020)

Conclusions

The area of industrial waste mineral carbonation is rapidly evolving and expanding in different directions depending on the type of the waste and the process, but only in lab or bench scale. It is worth noting that studies on life cycle assessments (LCA) of solid waste are rather limited and often restricted to case studies on a specific waste. However, all assessments seem to confirm the economic feasibility and profitability of using solid wastes for MC.

Major industrial wastes emitting industries, such as steel and cement manufacturing, have yet to get seriously involved in MC efforts at a large scale, and this can be seen in the low number of industrial and pilot scale MC implementation using the wastes.

Nonetheless, using various types of wastes can offer an attractive route for the problematic waste disposal and at the same time mitigate CO2 emissions and produce value added products.

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 "State of the art and future prospects for catalytic and electrochemical routes to CO2 conversion" in the next issue.

More information

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

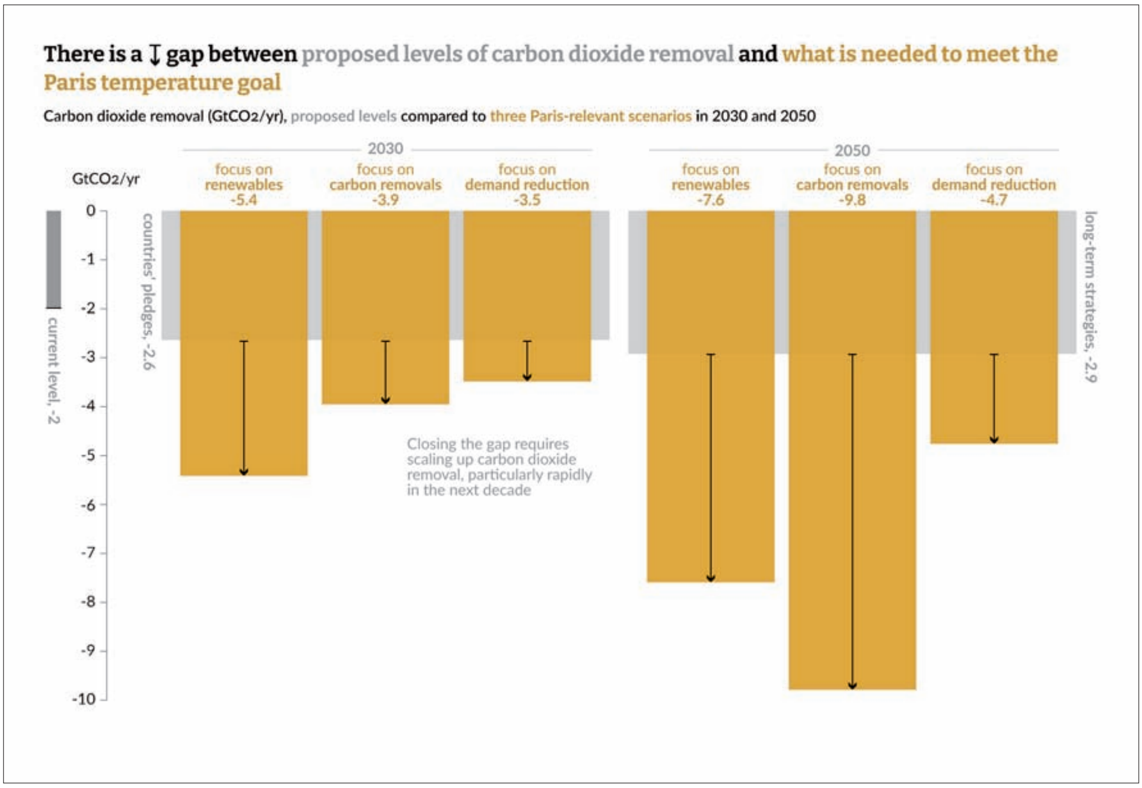
www.catalystgrp.com/tcg-resources/member-programs/co2-capture-conversion-co2cc-program/

Report: the State of Carbon Dioxide Removal

The report finds a gap between proposed CDR deployment and what will be needed to meet the Paris temperature goal to limit warming to well below 2°C and pursue efforts to achieve 1.5°C. The primary policy implications of this first assessment are that meeting the Paris temperature goal requires us to accelerate emission reductions, increase conventional CDR and rapidly scale up novel CDR.

The letter, written by leading NGOs including Bellona Europa and the Clean Air Task Force, underscores the need for a policy framework for carbon capture and storage based on a robust set of guiding principles and safeguards to facilitate the deployment of this critical infrastructure for industrial decarbonisation at scale by 2030.

The coalition of signatories spreads well beyond Brussels, with signatory groups from no less than five Member States across various regions including the Netherlands, Denmark, Romania, Poland, and Germany, highlighting the need for carbon capture and storage deployment across the continent.



The report found a gap between how much CDR countries are planning and what is needed in scenarios to meet the Paris temperature goal. The size of the "CDR gap" differs across scenarios, depending on how we choose to transform the global conomy towards net-zero emissions

"As the Fit for 55 package nears completion, the CCS discussion has reignited in the EU as it has become clear that it will be needed to cut emissions fast," begins the letter.

"As CCS moves from planning to deployment, in part with the aid of the EU Innovation Fund, the need for a policy framework, based on a robust set of guiding principles and safeguards, is needed to facilitate the deployment of critical infrastructure for industrial decarbonisation at scale by 2030."

"Deployment of CCS in Europe should prioritise high-value applications, and hard-to-electrify industrial processes with unavoidable process emissions, while also implementing appropriate guardrails. These are necessary to achieve greater public acceptance."

"We welcome the European Commission's announcement to publish its Communication on the Strategic Vision on CCUS in early 2023. However, the European Commission's recently published Work Programme for 2023 excludes plans to publish said Communication."

"We strongly urge the Commission to grant such a Communication priority, in line with the need and urgency expressed by CCS stakeholders at the CCUS Forum and the commitment made by European Commission officials present."

"The European Commission is uniquely placed to facilitate high-level strategic leadership in the deployment of CCS in Europe. As various EU Member States such as Denmark and Germany have prepared or are preparing their own national strategies to accelerate CCS deployment, it is imperative that regional and international factors are accounted for in order to ensure consistency is maintained on CCS deployment in the EU."

More information

www.stateofcdr.org

CO2 Capture Project concludes with final results, makes work open access

Increased CCS policy confidence and a growth in regulatory regimes for CO2 storage worldwide are among the key findings of the final report published by the CO2 Capture Project. CCP's published work is now available to all for a period of up to five years.

The CO2 Capture Project (CCP) has published the results of its fourth and final phase of activity in a comprehensive volume entitled Volume 5: Carbon Dioxide Capture for Storage in Deep Geologic Formations – Results from the CO2 Capture Project, CCS Technology Development and Demonstration Results (2015-2022).

The final phase of CCP aimed to build further depth into the understanding of CO2 capture solutions for oil and gas scenarios, with a natural gas production scenario added to the scope. The main storage focus was on leakage mitigation testing as well as completion of monitoring trials. Highlights included:

• Carried out pilot testing of novel solvents, adsorbents and membranes

• Completed techno-economic evaluation of range of novel technologies, including molten carbonate fuel cells, membranes, and high-pressure solvent absorption • Undertook natural gas landscape study of state-of-art technologies

• Partnered in a consortium that developed 3D printing of sorbent capture structures for pre- and post-combustion.

• Completed multi-faceted well sealing experiment at Mont Terri underground lab – with testing of four sealants - plus fluid transmission and fault slippage studies.

• Undertook repeat electromagnetic monitoring survey and borehole microgravity testing at Aquistore, with integration of data.

• Carried out storage studies, including: top seal enhancement/repair; plugged and abandoned well contingencies; EOR as de facto storage; and permeability modifier tests.

• Published a series of keynote CCP policy reports: Transitioning EOR to storage; Energy transition; Storage regulations.

CCP Chairman, Tony Espie, commented, "This fourth and final phase of the CO2 Capture Project saw a broad and varied programme of activity spanning capture, storage, policy and communications. Our thanks go to the dedicated teams from our member companies and all of the partners involved who made it happen."

Results open access

Open access to CCP's published work is now available to all for a period of up to five years, and all volumes of CCP Results Books (Phases 1-4) are accessible. General information on CCS continues to be available from www.ccsbrowser.com

CCP was set up in 2000 as a partnership of eight major energy companies – with the aims of:

• Driving down the cost of CO2 capture in oil and gas applications through R&D and demonstration

• Advancing knowledge of CO2 storage and monitoring

• Informing the development of legal and policy frameworks.

Project highlights have included:

• New, technically viable and lower cost capture routes identified and tested

• Perceived uncertainties around subsurface storage addressed

• 150+ projects to increase understanding of science, engineering, application and economics of CCS

• CCP technical and policy insights made available to wider world

• Twice received Carbon Sequestration Leadership Forum (CSLF) Recognition Award.

The programme comprised four phases, each with a distinct theme and focus:

Phase 1: The initial aim was to identify next generation capture technologies at significantly lower cost. Over 200 technologies were screened, with high potential pre-combustion, postcombustion and oxy-firing technologies identified for further development. A risk-based approach for geological storage site selection, operation and closure was pioneered.

Phase 2: The most promising capture technologies were progressed with a specific focus on heavy oil, refining and natural gas power scenarios. A definitive technical volume on CO2 storage was published, as was an industry-first study on funding mechanisms for CO2 pipeline networks. CCP also engaged with policymakers, NGOs and media to build awareness.

Phase 3: Much of the activity focused on moving from theory to reality. Two full field demonstrations of FCC (fluidized catalytic cracker) and OTSG (once-through steam generator) oxy-firing capture technologies were carried out, as were field trials of innovative monitoring technologies. A Certification Framework was completed providing a consistent means of storage site assessment.

Phase 4: The fourth phase began in 2015 with natural gas production added to the capture scenarios. Development of a comprehensive approach to manage unexpected leakage of stored CO2 culminated in a multi-faceted well sealing experiment at an underground laboratory - with testing of four sealants plus fluid transmission and fault slippage studies.

More information

www.co2captureproject.org

Projects and policy news

Decarbonization of industrial clusters initiative gains global momentum

www.weforum.org

Nine leading industrial clusters in China, Indonesia, Japan, Spain, and the United States have joined the World Economic Forum initiative, Transitioning Industrial Clusters towards Net Zero.

Launched in 2021 and supported by Accenture and EPRI, the initiative focuses on reducing heavy industry asset emissions in regional industrial zones, while supporting job creation and increasing economic competitiveness.

Industrial clusters account for 15%-20% of global CO_2 emissions, making them an attractive target for emission reductions. Industries in the same general location benefit not only from sharing risk, infrastructure and natural resources but also from a united approach to tackle decarbonization along with workforce transformation and environmental justice.

Industrial clusters are areas where companies, representing either a single or multiple industries, provide opportunities for scale, sharing of risk/resources, aggregation and optimization of demand.

Combined, the new clusters add significant decarbonization potential, bringing the CO_2 emissions of all the initiative's members to 451 million metric tonnes emitted per year, comparable to the annual emissions of Turkey. The 17 members also contribute economically by employing more than 2.7 million people and represent an annual GDP contribution of $218 billion.

SINTEF and TU Delft research shows significant CO2 reductions at marginal cost

www.sintef.no
www.tudelft.nl

Recent research demonstrates that implementing CCS in industrial facilities can result in significant CO_2 reductions at a minimal cost to the general public.

These findings have been published as a paper "Is CCS really so expensive? An analysis of cascading costs and CO_2 emission reduction of industrial CCS implementation on the construction of a bridge", in the latest edition of Environmental Science and Technology.

The paper, authored by Sai Gokul Subraveti (SINTEF), Elda Rodríguez Angel (TU Delft), Andrea Ramírez (TU Delft) and Simon Roussanaly (SINTEF), examines how CCS implementation in steel and cement production would have impacted the cost of the Lake Pontchartrain Causeway bridge in Louisiana, USA. The bridge is currently the longest beam bridge over continuous water in the world, and consists of approximately 225,000 m3 of concrete and 24,209 tonnes of steel. This work was performed in connection with the Norwegian CCS Research Centre.

CCS has often been criticised for being too expensive. However, while many studies have already investigated the impact of CCS implementation on industrial plants, they do not examine the impact of CCS implementation on the end user. This is a significant gap, as most people do not buy raw materials such as cement or steel, but products that the cement and steel were used to create, such as houses or bridges.

In terms of the case study, CCS initially resulted in a significant cost increase of raw materials: 60% for cement and 13% for hot-rolled coil (HRC) steel. However, as cement and HRC are only a part of the bridge construction cost, the overall cost increase due to CCS would be approximately 1%.

"Cement and steel represent, in fact, only a small fraction of the total cost of building a bridge," explained Simon Roussanaly. "And therefore, their impact is not as significant as it is perceived to be when you look solely at a cement and steel plant."

ABB and Pace CCS partner on delivering CCS infrastructure

www.abb.com

www.paceccs.com

ABB and Pace CCS have joined forces to deliver a solution that reduces the cost of integrating carbon capture and storage into new and existing industrial operations.

Working to make the capture, transportation and storage of industrial carbon dioxide emissions more accessible, ABB has signed a partnership agreement with Pace CCS, a global leader in engineering solutions for this market.

Together, the two companies will apply their respective expertise to make it easier for industrial companies to implement CCS infrastructure by lowering the CAPEX and operational investment required to enter this market.

For countries to achieve their net-zero commitments, uptake by industry needs to grow 120-fold by 2050, according to McKinsey & Company analysis. If successful, CCS alone could be responsible for reducing carbon emissions generated by the industrial sector by 45 percent.

"To date one of the biggest challenges to the mainstream adoption of CCS has been a lack of operational practice across the full value chain, but the combined expertise of ABB and Pace CCS can change this," said Matt Healey, Chief Executive Officer of Pace CCS.

"While companies can see the benefits of CCS, there is still a reluctance to make the investment without clear knowledge of how things will work on the ground, at every stage of the process."

The ABB and Pace CCS partnership will address this through use of digital twin technology, which provides a virtual replica of a real, physical process or facility. The technology simulates the design stage and tests scenarios to deliver proof of concept to ensure the design is fit for purpose.

This will demonstrate to customers how they can smoothly transition into CCS operations. The solution will map out various scenarios, including subsurface modelling, and will incorporate ABB Ability™ OPTIMAX® energy management system to forecast and manage power consumption.

"Carbon capture and storage is a critical component in accelerating the global decarbonization agenda. While we add new, renewable energy sources into the mix, we will still need to access traditional energy infrastructure," said Brandon Spencer, President of ABB Energy Industries. "We need to make these more sustainable, minimizing emissions, and this can be achieved by taking the carbon dioxide they produce out of the atmosphere and into the ground for storage."

World's first carbon capture pilot for smelters inaugurated at Elkem

The Mobile Test Unit (MTU), delivered by Aker Carbon Capture, is now connected to Elkem's plant in Rana, Norway, which produces high-purity ferrosilicon and microsilica.

The carbon capture pilot testing is a collaboration between Elkem, Mo Industripark, SMA Mineral, SINTEF, Alcoa, Celsa Group, Ferroglobe PLC, Norcem AS, NorFraKalk AS, ACT Cluster and Aker Carbon Capture.

With full-scale implementation, 1.5 million tonnes of CO2 can be captured from their combined emissions. In a couple of months, testing will commence at SMA Mineral.

Amund Vik, Deputy Minister from the Norwegian Ministry of Petroleum and Energy, spoke at the ceremony. "There is no doubt that we need carbon capture, utilisation and storage (CCUS) to reach our climate targets. We need CCS in hard-to-abate industries to keep industrial jobs in Europe. This pilot will provide important learning related to CO2-capture in metal industries, and will be an important hub for other companies in the Industrial Park to test CO2-capture technology."

Elkem's plant in Rana, Norway, was established in 1989 and today has around 140 employees. It produces speciality ferrosilicon products and microsilica based on renewable hydropower.

The pilot test is part of a larger R&D project, CO2 HUB Nord, which runs over two years and is funded by Climit Demo. The main goal of the project is to verify the technology on real industrial gases from smelters and other process industries, in order to prepare a full-scale plant for industrial carbon capture.

"The Mobile Test Unit was built in 2008 and has continuously been upgraded in accordance with our latest technology developments. Aker Carbon Capture can therefore offer our customers a unique opportunity to test our technology at their site and de-risk the project prior to a possible full-scale implementation. It is truly great to officially kick off this project today with all our partners in Rana," said Valborg Lundegaard, Chief Executive Officer at Aker Carbon Capture.

Elkem opening ceremony

Through development and verification of new technology for carbon capture, the CO2-HUB Nord accelerates innovation and industrialization of the carbon capture, utilization and storage (CCUS) value chain. Industrialization of such technology is considered as an important contributor to reducing CO2 emissions and delivering on the global sustainability goals.

"Elkem is very pleased to be a part of this pilot. The world needs more metals and other materials to succeed with the green transition, but we also need to achieve lower global CO2 emissions," said Elkem's CEO Helge Aasen.

“Carbon capture can potentially contribute significantly towards our global climate roadmap of reducing emissions towards net zero while growing supplies to the green transition. At the same time, Elkem is dependent on our stakeholders to enable green technologies at an industrial scale. That is why we are particularly pleased about the good collaboration between several partners in this project, and we will monitor the results of the pilot closely.”

Captures emissions from two different plants

The other company that will connect its flue gases to the treatment plant is SMA Mineral, which produces lime and dolomite. They see great opportunities to strengthen their position with carbon capture. “It is very exciting to be part of this project from the very beginning. We believe that results and experience from the test facility contribute to opportunities to reduce the climate footprint from the company's other factories,” says site manager at SMA Mineral in Mo, Johnny Vangen.

Mo Industrial Park will be the project owner and SINTEF will have a leading role in the project management of the program.

More information

www.elkem.com
www.smamineral.se
www.akercarboncapture.com

Researchers unravel the complex reactions in zero carbon fuel synthesis

Electrochemical carbon dioxide reduction is a potential pathway for sustainable production of fuels and chemicals from CO2. Researchers from Cambridge and Berkeley explore how the chemical industry, which is the third largest subsector in terms of direct CO2 emissions, can recycle its own waste within current manufacturing processes.

When "eCO2EP: A chemical energy storage technology" started in 2018, the objective was to develop ways of converting carbon dioxide emitted as part of the industrial process into useful compounds. This process is formally known as electrochemical CO2 reduction (eCO2R).

While eCO2R is not a new technique, the challenge has always been the inability to control the distribution of products formed. A new CARES-affiliated paper in Nature Catalysis outlines how carbon isotopes were used to trace intermediates during eCO2R, thereby shedding light on the complex formation pathways for the desired products.

This will allow researchers to create more selective catalysts, exert control over product selectivity, and promote eCO2R as a more promising production method for chemicals and fuels in the low-carbon economy.

The Principal Investigators for the project were Prof Alexei Lapkin, from Cambridge's Centre for Advanced Research and Education in Singapore (CARES Ltd), and Prof Joel Ager, from the Berkeley Education Alliance for Research in Singapore (BEARS Ltd).

Both organisations are part of the Campus for Research Excellence and Technological Enterprise (CREATE) funded by Singapore's National Research Foundation; CREATE became the crucial link to conceive and execute the three-year eCO2EP programme. While the project successfully completed in June 2021, ongoing research outcomes such as this paper continue to highlight the project's impact.

Prof Lapkin adds, "The set-up of the project within CREATE Campus allowed Joel and I to create an environment of creativity and ambition, to enable the researchers to excel and to target the really complex and interesting problems."

In the 1950s, Melvin Calvin (a professor at Berkeley) deduced the elementary steps used in Nature to fix carbon dioxide in photosynthesis. Calvin and his colleagues used a radioactive form of carbon as a tracer to learn the order in which intermediates appeared in the cycle now named after him (Calvin won the Nobel Prize in Chemistry in 1961 for this work).

The eCO2EP team reasoned that with a sufficiently sensitive mass spectrometer, they could use the small differences in reaction rates associated with the two stable isotopes of carbon, carbon-12 and carbon-13, to perform similar types of analyses.

Scientific method and discoveries

Firstly, a mixture of products was generated by a prototype reactor that was built to operate under industrially-relevant conditions. In order to detect both major and minor products in real-time as the operating conditions were changed, high-sensitivity mass spectrometry was used.

As high-sensitivity mass spectrometry is more commonly used in biological and atmospheric sciences, Research Fellows Dr Mikhail Kovalev and Dr Hangjuan Ren had to adapt the technique to the prototype system. They developed a new methodology to directly sample the reaction environment with unprecedented sensitivity and time response. They used the difference in reaction rates of carbon-12 and carbon-13 to group a product such as ethanol and its major intermediates sharing the same pathway, to deduce key relationships in the chemical network. This led to several discoveries.

The first discovery is that the mechanism in reactors being scaled up to commercial size has substantial differences compared to what had previously been known in smaller reactors operating at lower conversions. This knowledge will enable researchers to better control product selectivity.

The second discovery is that the discrimination against the heavier of the two stable carbon isotopes, i.e., carbon-13, is five times larger than that in natural photosynthesis. This is inspiring efforts in Prof Ager's lab to better understand fundamental physics and its chemical origins of this large and unanticipated kinetic isotope effect.

Conclusions

"The operando monitoring of multiple species in such a complex reaction is, by itself, a significant breakthrough by the team. But the ability to further dig into the mechanism by exploring the isotope enrichment effect has made all the difference," said Prof Lapkin.

An international patent application has been filed on the large carbon isotope discrimination effect that was discovered in the project.

Prof Ager concludes, "This work required an interdisciplinary approach drawing on expertise from both Cambridge and Berkeley. CREATE campus provided an ideal environment to realise this collaborative research with a skilled and motivated team."

The paper related to this research is "Operando proton-transfer-reaction time-of-flight mass spectrometry of carbon dioxide reduction electrocatalysis" (DOI: 10.1038/s41929-022-00891-3) published in Nature Catalysis. First-author Dr Hangjuan Ren has also contributed a "Behind the Paper" piece on this research for the Nature Portfolio Chemistry Community.

More information

www.cares.cam.ac.uk

Solar-powered system converts plastic and greenhouse gases into fuels

Researchers at the University of Cambridge have developed a system which can convert two waste streams into two chemical products at the same time – the first time this has been achieved in a solar-powered reactor.

The reactor converts carbon dioxide (CO2) and plastics into different products that are useful in a range of industries. In tests, CO2 was converted into syngas, a key building block for sustainable liquid fuels, and plastic bottles were converted into glycolic acid, which is widely used in the cosmetics industry. The system can easily be tuned to produce different products by changing the type of catalyst used in the reactor.

Converting plastics and greenhouse gases – two of the biggest threats facing the natural world – into useful and valuable products using solar energy is an important step in the transition to a more sustainable, circular economy. The results are reported in the journal Nature Synthesis.

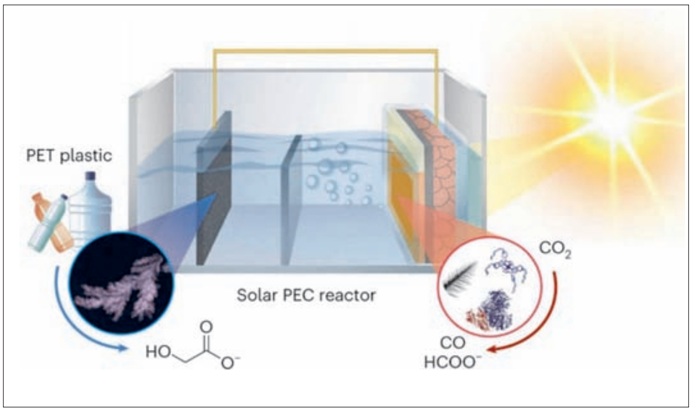
"Converting waste into something useful using solar energy is a major goal of our research," said Professor Erwin Reisner from the Yusuf Hamied Department of Chemistry, the paper's senior author. "Plastic pollution is a huge problem worldwide, and often, many of the plastics we throw into recycling bins are incinerated or end up in landfill."

Reisner also leads the Cambridge Circular Plastics Centre (CirPlas), which aims to eliminate plastic waste by combining blue-sky thinking with practical measures.

Other solar-powered 'recycling' technologies hold promise for addressing plastic pollution and for reducing the amount of greenhouse gases in the atmosphere, but to date, they have not been combined in a single process.

"A solar-driven technology that could help to address plastic pollution and greenhouse gases at the same time could be a game-changer in the development of a circular economy," said Subhajit Bhattacharjee, the paper's co-first author.

"We also need something that's tuneable, so that you can easily make changes depending on the final product you want," said co-first author Dr Motiar Rahaman.



A solar-driven technology that could help to address plastic pollution and greenhouse gases at the same time could be a game-changer in the development of a circular economy

The researchers developed an integrated reactor with two separate compartments: one for plastic, and one for greenhouse gases. The reactor uses a light absorber based on perovskite – a promising alternative to silicon for next-generation solar cells.

The team designed different catalysts, which were integrated into the light absorber. By changing the catalyst, the researchers could then change the end product. Tests of the reactor under normal temperature and pressure conditions showed that the reactor could efficiently convert PET plastic bottles and CO2 into different carbon-based fuels such as CO, syngas or formate, in addition to glycolic acid. The Cambridge-developed reactor produced these products at a rate that is also much higher than conventional photocatalytic CO2 reduction processes.

"Generally, CO2 conversion requires a lot of energy, but with our system, basically you just shine a light at it, and it starts converting harmful products into something useful and sustainable," said Rahaman. "Prior to this system, we didn't have anything that could make high-value products selectively and efficiently."

"What's so special about this system is the versatility and tuneability – we're making fairly simple carbon-based molecules right now, but in future, we could be able to tune the system to make far more complex products, just by changing the catalyst," said Bhattacharjee.

Reisner recently received new funding from the European Research Council to help the development of their solar-powered reactor. Over the next five years, they hope to further develop the reactor to produce more complex molecules. The researchers say that similar techniques could someday be used to develop an entirely solar-powered recycling plant.

"Developing a circular economy, where we make useful things from waste instead of throwing it into landfill, is vital if we're going to meaningfully address the climate crisis and protect the natural world," said Reisner. "And powering these solutions using the Sun means that we're doing it cleanly and sustainably."

The research was supported in part by the European Union, the European Research Council, the Cambridge Trust, Hermann and Marianne Straniak Stiftung, and the Engineering and Physical Sciences Research Council (EPSRC), part of UK Research and Innovation (UKRI). Erwin Reisner is a Fellow of St John's College, Cambridge.

More information

www.energy.cam.ac.uk

Norway backing Removr's efforts to industrialise Direct Air Capture

Removr, a Norwegian company that removes CO2 directly from the atmosphere, has received NOK 36.3 million in governmental backing for an industrial-scale pilot.

"Together with TCM, we believe we have an excellent starting point to remove CO2 from the atmosphere" - Einar Tyssen, CEO of Removr

This will be the first-ever Direct Air Capture (DAC) pilot at Technology Centre Mongstad (TCM), Norway, the world's leading carbon capture technology test center.

"We believe Removr will be able to become a central and preferred technology partner for streams with low CO2 concentrations, both for capture from ambient air and process gas, for example from aluminum works," said marketing director Astrid Lilliestråle at Enova.

The backing was provided in the form of an innovation grant from the Norwegian governmental body Enova, and is Norway's first grant to DAC. Enova is owned by the Norwegian Ministry of Climate and Environment and supports the development of energy and climate technology.

"Even with maximum efforts to reduce emissions, we have already filled the atmosphere with such large amounts of greenhouse gases that the greenhouse effect will continue to warm the globe even if emissions go to net zero. It may be necessary to ensure that carbon is removed from the air. We need actors who go ahead and test solutions. I admire Removr for their initiative which can play an important role in the development of technology for carbon removal," said Norwegian Minister of Climate and Environment, Espen Barth Eide (Ap), in a statement to Enova.

Removr and its technology partner GreenCap Solutions have demonstrated proof of concept through four successful pilots to date. The company follows a stepwise-plan to industrialise DAC and establish market leadership based on its energy-efficient and scalable technology. Removr's first industrial pilot at TCM will capture 300 tons of CO2 annually from 2024, it will be followed by the company's first commercial pilot with a capacity of 2,000 tons per year in 2025 and its first large-scale facility with a capacity of 30,000 tons per year in 2027.

The company now works with a number of partners, including SINTEF, Metier, DNV, Citec and Carbfix on its next facilities while developing a concept for what will be the world's first million-ton DAC facility based on solid sorbent in 2029.

Removr's DAC technology involves removing CO2 directly from the atmosphere. Removr does this by blowing large amounts of air through a zeolite molecular sieve. When the zeolite is saturated with CO2, it is heated, and the CO2 gas is released so it can be extracted as a separate CO2 stream. The technology has been used for decades in the space industry.

"The support from the Norwegian government through Enova sends a clear signal about the importance of our solution as a pioneering project. We are in a hurry and need to scale the right technologies quickly to reach the 1.5 degree target. Norway has extensive experience in carbon capture and can take a leading position in direct air capture of CO2. Together with TCM, we believe we have an excellent starting point to remove CO2 from the atmosphere", said Einar Tyssen, CEO of Removr.

The uniqueness of Removr's technology lies in it being water-free, energy-efficient and able to capture CO2 from low concentrations levels, down to atmospheric concentrations. The process runs entirely on renewable electricity and is flexible when it comes to siting.

"We think it is encouraging that Enova has chosen to support Removr to make such a test campaign possible on TCM. Demonstration of technologies and helping to mature them to a level where they can be launched in the market is the purpose of TCM and we can offer unique carbon capture expertise that is globally recognized. This will be our first test campaign with DAC and we look forward to being able to collaborate with yet another technology supplier seeking climate solutions with ground-breaking technology," said Muhammad Ismail Shah, CEO at TCM.

Project timeline

50 tpa - 2016-2023

Four successful pilots demonstrating proof of concept, Norway

300 tpa - 2024

Industrial scale pilot at Technology Center Mongstad, Norway

2,000 tpa - 2025

Commercial scale facility, Iceland/Norway

30,000 tpa - 2027

Commercial scale facility, Iceland/Norway

1 million tpa - 2029

The world's first large-scale solid sorbent DAC facility, location TBD (see front cover image)

More information

www.removr.no

Capture & utilisation news

Calix consortium to manufacture sustainable fuels from captured CO2

www.calix.com

The Solar Methanol Project, of which Calix is a consortium member, has been awarded funding to develop the production of sustainable fuels from captured process CO2 emissions.

As announced by the Hon Chris Bowen MP, Minister for Climate Change and Energy on 27 January, the HyGATE Solar Methanol Project has been awarded AU$19.48 million from the Australian Renewable Energy Agency (ARENA) and €13.2 million from Germany's Federal Ministry of Education and Research (BMBF) to develop a world-first green methanol demonstration plant in Port Augusta, South Australia.

To synthesise "green" methanol, the Project intends to use up to 15,000 tonnes per annum of CO2 captured by Calix's Low Emissions Intensity Lime and Cement (Leilac) technology during the production of low emissions lime. As part of its net zero emissions pathway, Adbri is partnering with Calix and Leilac to explore opportunities to produce low and zero emissions lime.

The green methanol produced by the Project will be developed into sustainable fuels for the maritime and aviation sectors, two of the hardest-to-abate transport sectors responsible for 4.3% of global CO2 emissions.

Leilac and Heirloom bring lime-based Direct Air Capture technology to market

www.leilac.com
www.heirloomcarbon.com

Calix's 93% owned subsidiary Leilac focusing on decarbonisation of cement and lime has signed an MoU with Heirloom, a Bill Gates-backed direct air capture company.

The partnership between Leilac and Heirloom brings together two leading climate technologies to provide an innovative, highly efficient and easily scalable approach to atmospheric carbon dioxide removal by DAC.

Heirloom CEO, Shashank Samala said, "We're incredibly excited about incorporating Leilac's world-leading electric kiln technology into our Direct Air Capture facilities because it will accelerate our efforts to capture 1 billion tons of CO2 from the atmosphere by 2035 owing to its highly modular and energy-efficient design."

The MoU outlines the key terms for a global and binding licence and collaboration agreement, expected to be executed in the coming weeks.

"Heirloom and Leilac are well matched. Heirloom is a sophisticated and innovative Direct Air Capture company who shares our mission to reduce and remove global CO2 emissions," said Leilac CEO, Daniel Rennie. "Heirloom uses low-cost and abundant limestone, which Leilac's technology is specifically designed for. Both technologies are modular, easily scalable and can be renewably powered.

"Over more than eight years, Leilac's decarbonisation technology has been developed for, and in partnership with, the cement and lime industries. Leilac's pilot plant, Leilac-1 has proven the Leilac technology at a scale significantly beyond all existing DAC facilities. Leilac is well advanced on its pathway to engineering multiple capture facilities each with around one million tonnes of annual CO2 capacity, via the development of a replicable module in Leilac-2."

Standard Lithium installs Carbon Capture Pilot Plant

www.standardlithium.com

The Pilot Plant has been successfully installed at the final testing location in southern Arkansas where it will assess the technical and financial viability of capturing CO2 directly from natural gas burning flue-gas streams.

This pilot testing supports the Company's wider Carbon Capture Utilization and Sequestration strategy, and will be integrated with ongoing work to understand how captured carbon can be utilized in the Company's lithium brine processing flowsheet, and potentially in permanent geological sequestration.

Standard Lithium is one of the owners of this novel carbon capture technology via a $2.5 million equity investment in Aqualung

Dr. Andy Robinson, President and COO of Standard Lithium commented, "Standard Lithium is committed to ushering in a new generation of sustainable mineral extraction by exploring novel, cutting-edge technologies designed to minimize carbon emissions. We look forward to testing this innovative carbon capture technology to better understand how Standard Lithium can engage in the most sustainable production processes, while integrating low-carbon lithium products into North America's energy transition supply chain."

The Carbon Capture Pilot Plant was designed and constructed in the United Kingdom by Standard Lithium's partner, Aqualung. Following initial commissioning and testing with a CO2-rich flue-gas stream, the plant was then shipped to the Gulf Coast and installed at the final testing location, a natural gas processing site in southern Arkansas that is owned and operated by Mission Creek Resources LLC.

Carbon Clean joins with industry to demonstrate CO2 conversion technology

www.carbonclean.com

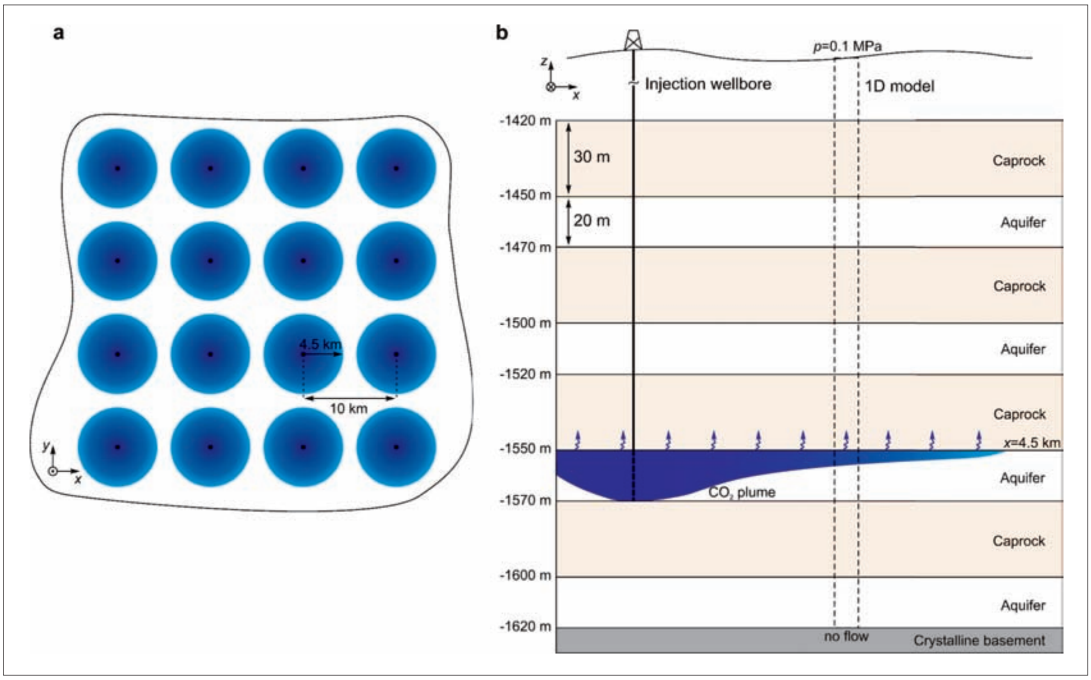
The company has joined forces with 14 other organisations, including BASF, Tata Steel and Unilever, to demonstrate the value of carbon capture to the UK consumer products sector.

The two-year Flue2Chem project will develop a new value chain to convert industrial waste gases into sustainable materials for consumer products, which could result in a saving of 15-20 million tonnes of CO2 emissions a year in the UK. It is receiving £2.68 million of grant funding from Innovate UK's Transforming Foundation Industries (TFI) Challenge.

Foundation industries such as metals, glass, paper and chemicals could provide alternative sources of CO2 for UK consumer product production, at a time when most of the carbon used in everything from electronics to home care and many other products is extracted from coal, oil and gas. If the UK is to reach its net zero target by 2050, industries must find an alternative source for the carbon in these goods.

Storing carbon dioxide underground low risk says study

A study led by the Institute of Environmental Assessment and Water Research (IDAEA) and the Mediterranean Institute for Advanced Studies (IMEDEA CSIC-UIB), both belonging to the Spanish National Research Council (CSIC), has shown that injecting billions of tons of atmospheric CO2 underrground has a low risk of leakage back to the surface.



Conceptual representation of basin-wide CO2 injection (not to scale). (a) A bird's eye perspective of CO2 injection into the reservoir through a dense pattern of wellbores (filled black circles) with a spacing of 10 km. Under buoyancy, the CO2 plume migrates along the top of the aquifer (blue circular regions; the same color is used for illustration on the x–z plane). (b) The model comprises a sequence of aquifers and caprocks with representative thicknesses and depths

According to the simulations, the CO2 would remain deep in the subsurface for millions of years, even if the overlying low-permeability rocks were fractured. These results indicate that this technology, called geological CO2 storage, can be safely undertaken to mitigate climate change.

The study, published in the journal Geophysical Research Letters, has been carried out in collaboration with the Lawrence Berkeley National Laboratory and the University of Illinois at Urbana-Champaign. This interdisciplinary research has developed a novel methodology to calculate the probability of CO2 leakage considering billion tons of CO2 injected underground over a time scale of millions of years, much larger than what had been investigated until now.

"The objective of CO2 storage is to take this greenhouse gas from the hard-to-abate industry and inject it deep underground. For the gas to remain at depth, it must be injected into rocks with high permeability and porosity, such as sandstones," explains the IDAEA-CSIC researcher Iman Rahimzadeh Kivi and first author of the study.

"However, there is a risk of CO2 leakage, as CO2 is less dense than the saline water that fills the pores at great depth, so it can float upwards and leak back to the surface," To calculate the risk of CO2 leakage, researchers predicted the gas flow to the surface after its injection at 1,550 meters deep (the common depth to store the gas underground) using numerical transport models in two different scenarios.

"Our predictions show that in the best-case scenario, when the underground rock properties remain intact, the CO2 would only rise 200 meters upwards after one million years. In our worst-case scenario, when the rocks present a large number of fractures, CO2 would rise 300 meters upwards," indicates Victor Vilarrasa, researcher at IMEDEA-CSIC-UIB and principal author of the study.

"This means that even in the worst possible scenario, the CO2 would be indefinitely contained in the subsurface at 1250 meters' depth for millions of years," says Rahimzadeh Kivi.

The authors highlight that this study is relevant to increase confidence in the security of underground CO2 storage to achieve carbon neutrality and mitigate the effects of the climate emergency.

"The scenarios proposed by the Intergovernmental Panel on Climate Change (IPCC) to achieve zero emissions, and even net-carbon removal from the atmosphere, require geological CO2 storage. And this study shows that permanent CO2 storage can be safely achieved," concludes Vilarrasa.

More information

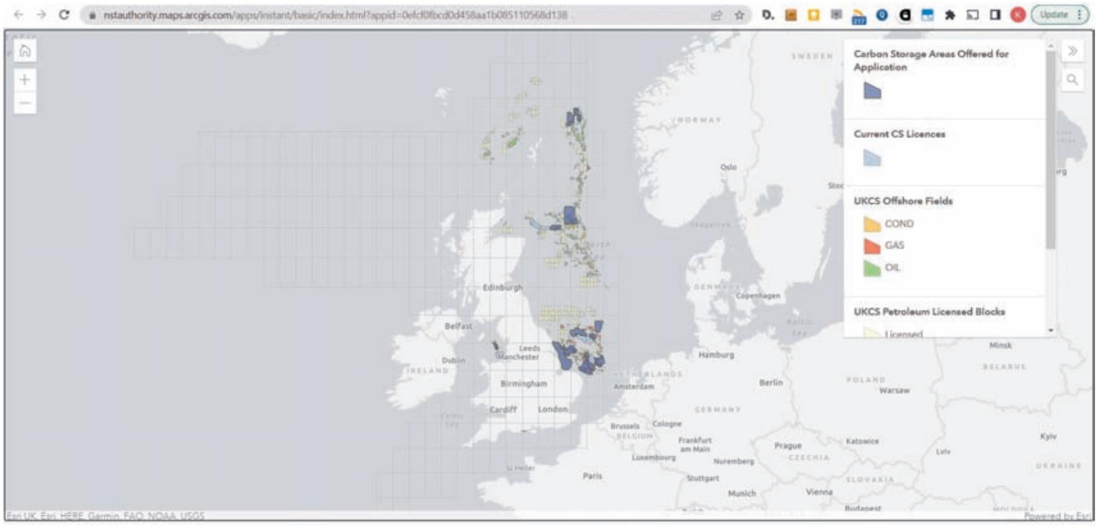
www.csic.es

NSTA sets up dedicated team to oversee the delivery of carbon storage

The North Sea Transition Authority has responded to the rapid growth of the UK's carbon capture and storage industry by setting up a dedicated carbon transportation and storage team.

The team supplements the NSTA's established Exploration & New Ventures team and shows its commitment to the energy transition, which is also reflected in the organisation's name change. The change comes as NSTA considers applications for the first ever CCS licensing round.

The team will oversee the delivery of offshore carbon transportation and storage developments, following successful exploration and appraisal. This is another important milestone in the NSTA's support of the industry on the path to net zero.



Carbon storage areas on the UK Continental Shelf available for CO2 storage licensing

Alistair Macfarlane, NSTA Area Manager, said, "The importance of carbon capture and storage as part of the energy transition and helping the UK to meet net zero cannot be overestimated."

"I am very excited to be heading this team and building a centre of excellence to deliver the regulatory role the NSTA has as efficiently and smoothly as possible to support this growing industry which can play a crucial role in supporting the move towards net zero and providing skilled jobs."

The Climate Change Committee's 6th Carbon Budget report and the NSTA-led Energy Integration Project found that CCS is vital for meeting net zero targets. The government has also set a target to capture 20-30 million tonnes of CO2 a year by 2030 for the UK to reach net zero by 2050.

Additionally, a successful CCS industry could support an estimated 50,000 jobs and enable further low-carbon technologies, such as blue hydrogen – producing hydrogen from natural gas whilst capturing and storing the CO2.

In March 2022, the North Sea Transition Authority took on its new name to underline the growing importance of the Energy Transition, alongside the continuing role of oil and gas.

The UK's first ever carbon storage licensing round was launched in June last year, offering 13 areas for which 26 bids were made. It is expected that licences will be offered for award in the coming weeks.

However, this round is expected to be the first of many, with estimates that up to 100 separate stores could be required for the UK to meet its domestic storage requirements.

A new NSTA carbon storage development team, headed by Alistair Macfarlane, has been established to steward the industry from the point of site characterisation to permit application and beyond as it develops and grows.

The team, which includes experienced reservoir engineers and geoscientists, will work with operators on their development plans, execution of their work programs and, following commencement of CO2 injection, ensuring projects are operating as per the conditions of their storage permit.

The existing Exploration & New Ventures Team will continue to handle the UK storage portfolio, execute licensing rounds, and steward industry exploration and appraisal work programmes from the point of licence award to the end of site characterisation.

Jo Bagguley, NSTA Principal Regional Geologist, added, "The NSTA is progressing evaluations of applications in the UK's groundbreaking First Carbon Storage Round at pace, and we hope to be in a position to make offers of award within weeks."

"Pending award, many of these licences should result in substantial exploration and appraisal activity over the next several years, resulting in better characterisation of subsurface storage sites that can subsequently be passed into the development cycle."

More information
www.nstauthority.co.uk

Transport and storage news

Spirit Energy to transform depleted gas fields into carbon storage cluster

www.spirit-energy.com

Spirit Energy plans to convert its depleted South Morecambe and North Morecambe gas fields and Barrow Terminals into a world-class carbon storage cluster.

Spirit Energy is the joint venture energy company of Centrica plc and Stadtwerke München GmbH. If granted a licence by the North Sea Transition Authority and subject to other regulatory approvals, the project will support the UK's Net Zero ambitions.

Neil McCulloch, CEO of Spirit Energy, said, "Our project will introduce cost-effective decarbonisation to businesses all over the UK, with a multi-billion-pound facility which means that a connection to a CO2 export pipeline is no longer necessary to access carbon storage. Our new cluster will provide a solution for the UK's industrial heartlands to reduce their carbon emissions, while also injecting significant green investment into Cumbria and the North West of England, where we have a proud history of working closely with the community and supporting local jobs and enterprise."

The cluster will provide a carbon storage solution for the UK's industrial heartlands and is set to be one of the biggest carbon storage and hydrogen production clusters in the UK. Under current projections, the project has the capacity to store up to one gigaton of CO2 - which equates to roughly three years' worth of UK CO2 current emissions. This will enable emitters within carbon-intensive industries, including the North West, South Wales, and the Solent, to store their carbon emissions.

Thanks to the location of the site near the Port of Barrow, the project will be able to accept CO2 transported by ship. This will mean industrial sites which do not have a direct connection to a CO2 pipeline can access a feasible and realistic solution to deal with their carbon emissions, remain profitable and meet climate change goals.

Spirit Energy will continue to maximise the use of the gas fields until they are fully depleted to ensure continuity of domestic energy supply. The work on carbon storage will take place in tandem with gas production until the facility is predicted to cease production in the second half of the decade.

Additionally, the two gas fields have the potential to form the core of a future low-carbon hub, thanks to their location in the North West and connectivity in the area. Spirit Energy continues to explore opportunities such as blue hydrogen production, hydrogen power generation, direct air capture, and integration with renewable power generation which could expand the cluster, working in tandem with the carbon storage facility to help realise the area's full potential.

LedaFlow forms CCS research consortium

www.ledaflow.com

LedaFlow Technologies has formed a research consortium with with a range of energy companies and suppliers to enhance its multiphase transport simulator technology for transport and injection of CO2.

The consortium, called CO2Flow project, aims to analyze opportunities for safe transport and injection of CO2 both with and without impurities to accelerate CCS technology development. It comprises ConocoPhillips, TotalEnergies, Equinor, and ExxonMobil Technology & Engineering, as well as Kongsberg Digital, SINTEF Industry, and SINTEF Energy Research.

The consortium also aims to contribute to accelerating the global deployment of CCS, as the partners can put project results into industrial use and benefit from the improved functionalities through more optimal design and reliable operation.

Accurate simulations will enable reduced design margins and decreased investment costs of CO2 transport and injection systems while maintaining operational safety. Precise predictions are also essential for energy and cost-efficient operations and will help minimize risk through simulations of various operational scenarios.

Kongsberg Digital will deliver industrial software in a secure, user-friendly, and reliable way which can also be deployed on digital twins to operate assets. SINTEF Industry and SINTEF Energy Research will provide access to resources and information regarding multiphase flow modelling as well as experimental facilities with CO2 flow competence.

Equinor, TotalEnergies and SINTEF Energy Research have been collecting experimental well data for CO2 injection in the DeFacto flow loop since 2016. The experimental data has been shared with the consortium for model improvement.

By harnessing the resources and data available through the four participating energy companies, LedaFlow Technologies gains access to a vast range of organizations with net zero ambitions.

"Together, our aim is to qualify LedaFlow technology for industrial use by securing simulation accuracy and robustness. The goal is to drive down the design and associated costs for CCS operations and accelerate its broader implementation within the energy mix. This contributes to make cleaner energy more affordable," said Jan Gerhard Norstrøm, Managing Director at LedaFlow Technologies.

Deep geological storage of CO2 examined on the UK Continental Shelf

www.iom3.org

More than 99% of injected CO2 is expected to remain contained after 100 years of deep geological storage on the UK Continental Shelf (UKCS), finds UK government report.

Released by the UK Department for Business, Energy & Industrial Strategy (BEIS), the publication shares insights after modelling two examples sites over 25 years of injection operations and 100 years of post-injection containment. BEIS commissioned a group of independent expert advisors to produce the report.

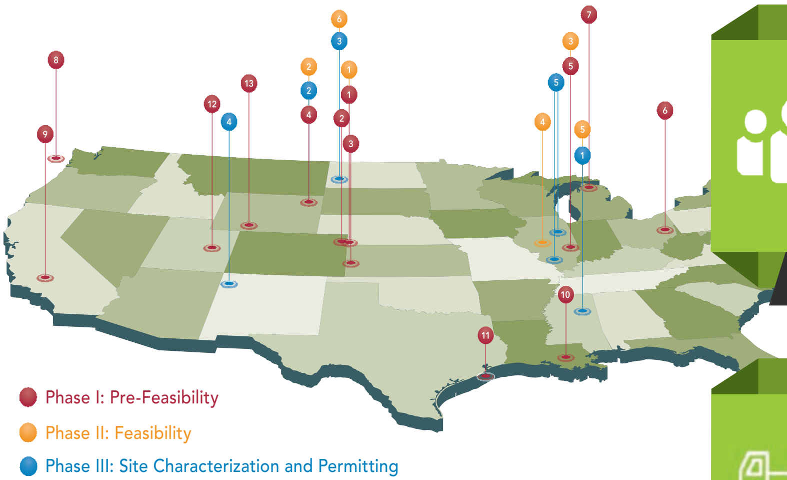
The two sites are designed to reflect the features of 'typical' UK offshore sites. The report says, 'While the risks will vary on a site-specific basis, the results indicate a very high level of confidence in the long-term security of CO2 containment in typical carbon capture and storage complexes on the UKCS.'

It continues, 'To calculate the statistical probable worst-case scenario leakage from an example storage complex over its injection life and post-closure period, the maximum probability of occurence and maximum leak rate have been used. This provides a conservative calculation of the risked estimate of overall leakage.'

Carbon Storage Assurance Facility Enterprise (CarbonSAFE)

The CarbonSAFE Initiative builds off the work done by the Regional Carbon Sequestration Partnerships to fund and develop projects focused on ensuring carbon storage complexes will be ready for integrated Carbon Capture, Utilization, and Storage (CCUS) system deployment in the 2025-2030 timeframe.

CarbonSAFE Illinois Macon County



PROGRAM OBJECTIVES

- Address the R&D knowledge gaps and develop the technologies needed to nationally deploy commercial scale (50+ million metric ton) CO_2 storage.
- Understand the development of a CCUS storage complex from the feasibility study through the point of injection.
- Improve understanding of commercial-scale project screening, site selection, geologic characterization, modeling, and monitoring.
- Address both the technical and non-technical challenges associated characterization, permitting, and monitoring of a geologic storage complex.

Phase I: Integrated CCS Pre-Feasibility 12-18-month initiative

- Formation of a team; development of a feasibility plan; and high-level technical evaluation of the sub-basin and potential CO_2 sources
- Thirteen projects funded

Phase II: Storage Complex Feasibility 18-24-month initiative

- Data collection; geologic analysis; analysis of contractual and regulatory requirements; subsurface modeling; risk assessment; evaluate monitoring requirements; and public outreach
- Six projects funded

Phase III: Site Characterization and Permitting <3-year initiative

- Detailed site characterization; submit UIC Class VI permit to construct; CO_2 Capture Assessment; NEPA approvals
- Five projects funded
- Phase III.5: NEPA and FEED Studies Only - for applicants who have completed most Phase III activities independent of DOE

Phase IV: Construction <2.5-year initiative

- Obtain UIC Class VI permit to inject; drill and complete injection and monitoring wells; complete risk and mitigation plans
- Subject to funding

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