Carbon Capture Journal

CCUS in the U.S.

A New U.S. Industrial Backbone - Exploring Regional CCUS Hubs

National Carbon Capture Center tops 150,000 testing hours

Baker Hughes' most interesting tech

Mar / Apr 2024 Issue 98

Morecambe Net Zero set to be one of UK and Europe's largest CO2 stores

Image: Spirit Energy

- EU NZIA and an obligation on oil companies to store
- Transforming concrete from a carbon problem to a carbon solution
- Direct Air Capture's role in the urgent call to lower escalating emissions
- Offshore CO2 storage: a prerequisite for net zero - Martin van Onna, Strohm

No climate neutrality without CCU: CO2 Value Europe quantifies EU potential

CO2 Value Europe has launched a first-of-a-kind report titled "The Contribution of Carbon Capture & Utilisation Towards Climate Neutrality in Europe", a multidisciplinary study aimed at quantifying the climate mitigation potential of Carbon Capture and Utilisation (CCU) in Europe.

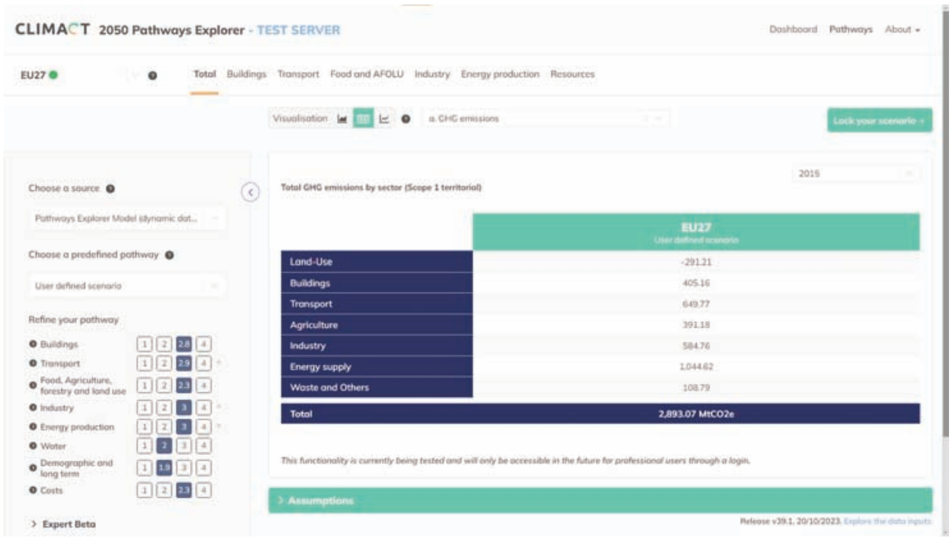
Human-made GHG emissions, largely related to fossil carbon use, are causing drastic disturbances in our climate and ecosystems. To mitigate climate change, there is an urgency to reduce those emissions and to substitute virgin fossil carbon products. Some essential transport and industrial processes can easily be electrified and use renewable electricity, while others, such as process industries, and air and maritime transport need non-fossil hydrocarbons to become compatible with climate neutrality targets.

CO2 Value Europe is advocating for the "defossilisation" of these sectors by promoting the creation of a circular carbon economy based on the principle of CCU. Depending on the context, these technologies can reduce or avoid greenhouse gas emissions, but they can also create negative emissions via Carbon Dioxide Removal (CDR) when CO2 from the air or biogenic processes is sequestered permanently in products.

The Contribution of Carbon Capture & Utilisation Towards Climate Neutrality in Europe is the first quantitative assessment of the crucial role CCU will play in mitigating climate change in Europe. This two-year exercise was undertaken with international academic, industrial, technological and economic world experts on CCU and related subjects to understand and quantify the potential of CCU, but also to describe the main parameters and key uncertainties associated with the upscaling of these technologies.

Key results from the report

• The EU will not reach climate neutrality without CCU. Currently in place economics and regulatory measures represent only 34% of the effort required to reach climate neutrality. These measures must therefore be significantly reinforced by additional measures including societal changes (30%) and technological development (37%).



The 2050 Pathway Explorer for CCU is a first-of-a-kind, open-access CCU model to explore and put in context the contribution of the different CCU pathways in the EU

• CCU represents approx. 21% of the overall GHG emission reduction that can be achieved through technological solutions in the EU.

• By 2050, the EU will be able to capture at least 320 MtCO_2 mainly from biogenic, atmospheric and process emission sources, and convert 55% of it into products, while the rest might need to be stored underground.

• By producing 30% of the chemicals, 18% of the fuels, 76% of ceramics, and 100% of prefab concrete, CCU will reduce EU industrial emissions by 20% in 2050. Using CCU fuels in the maritime and aviation sectors will reduce their emissions by 35% and 38%, respectively.

• CCU fuels will answer at least 13% of the EU primary energy demand by 2050.

This exercise is the first stage of a continuous process to monitor and quantify the role of CCU in contributing to climate neutrality in the EU. More than a report, CO2 Value Europe, together with CLIMACT, have created the 2050 PATHWAY EXPLORER FOR CCU, a first-of-a-kind, open-access CCU model to explore and put in context the contribution of the different CCU pathways in the EU.

CO2 Value Europe is a non-profit association representing the CCU Community in Europe with more than 90 members along the CCU value chain. Its mission is to promote the development and market deployment of sustainable industrial solutions that convert captured carbon into valuable products, contribute to the net reduction of global CO2 emissions and substitute fossil carbon. CCU technologies offer a large panel of solutions for hard-to-abate sectors where no or very few other alternatives exist.

More information

Read more at:
www.co2value.eu

Carbon Capture Journal

Mar / Apr 2024 Issue 98

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

Editor
Keith Forward
editor@carboncapturejournal.com

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

Subscriptions
subs@carboncapturejournal.com

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

Carbon Capture Journal is your one stop information source for new technical developments, opinion, regulatory and research activity with carbon capture, transport and storage.

Carbon Capture Journal is delivered on print and pdf version to a total of 6000 people, all of whom have requested to receive it, including employees of power companies, oil and gas companies, government, engineering companies, consultants, educators, students, and suppliers.

Subscriptions: £250 a year for 6 issues. To subscribe, please contact Karl Jeffery on subs@carboncapturejournal.com Alternatively you can subscribe online at www.d-e-j.com/store

Front cover: Spirit Energy's Barrow Terminal will have the capacity to accept CO2 by pipeline, ship and rail for storage offshore (pg. 13)

Back cover: "Roads to Removal: Options for Carbon Dioxide Removal in the United States" charts a path to achieve a net-zero economy by 2050 – one part of the solution is Direct Air Capture (pg. 4)

Carbon capture journal (Print) ISSN 1757-1995
Carbon capture journal (Online) ISSN 1757-2509

Leaders - CCUS in the U.S.

Projects and policy

Capture and utilisation

Transport and storage

Scaling CCS for hard-to-abate industries

The U.S. Department of Energy's (DOE) Office of Fossil Energy and Carbon Management released a Request for Information: Industrial Deployment and Demonstration Opportunities for Carbon Capture Technologies seeking input from key partners (domestic and international) on what is needed to accelerate deployment of carbon capture, use, and storage for industrial systems.

Industry is responsible for approximately 30 percent of total global carbon dioxide emissions. More than half of these emissions come from industries that are hard-to-abate due to high-temperature and high-pressure processes that are difficult to economically electrify or decarbonize through other carbon-free methods. These industries are also characterised by large investments in facilities and equipment with decades of useful life, slow turnover of that capital stock, and low economic margins.

Carbon capture is a significant part of the solution to decarbonizing these industries. Over $12 billion from the Bipartisan Infrastructure Law has been allocated for carbon management including integrated commercial-scale carbon capture, transport, and storage demonstrations; large-scale carbon capture pilots; and the buildout of regional carbon dioxide transport and storage hubs.

The information being sought through the RfI is intended to assist DOE in the planning of priorities and initiatives to catalyze the development, demonstration, and deployment of CCUS for industrial decarbonisation.

It focusses on 11 industries: petrochemical, ammonia, aluminum, iron-steel, refining, soda ash, lime, pulp and paper, cement, glass, and LNG, with carbon dioxide equivalent emissions of 479 million tonnes/year in the United States and 9,487 million tonnes per year globally (see Table).

Multiple business models are being explored in these industries to improve the economics of industrial carbon capture and storage. These business models consider the proximity to storage sites and the potential of sharing of carbon transport and storage infrastructure with nearby facilities.

A recent paper from Princeton University, "Shared CO_2 capture, transport, and storage for decarbonizing industrial clusters" found that when carbon dioxide pipelines are shared rather than dedicated to individual capture facilities, average transport costs can be reduced by two-thirds. The paper also analysed how pooling emissions streams from facilities with different concentrations of carbon dioxide to a central capture site would reduce costs even further.

Industrial Sector	Annual US Scope 1 CO_2e Emissions (million tonnes/year) [1] [% of total Scope 1 industrial emissions]	Annual Global Scope 1 CO_2e Emissions (million tonnes/year)
Aluminum	2.9 [< 1]	270.0 [2]
Ammonia	34.0 [4]	500.0 [3]
Cement	69.0 [7]	2420.0 [5]
Glass	7.8 [1]	95.0 [4]
Iron-Steel	66.0 [7]	2620.0 [5]
Lime	27.0 [3]	494.5 [5]
Petrochemicals	63.0 [7]	1330.0 [5]
Paper	25.0 [3]	150.0 [5]
Refining	165.0 [17]	1590.0 [6]
Soda Ash	5.3 [< 1]	17.4 [7]
LNG	14.0 [1]	Unknown
Total for the Sectors Noted	479.0	9487.0

Annual US and Global Scope 1 CO_2e Emissions for Specific Industrial Sectors. [1] EPA Flight Data (2021)

An aspect of CCUS for industrial purposes is the global multiplier potential of domestic deployment of the technology in the United States. Although U.S. emissions represent ~5% of global carbon dioxide emissions in these industries, many international companies have facilities in the United States.

Nearly 30 percent of industrial plants in the United States, including petrochemical, ammonia, aluminum, iron and steel, refining, soda and ash, lime, and pulp and paper, and more than 50 percent of cement and glass facilities, have an international parent company. These companies have facilities all over the world and can deploy the technology developed for their U.S. operations at their facilities in other countries.

The most compelling financial incentive for industry to implement carbon capture and storage is the 45Q tax credit. The 45Q tax credit pays up to $85 per ton of carbon dioxide stored; requires that qualified projects commence construction by the end of 2032; and allows the taxpayer to claim the credit for 12 years once a project is placed in service.

However, for some industries, the 45Q tax credit will not be enough to make carbon capture and storage economic for many individual facilities. Other funding mechanisms such as federal loan guarantees, grants, and state or local incentives are likely to be required. Additionally, synergies in sharing infrastructure and workforce with other carbon management projects in regions and clusters to reduce investment and operating costs, access to technical expertise through the U.S. national laboratories to support deployment, and the opportunity to deploy technologies and best practices to facilities in other markets will also improve the business case.

The request for information is an important opportunity for key domestic and international partners to contribute to potential new areas of focus and innovation; identify challenges and knowledge gaps; identify funding opportunities; identify regional opportunities; and determine the potential for clean energy and carbon management careers.

More information

www.energy.gov/fecm

"Shared CO_2 capture, transport, and storage for decarbonizing industrial clusters"

doi.org/10.1016/j.apenergy.2024.122775

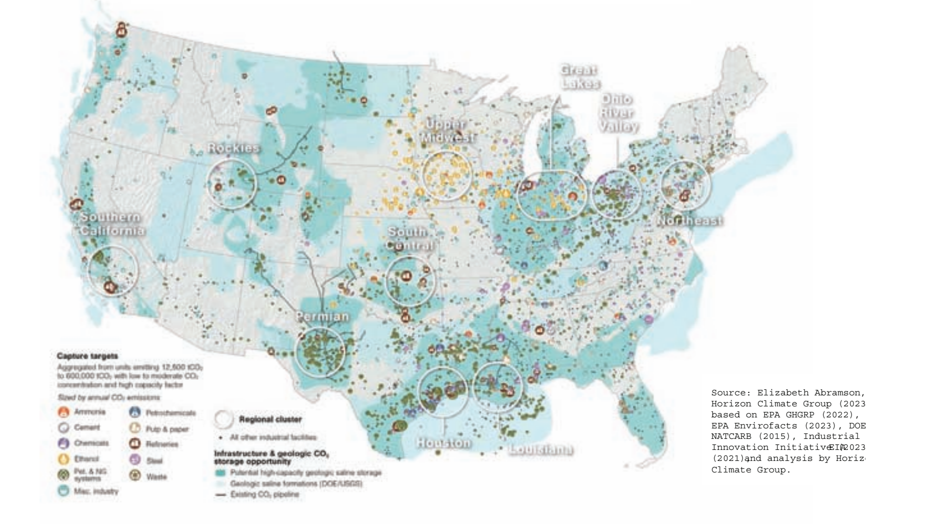
EFI Foundation report on CCUS Hubs in America

"A New U.S. Industrial Backbone: Exploring Regional CCUS Hubs for Small-to-Midsize Industrial Emitters" identifies next steps in the development of CCUS Hubs.

Horizon Climate Group co-authored the report, providing the work to support the analysis, and Carbon Clean sponsored the report.

"To reach our climate goals, we must go well beyond the power sector and pursue industrial decarbonization and carbon dioxide removal," said Ernest J. Moniz, CEO and President of the EFI Foundation and former U.S. Secretary of Energy (2013-2017). "Carbon capture, utilization, and storage hubs are pathways to effective industrial decarbonization of small and midsize emitters."

Previous CCUS studies have tended to focus on the largest emitters with the highest concentrations of carbon dioxide emissions. Small-to-midsize industrial emitters in the United States have not received as much attention, even though they account for 25% of industrial emissions. CCUS can reduce emissions for refining and natural gas processing, hydrogen production, and other facilities.



Small-to-midsize industrial capture targets for potential CCUS hubs

However, deploying CCUS on small-to-midsize industrial facilities can be expected to raise end-to-end costs relative to the unit costs of large facilities, even with current incentives in the Bipartisan Infrastructure Law and the Inflation Reduction Act.

CCUS hubs can allow multiple emitters access to shared CO2 transport and storage operations, offering scale at a lower cost. The report screened data on all U.S. industrial emitters to identify 10 potential regional clusters of small-to-midsize facilities that were within close proximity to form a CCUS hub.

The 10 potential clusters include 1,000 facilities with total annual emissions of 111 million metric tons per year. The report selected four of these clusters for more detailed technological characterization. These four clusters alone include more than 700 small-to-midsize units with over 70 million metric tons of annual CO2 emissions.

The report identifies a series of next steps in the formation of CCUS hubs, including further techno-economic assessments for CCUS hub feasibility, prioritizing the establishment of hubs around currently planned large-scale CCUS projects, and coordinating CCUS hub formation with direct air capture and blue hydrogen hubs. The report recommends that the U.S. Department of Energy expand its existing program to provide funding for initial prefeasibility studies of CCUS hub formation for small-to-midsize emitters.

The report also recommends modifying the Section 45Q credit to extend transferability of the credit and expand the use of the direct pay option. Finally, the report underscores recommendations from various other studies on the need for permitting reforms for CCUS infrastructure.

In its recommendations for industry, the report suggests initiating CCUS hub development within state boundaries, as the complexity of CCUS hub development makes it difficult to build infrastructure that crosses state lines. As the experience of early hub development has shown, longer pipeline projects increase the risk of obstacles that can torpedo a project. The four case studies presented in the report show that some states have a sufficient cluster of small-to-midsize emitters and CO2 storage potential to support intrastate CCUS hubs as the initial phase of interstate hub development.

Large-scale CCUS demonstration and deployment projects could serve as anchor tenants for formation of CCUS hubs for small-to-midsize industrial emitters. Industrial CCUS efforts often focus on large-scale deployment at very large facilities (e.g., petroleum refineries or petrochemical complexes) or clusters of a single industry (e.g., ethanol facilities). There also are a number of one-off, single demonstration projects (e.g., steel, cement) that are in planning and development. These projects can serve as anchor tenants for small and midsize emitters to join to form regional hubs.

More information

www.efifoundation.org

horizonclimategroup.com

A path to achieve a net-zero greenhouse gas economy

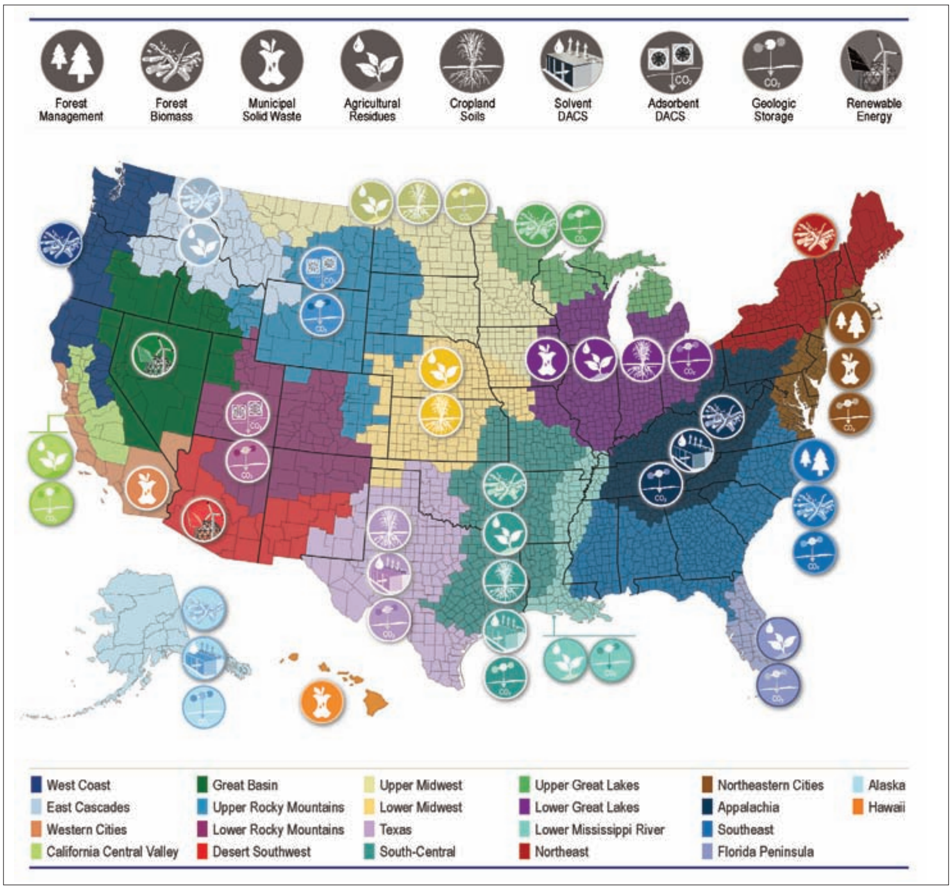
A new report co-authored by scientists at Penn's Kleinman Center charts a path for the U.S. to achieve a net-zero greenhouse gas economy by 2050.

A report co-authored by 68 scientists from more than a dozen institutions, including the University of Pennsylvania, offers a first-of-its-kind high-resolution assessment of carbon dioxide removal (CDR) in the United States.

"Roads to Removal: Options for Carbon Dioxide Removal in the United States" charts a path for the United States to achieve a net-zero greenhouse gas economy by 2050, ensuring the nation's climate security and resilience by cleaning up Earth's atmosphere and addressing the root cause of climate change.

The report provides an integrated analysis of the CDR techniques and resources that are currently available, along with the costs that will be incurred on the path to net-zero.

"This report shows that to achieve the billion-ton scale of carbon dioxide removal needed by 2050 to achieve net-zero goals, the United States must use all removal methods available—oceans, forests, cropland soils, biomass and minerals and chemicals through direct air capture—to make it happen," said Jennifer Wilcox, principal deputy assistant secretary for Fossil Energy and Carbon Management at DOE. Wilcox is currently on leave from Penn, where she leads the Clean Energy Conversions Lab, an affiliated lab of the Kleinman Center for Energy Policy.



Regions map with county grouping defined by primary carbon-removal resources. The icons qualitatively highlight key regional resources that can contribute to CO2 removal

Included in the analysis is a chapter dedicated to the transportation of CO2 and biomass, written by researchers from Wilcox's lab: Peter Psarras, Hélène Pilorgé, Maxwell Pisciotta, Diamantoula Giannopoulos, and Alina Ho.

"Historically transport has almost been forced because we've been focused on point-source capture. And the storage basins aren't movable," said Psarras, who currently leads Wilcox's lab.

"What's beautiful about CDR is we have liberty about where to site things. The best transport option we have found is—none at all. Co-locate these with storage basins, so we can take transport out of the picture. Take those risks and costs out of the picture. We think communities would be very supportive of that."

The report found that with today's technologies, removing 1 billion tonnes of CO2 will cost roughly $130 billion per year in 2050, or about 0.5% of current gross domestic product (GDP). New technologies and approaches would likely reduce that total cost.

The overall CO2 removal capacity for forestry, cropland soil, biomass carbon removal and storage (BiCRS), and direct air capture with storage (DACS) is considerably larger than estimates of what the United States needs to remove. This extra removal capacity will make it feasible to pick regional implementations that match local needs.

Communities can clearly see their local opportunities and determine a best course of action. Optimising early projects to maximize community benefits can help accelerate initial adoption and learning.

More information
www.roads2removal.org

Oregon State University finds CCS 'goldilocks' molecule

The element is vanadium, and research by Oregon State University scientists has demonstrated the ability of vanadium peroxide molecules to react with and bind carbon dioxide.

The study is part of a $24 million federal effort to develop new methods for direct air capture (DAC). The element shows a "Goldilocks" level of reactivity – neither too much nor too little – that makes it a strong candidate as a carbon scrubbing tool.

Facilities that filter carbon from the air have begun to spring up around the world but they're still in their infancy. Technologies for mitigating carbon dioxide at the point of entry into the atmosphere, such as at power plants, are more well developed. Both types of carbon capture will likely be needed if the Earth is to avoid the worst outcomes of climate change, scientists say.

In 2021 Oregon State's May Nyman, the Terence Bradshaw Chemistry Professor in the College of Science, was chosen as the leader of one of nine direct air capture projects funded by the Department of Energy. Her team is exploring how some transition metal complexes can react with air to remove carbon dioxide and convert it to a metal carbonate, similar to what is found in many naturally occurring minerals.

Transition metals are located near the center of the periodic table and their name arises from the transition of electrons from low energy to high energy states and back again, giving rise to distinctive colors. For this study, the scientists landed on vanadium, named for Vanadis, the old Norse name for the Scandinavian goddess of love said to be so beautiful her tears turned to gold.

Nyman explains that carbon dioxide exists in the atmosphere at a density of 400 parts per million. That means for every 1 million air molecules, 400 of them are carbon dioxide, or 0.04%.

"A challenge with direct air capture is finding molecules or materials that are selective enough, or other reactions with more abundant air molecules, such as reactions with water, will outcompete the reaction with CO2," Nyman said. "Our team synthesized a series of molecules that contain three parts that are important in removing carbon dioxide from the atmosphere, and they work together."

One part was vanadium, so named because of the range of beautiful colors it can exhibit, and another part was peroxide, which bonded to the vanadium. Because a vanadium peroxide molecule is negatively charged, it needed alkali cations for charge balance, Nyman said, and the researchers used potassium, rubidium and cesium alkali cations for this study.

She added that the collaborators also tried substituting other metals from the same neighborhood on the periodic table for vanadium.

"Tungsten, niobium and tantalum were not as effective in this chemical form," Nyman said. "On the other hand, molybdenum was so reactive it exploded sometimes."

In addition, the scientists substituted ammonium and tetramethyl ammonium, the former of which is mildly acidic, for the alkalis. Those compounds didn't react at all, a puzzler the researchers are still trying to understand.

"And when we removed the peroxide, again, not so much reactivity," Nyman said. "In this sense, vanadium peroxide is a beautiful, purple Goldilocks that becomes golden when exposed to air and binds a carbon dioxide molecule."

She notes that another valuable characteristic of vanadium is that it allows for the comparatively low release temperature of about 200 degrees Celsius for the captured CO2.

"That's compared to almost 700 degrees Celsius when it is bonded to potassium, lithium or sodium, other metals used for carbon capture," she said.

"Being able to rerelease the captured CO2 enables reuse of the carbon capture materials, and the lower the temperature required for doing that, the less energy that's needed and the smaller the cost. There are some very clever ideas about reuse of captured carbon already being implemented – for example, piping the captured CO2 into a greenhouse to grow plants."

Vanadium, one of the CO2 capture materials, displaying a brilliant deep purple color (image provided by May Nyman, chemistry professor, OSU College of Science)

Other Oregon State authors on the paper included Tim Zuehlsdorff, assistant professor of theoretical/physical chemistry, and postdoctoral researcher Eduard Garrido.

"I'm also really proud of the hard work of the graduate students in my lab, Zhiwei Mao and Karlie Bach, and undergraduate Taylor Linsday," Nyman said. "This is a brand new area for my lab, as well as for Tim Zuehlsdorff, who supervised Ph.D. student Jacob Hirschi on the computational studies to explain the reaction mechanisms. Starting a new area of study involves many unknowns."

Eric Walter of the Pacific Northwest National Laboratory and Casey Simons of the University of Oregon also took part in the study, which was published in Chemical Science, the flagship journal of the Royal Society of Chemistry.

More information

oregonstate.edu

Argonne scientists use AI to identify new materials for carbon capture

Generative AI techniques, machine learning and simulations give researchers new opportunities to identify environmentally friendly metal-organic framework materials.

Suitable materials for effective carbon capture at low cost have yet to be found, one candidate is metal-organic frameworks, or MOFs. This porous material can selectively absorb carbon dioxide.

MOFs have three kinds of building blocks in their molecules — inorganic nodes, organic nodes and organic linkers. These can be arranged in different relative positions and configurations. As a result, there are countless potential MOF configurations for scientists to design and test.

To speed up the discovery process, researchers from the U.S. Department of Energy's (DOE) Argonne National Laboratory are following several pathways. One is generative artificial intelligence (AI) to dream up previously unknown building block candidates. Another is a form of AI called machine learning. A third pathway is high-throughput screening of candidate materials. And the last is theory-based simulations using a method called molecular dynamics.

Joining Argonne in this project are researchers from the Beckman Institute for Advanced Science and Technology at the University of Illinois Urbana-Champaign (UIUC), the University of Illinois at Chicago and the University of Chicago.

Designing MOFs with optimal carbon selectivity and capacity is a significant challenge. Until now, MOF design has relied on painstaking experimental and computational work. This can be costly and time-consuming.

By exploring the MOF design space with generative AI, the team was able to quickly assemble, building block by building block, over 120,000 new MOF candidates within 30 minutes. They ran these calculations on the Polaris supercomputer at the Argonne Leadership Computing Facility (ALCF). The ALCF is a DOE Office of Science user facility.

They then turned to the Delta supercomputer at UIUC to carry out time-intensive molecular dynamics simulations, using only the most promising candidates. The goal is to screen them for stability, chemical properties and capacity for carbon capture. Delta is a joint effort of Illinois and its National Center for Supercomputing Applications.

The team's approach could ultimately allow scientists to synthesize just the very best MOF contenders. ?“People have been thinking about MOFs for at least two decades,” said Argonne computational scientist Eliu Huerta, who helped lead the study. ?“The traditional methods have typically involved experimental synthesis and computational modeling with molecular dynamics simulations. But trying to survey the vast MOF landscape in this way is just impractical.”

Even more advanced computing will soon be available for the team to employ. With the power of the ALCF's Aurora exascale supercomputer, scientists could survey billions of MOF candidates at once, including many that have never even been proposed before.

What's more, the team is taking chemical inspiration from past work on molecular design to discover new ways in which the different building blocks of a MOF could fit together.

“We wanted to add new flavors to the MOFs that we were designing,” Huerta said. ?“We needed new ingredients for the AI recipe.” The team's algorithm can make improvements to MOFs for carbon capture by learning chemistry from biophysics, physiology and physical chemistry experimental datasets that have not been considered for MOF design before.

To Huerta, looking beyond traditional approaches holds the promise of a transformative MOF material — one that could be good at carbon capture, cost-effective and easy to produce.

“We are now connecting generative AI, high-throughput screening, molecular dynamics and Monte Carlo simulations into a standalone workflow,” Huerta said. ?“This workflow incorporates online learning using past experimental and computational research to accelerate and improve the precision of AI to create new MOFs.”

The atom-by-atom approach to MOF design enabled by AI will allow scientists to have what Argonne senior scientist and Data Science and Learning division director Ian Foster called a ?“wider lens” on these kinds of porous structures. ?“Work is being done so that, for the new AI-assembled MOFs that are being predicted, we incorporate insights from autonomous labs to experimentally validate their ability to be synthesized and capacity to capture carbon,” Foster said. ?“With the model fine-tuned, our predictions are just going to get better and better.”

A paper based on the study was authored by Hyun Park, Xiaoli Yan, Ruijie Zhu, Eliu Huerta, Santanu Chaudhuri, Donny Copper, Ian Foster and Emad Tajkhorshid. It appeared in the online issue of Nature Communications Chemistry.

“The study demonstrates the great potential of using AI-based approaches in molecular sciences,” said UIUC's Tajkhorshid. ?“We hope to extend the scope of the approach to problems such as biomolecular simulations and drug design.”

“This work is a testament to the collaboration between graduate students and early-career scientists from different institutions who came together to work on this important AI for science project,” Huerta said. ?“The future will stay bright as we continue to inspire and be inspired by talented young scientists.”

The work was supported by DOE's Office of Science, Office of Advanced Scientific Computing Research, laboratory-directed research and development funds, and the National Science Foundation.

More information

www.anl.gov/organizations/argonne-national-laboratory

National Carbon Capture Center tops 150,000 testing hours

Testing has helped advance cost-effective and commercially viable carbon management technologies to reduce greenhouse gas emissions from fossil-based power plants and industrial sources.

The NCCC provides real-life industrial operating conditions combined with the infrastructure to evaluate cutting-edge technologies for scale-up and future commercial adoption.

Through the testing and development of more than 75 new technologies, the center has already reduced the projected cost of CO2 capture from fossil-based power generation by more than 40%. Nine technologies evaluated at the NCCC have been scaled up or are ready to be demonstrated at 10-plus megawatts.

The center's scope of research also includes new progress in technologies for carbon conversion and direct air capture.

"I applaud the center's highly skilled employees for their unwavering commitment to building the future of energy through innovation," said John Northington, NCCC director.

"This momentous milestone is a testament to the highest level of collaboration with the Department of Energy, our sponsors and numerous technology developers. It's an honor to be a part of such a long-standing and successful team effort to advance and demonstrate next-generation carbon management technologies."

Fifteen years after embarking on its mission, the NCCC (managed and operated by Southern Company) continues to collaborate with third-party technology developers – including to date more than 50 government, industry, university and research organizations from seven countries – to offer innovative solutions to advance emerging technologies out of the laboratory and demonstrate them in real-world operating conditions.

The NCCC, located in Wilsonville, Alabama, adjacent to Southern Company subsidiary Alabama Power's Plant Gaston, was created by DOE's Office of Fossil Energy and Carbon Management and National Energy Technology Laboratory as a neutral research and development facility. Since its inception in 2009, the center has accelerated the commercialization of advanced technologies to reduce GHG emissions.

The National Carbon Capture Center in Alabama has been testing a variety of new carbon capture and conversion technologies for the past fifteen years

The overall scope of technology development at the NCCC has evolved from focusing primarily on post-combustion carbon capture for coal-fired power generation to testing carbon capture technologies for natural gas-fired power plants, as well as carbon conversion processes (turning captured carbon dioxide into valuable products such as chemicals, fuels, building materials and plastics) and direct air capture.

Research at the NCCC can concurrently evaluate numerous technologies at various levels of development, accelerating the pace of progress. 150,000 hours of technology testing has culminated with some exciting emerging technologies currently under development at the NCCC:

• Southern States Energy Board and Aircapture are working together to scale up and demonstrate a direct air capture system. Their technology highlights solid-amine adsorbents contained in a monolith contactor to produce a CO2 stream of at least 95% purity using low-grade waste heat (often available in a fossil fuel plant setting). The NCCC is assisting with the field testing by Aircapture.

• UCLA's CarbonBuilt tested their revolutionary CO2 conversion technology reducing concrete's carbon footprint by 70% to more than 100%. Their technology enables concrete manufacturers to capture CO2 emissions from industrial sites and embed it into the concrete. The NCCC will soon assist with further testing to measure process improvements and produce other concrete products.

• Carbon America's process of cryogenic separation of CO2 from industrial gases requires no external refrigerant and uses compression/expansion and heat integration to make the flue gas self-refrigerating. Then, CO2 is collected as a liquid. The NCCC is providing infrastructure and flue gas for testing the integrated pilot-scale cryogenic process.

• EPRI and Pacific Northwest National Laboratory (PNNL) are testing a water-lean, low-viscosity liquid solvent, which is expected to significantly lower the energy requirements of solvent-based CO2 capture. The NCCC is providing EPRI and PNNL with a pilot-scale platform customized to test the specialized solvent and evaluate its performance under different conditions.

More information

www.nationalcarboncapturecenter.com
www.southerncompany.com

Sanford researchers discover microbes that turn CO2 into rocks

The discovery by researchers at Sanford Underground Research Facility could have major implications for the permanent storage of CO2 underground.

At room temperature, carbon dioxide, or CO2, is a gas, which makes it hard to store for long periods of time and keeping captured CO2 underground is a challenge.

“When injected as a gas, CO2 has the potential to leak back to the atmosphere,” said Gokce K Ustunisik, Ph.D., an associate professor in the Department of Geology and Geological Engineering at South Dakota Mines. “For example, if a geologic fault occurs or when there are changes in pressure following the initial pumping on the surface, stored gas will be looking for a way to escape.”

To solve this problem, scientists are exploring efforts to bind CO2 gas underground by pumping it into rock layers with specific geochemical properties that will dissolve the gas and turn it into a carbonate mineral in a process called in-situ mineralisation. However, this process takes a long time, between 7 to 10 years, in nature. But an innovation discovered by researchers working at the Sanford Underground Research Facility (SURF) could change this.

The team of researchers found a set of naturally occurring microbes inside SURF that eat carbon dioxide gas and turn it into solid rock through a process called carbon mineralization. The results come thanks to a National Science Foundation grant of $300,000 that funded the initial research.

“The first NSF EAGER grant on this project allowed us to design laboratory experiments to understand optimum conditions like pressure, temperature, time, acidity, and grain size necessary for mineralization without the help from bacteria as a first step. The conditions had never been studied before,” said Ustunisik. “Then we tested several microbes that can handle the conditions underground. Finally, we tested how fast the mineralization occurs with bacteria by running parallel experiments with and without biological activity. We found that we can store CO2 by crystallizing MgCO3-magnesite mineral in just ten days in microbe-bearing experiments.”

These microbes, or extremophiles, were found inside SURF located in the former Black Hills mining town of Lead, SD. The team has spent years hunting for these extremophiles that grow thousands of feet below ground inside water-filled rock fractures with unique properties that enable them to thrive in extreme environments.

A researcher from South Dakota Mines gathers microbes from SURF. Image: Matt Kapust

Researchers were able to isolate four types of microbes found at SURF and show, through a series of laboratory experiments, that they can turn large quantities of carbon dioxide into rocks that will remain stable and out of atmospheric circulation for thousands of years. The team of researchers now have a patent pending on their findings.

“The discovery of life deep in the rocks 4,100 feet below the surface in SURF was thrilling,” said Tanvi Govil, Ph.D., an assistant professor in the Karen M. Swindler Department of Chemical and Biological Engineering at Mines. “We are fortunate that SURF is home to these extraordinary microbes that have survived in this extreme subsurface environment with no light, scarcity of food and limited space.”

Rajesh Sani, Ph.D., a professor in the Karen M. Swindler Department of Chemical and Biological Engineering at Mines, suggests that the discovery of these subsurface microbes that accelerate the removal of CO2 biologically was thanks to the multidisciplinary effort in this research. “Working together in a supportive and collaborative team structure involving microbiologists, geochemists, and environmental scientists with shared responsibility is the key to strengthening climate action,” said Sani.

The findings may lead to new ways to permanently capture CO2 emissions, reducing the impacts of climate change.

“This not only helps with the climate crisis, but it also has potential to spur economic development through microbially-accelerated carbon sequestration," said Bret Lingwall, Ph.D., associate professor in the Department of Civil and Environmental Engineering at Mines.

The team of researchers now have a patent pending on their findings. Detailed scientific publications on the work hinge on the patent application. The team has presented this research at multiple scientific conferences in the United States and Europe, including the Dec. 2023 meeting of the American Geophysical Union in Chicago and the July 2023, Goldschmidt Conference in Lyon, France.

Ustunisik says the next phase of research could include an attempt to use the microbes to sequester CO2 in the field. The South Dakota Mines team is seeking funding to continue this research. According to Ustunisik, the target depth for a test well is a borehole about one mile deep where the rocks can be in the range of 80-100 degrees Celsius. She says it should not be a problem to find a suitable field site to continue this research.

More information

www.sanfordlab.org

DOE invests $12M in novel membrane technology that captures carbon

Ohio State engineers Yang Han and Winston Ho have been selected to receive funding from the U.S. Department of Energy (DOE) to demonstrate their transformational membrane technology's ability to capture carbon dioxide emitted by cement manufacturing and natural gas power plants.

They lead two of nine projects awarded $45 million in Office of Fossil Energy and Carbon Management funding to advance CO2 capture technologies and help establish the foundation for a successful carbon transport and storage industry.

Distinguished Professor of Engineering Winston Ho has developed methods to reduce fossil fuel-generated pollution during his extensive former career at Exxon and as an Ohio State faculty member for the past 21 years. He and Han created a membrane that cost-effectively captures at least 95% of the CO2 emitted from industrial gases and power plants.

"Our membrane research focuses on the synthesis of new CO2 carrier molecules with high CO2 sorption capacity, the fabrication of thin-film composite membrane, and the elucidation of facilitated transport mechanism," said Ho, a professor of chemical and biomolecular engineering and materials science and engineering.

"This is foundational to practical applications for CO2 capture from flue gases in cement and natural gas combined cycle (NGCC) power plants and from synthesis gases, including bio-syngas."

The DOE has supported work by Ho and his team to advance the membrane technology and test its use in electric power generation and industrial sectors with more than $39 million since 2012. Han, a research scientist who has worked with Ho since coming to Ohio State in 2013 where he obtained his doctorate degree in chemical engineering in 2018, is the primary investigator for the two latest DOE projects.

The duo have developed continuous processes to fabricate their prototype membranes in a roll-to-roll manner at a width of 21 inches. The membranes are then rolled into spiral-wound membrane modules, each with a membrane area of 35 square meters, in a commercial-size diameter of 8 inches. These membrane and module fabrication processes are readily transferrable to commercial manufacturing, transitioning the technology for commercial deployment.

Decreasing cement manufacturing emissions

For their first project, the Buckeye engineers and their industry partners were selected to receive up to $7 million in DOE funding, plus a $2 million cost share from sustainable building materials manufacturer Holcim US, to design and test a 3-metric ton CO2 per day carbon capture system at a Holcim cement plant in Holly Hill, South Carolina.

Researchers will use the university's transformational membrane to cost-effectively capture up to 99% of the CO2 from cement kiln gas with at least 95% purity. Purity of the captured gas is key to meet growing demand for quality carbon dioxide. Initial analysis shows capture costs of $29.90 per metric ton of CO2 at 99% capture, lower than the amine absorption technologies used today.

"Our membrane technology makes it possible to capture up to 99% of the carbon emissions from cement manufacturing," said Han.

"The captured carbon dioxide can be stored underground, used to strengthen concrete, or transformed into valuable products. This technology, with its simple operation and minimal utility needs, provides an easy retrofit for cement plants, bringing sustainable building solutions one step closer to reality."

In addition to Ohio State and Holcim, the project team also includes GTI Energy, who will operate the test unit; Trimeric Corporation, who will perform a techno-economic analysis of the carbon capture technology and an environmental health and safety risk assessment; and Zenith Purification LLC, who will perform membrane quality assurance and control.

Reducing natural gas power plant emissions

Han and Ho will also receive up to $5 million in DOE funding, plus a $1.25 million cost share, to test their engineering-scale carbon capture system for NGCC flue gas at the Wyoming Integrated Test Center (ITC) in Gillette, Wyoming.

Flue gas refers to the combustion exhaust gas produced at fossil fuel power plants. The team plans to modify their 20-metric ton CO2 per day engineering-scale test unit for coal flue gas into a 5-metric ton CO2 per day carbon capture system for natural gas combined cycle flue gas.

"Ohio State's membrane technology has shown exceptional performance, with promise of capturing 95% of CO2 from the flue gas at a competitive cost of $58.10 per metric ton," Han explained. "That's lower than the baseline recovery technology, Shell Cansolv, and other amine absorption technologies."

Besides Ohio State and ITC, the technical team also includes Trimeric Corporation and Zenith Purification LLC.

The researchers aim to demonstrate a continuous, steady-state operation of their carbon capture systems for a minimum of two months for each project and gather necessary data to further scale up the respective processes.

"These projects move us closer to commercialization of Ohio State's novel membrane technology, which could take another three to 10 years, and toward achieving the United States' ambitious goal of a net-zero emissions economy by 2050," Ho said. "This does not happen overnight and requires continual research effort."

More information

engineering.osu.edu

U.S. news

POET and Summit Carbon Solutions partner on carbon capture

www.poet.com/sustainability

www.summitcarbonsolutions.com

The deal will connect the world's largest biofuel producer with the world's largest carbon capture and storage project.

The partnership expands the carbon capture potential across the Midwest by incorporating POET's 12 facilities in Iowa and five facilities in South Dakota into the Summit project. This addition will facilitate the capture, transportation, and permanent storage of 4.7 million metric tons of CO2 annually from the 17 POET bioprocessing plants.

"POET is excited to partner with Summit Carbon Solutions on this historic project," said Jeff Broin, POET Founder and CEO.

"As the world seeks low-carbon energy solutions, carbon capture ensures that ag-based biofuels will remain competitive for decades to come. This is a tremendous opportunity to bring value to farmers, bioethanol producers, and rural communities and counties in participating states, and I believe it will unleash even more opportunities for ag and bioprocessing in the future."

The timeline for the addition of these plants has been strategically planned. The plants in South Dakota will be included in the upcoming state application, ensuring a streamlined integration into Summit's existing project framework.

Meanwhile, for the plants in Iowa, separate applications will be filed, acknowledging the unique requirements and opportunities in each state. This structured approach allows Summit to efficiently expand our project scope while adhering to local regulations and needs.

"Today marks a historic day for American agriculture and biofuels. POET is the largest bioethanol producer in the world, and their partnership with Summit Carbon Solutions ensures that decarbonizing bioethanol will lead to exciting new market opportunities for producers, rural economies, and American energy security," said Bruce Rastetter, Founder and Executive Chairman of Summit Agricultural Group.

Delek Texas refinery selected by US DOE for pilot

www.delekus.com

The Office of Clean Energy Demonstrations will negotiate a cost-sharing agreement in support of a carbon capture pilot project in the Big Spring refinery.

The DOE Carbon Capture Large-Scale Pilot Project program provides 70% cost-share for up to $95 million of federal funding to support project development.

"We are honored and pleased the DOE has selected Delek's carbon capture project," said Avigal Soreq, President and Chief Executive Officer of Delek US. "The selection of the Big Spring refinery validates its competitive advantage, solid operations, and the opportunities in our assets. Carbon Capture is important for decarbonizing hard-to-abate sectors."

The project will deploy Svante Technologies Inc.'s second-generation carbon capture technology at the Delek Big Spring refinery's fluidized catalytic cracking unit (FCCU), while maintaining existing production capabilities and turnaround schedule.

Expectations for the project are to capture 145,000 metric tons of carbon dioxide per year, as well as reduce health-harming pollutants, such as SOx and particulate matter.

Carbon dioxide is expected to be transported by existing pipelines for permanent storage or utilisation. A goal of the Big Spring refinery FCCU pilot is to achieve cost reductions and help commercialise carbon capture technology.

"This project will position Delek US as a strong leader in the energy transition while meeting our financial and other objectives for stakeholders and maintaining our disciplined approach to capital allocation," Soreq added.

"We look forward to working with the DOE and leading industry partners to advance carbon capture technology in a safe and environmentally responsible manner."

Delek said a carbon capture schoolhouse will be established to equip current and future workforces with valuable skillsets needed for the energy transition. The project is expected to create approximately 200 construction and operations jobs in 2027 and 2028.

GTI Energy receives award to study steel decarbonisation

www.gti.energy
www.ussteel.com

GTI Energy and U.S. Steel will test innovative solutions for the readiness of carbon capture technology for widescale deployment in industrial applications.

The company has been selected for new funding from the U.S. Department of Energy (DOE) for a project that will advance innovative carbon management technologies and pave the way for a net-zero emissions economy in the United States.

GTI Energy will demonstrate its ROTA-CAP™ carbon capture technology at U.S. Steel's Edgar Thomson facility in Braddock, Pennsylvania. The project will assess the readiness of carbon capture technology for commercial scale-up and widescale deployment. ROTA-CAP™ is GTI Energy's modular, scalable, integrated industrial carbon capture system that uses novel approaches to intensify the carbon capture process, reducing the size and cost compared to current processes.

"GTI Energy is not merely testing innovative carbon management solutions, we are demonstrating their real-world viability and economic potential," said Don Stevenson, Vice President of Carbon Management & Conversion, GTI Energy. "This partnership will showcase the power of collaboration and innovation in tackling the complex challenge of transitioning to cleaner energy systems."

DOE's Carbon Management Market Liftoff Report estimates that the U.S. needs to capture and store 400 to 1,800 million tonnes of carbon dioxide annually to meet its 2050 decarbonization goals. Industrial sectors such as steel and cement production contribute significantly to global CO2 emissions, typically at large individual point sources, and are considered hard to decarbonise.

"Lowering carbon emissions in our operations is a key part of the U. S. Steel strategy," said Scott Buckiso, U. S. Steel Senior Vice President and Chief Manufacturing Officer. "We welcome the collaboration with the DOE and GTI Energy at our Edgar Thomson plant, together we're creating solutions that will shape the future."

Baker Hughes' most interesting CCUS technologies

Baker Hughes is developing technologies for gas power generation with CCS and lower emissions, direct air capture, compact carbon capture, solvents, algae which convert CO2, and electrical hydrogen compression. By Karl Jeffery.

Energy technology company Baker Hughes is developing a number of technologies for different areas of CCUS. We spoke to Chris Barkey, Chief Technology Officer for the Industrial and Energy Technology division of Baker Hughes.

Mr Barkey is a former group director of engineering and technology for Rolls-Royce, where he was responsible for the entire engineering function of the company including roughly 17,500 engineers.

A portfolio of different technologies is being developed for carbon capture. The most appropriate one will depend on factors such as the concentration of CO2 in the input flow (very low for DAC), the volume of CO2 to capture (very high for a power station), and other factors such as the space available for equipment.

"For each of these technologies we believe we have strong competitive advantage, they are all interesting and exciting" - Chris Barkey, Chief Technology Officer, Baker Hughes

NET Power

The NET Power technology is for gas power generation with carbon capture.

Baker Hughes has invested in NET Power and announced a 'strategic partnership' in February 2022.

With the NET Power system, gas is combusted with pure oxygen, rather than air. The turboexpander (to generate power) is turned by high pressure CO2, rather than using the heat of the engine to make high pressure steam. Most of the CO2 is compressed and recirculated back to the turboexpander while a small portion exits the cycle, like a slowly overflowing bucket, and is captured.

The oxygen to feed into the combustor is generated from air, taken from an air separation unit.

Baker Hughes believes that the technology will be "hugely competitive" compared to conventional methods, combined cycle gas turbines (CCGT) which heat steam to drive a turbine, with a carbon capture system fitted on the back. This is for multiple reasons.

Firstly, it removes the step of using the heat of the combustion to heat water to drive the turbine. This increases overall efficiency.

Secondly, there is no CO2 released to the atmosphere at all. A conventional carbon capture system is normally only about 90 per cent efficient, with about 10 per cent of the CO2 released to the atmosphere. If gas is burned in oxygen, it produces only water and CO2. It is easy to separate out the water vapour by condensing the mixture, and then all the remaining gas, all CO2, can be sent to storage.

Thirdly, there are no NOx emissions. The air separation unit produces oxygen at about 99.5 per cent purity. So there is very little nitrogen entering the combustor. A conventional gas turbine system needs an additional scrubber to remove the NOx.

The air separation unit uses a lot of energy, but then so does a carbon capture unit, so there may be no big overall difference there.

The NET Power technology is being designed for power plants at "utility scale" in the 300 MWe range.

A 50 MW test system is being built in Texas, to be operational in 2028.

Mosaic Materials – DAC

Baker Hughes acquired Mosaic Materials, a company which is developing an adsorbent material for direct air capture, in April 2022. It is further developing the technology.

The CO_2 is captured in a proprietary metal organic framework (MOF) material which adsorbs CO_2.

This MOF has enormous surface area crammed into a small volume – a sugar cube sized piece of MOF has the surface area of a football field, Mr Barkey said.

There is an exothermic reaction when CO_2 is adsorbed onto the material.

The technology was originally developed at the University of Berkeley. It is already being used by the US Navy and NASA to improve breathing air quality on submarines and spacecraft.

So far, Baker Hughes has been testing a "Bravo" scale unit capturing 150 tonnes a year. It uses the names Alpha, Bravo, Charlie to signify a gradual scaling up of technology in development.

Bravo should complete testing and assessment by the end of the year when we will move onto Charlie, the exact size is still to be determined. Meanwhile the chemistry and other factors are being tweaked, Mr Barkey said.

Trials are being made to find the best method of heating the material evenly so that it desorbs (releases its CO_2). If any part of the material does not get heated, it will not desorb and so the whole process will be less efficient. It could be conventional convection heating, or microwaves, he said.

The material needs to be manufacturable in sufficient scale and cost and it needs to be durable. "The last thing we need is for it to be perfect for three weeks then you have to change it out," he said.

Indications so far show a small amount of degradation after first use, but only to a certain point, then degradation flatlines, he said.

"I'm really excited about Mosaic. Compared to some of the other direct air capture technologies it has [good] capacity for adsorption, speed of cycle," he said. "It makes it a really powerful and competitive product."

It may also be suitable for carbon capture from point sources.

Senior management at Baker Hughes have been putting pressure on technology developers to get it to market as fast as possible, he said.

Compact carbon capture

Baker Hughes is developing a compact carbon capture system, which uses rotating beds to increase the dynamics in system compared to conventional static gravity towers to bring the solvent into contact with the gas.

It may be suitable for applications which do not have space for conventional carbon capture towers, or do not want towers for other reasons, such as use offshore and on ships. It may also be less expensive, particularly in CAPEX, for emitters with lower volumes.

In conventional carbon capture, two towers are used, where the solvent flows down with gravity. In the first tower it comes into contact with the CO_2 rich gas, and in the second tower the solvent is heated and releases the CO_2.

The compact carbon capture system uses rotating beds instead of towers, where the solvent is sent from the centre towards the edge by centrifugal force instead of using gravity.

Baker Hughes is currently testing a 5 tonnes CO_2 per day system and is currently planning a larger 15 tonnes a day demonstration plant.

Other technologies

Baker Hughes is developing a Regenerative Froth Contactor which creates a froth in the solvent (many small bubbles). This increases the contact area for dissolving gases into it. It can work with any solvent. This technology is at a "slightly lower technology readiness level but still an exciting technology", Mr Barkey said.

For carbon capture solvents, Baker Hughes is looking at the chilled ammonia process, which uses standard ammonia as the solvent. Trials so far have shown that the solvent's capability is not influenced by trace components such as NO_x, oxygen, and other flue gas impurities. It does not show thermal and oxidative degradation.

Baker Hughes is also looking at potassium carbonate solvent, which has shown so far to be low cost, low toxicity, to have good ease of regeneration, low corrosiveness, low degradation and high stability. There is a test project at the U.S. Department of Energy's National Carbon Capture Center in Wilsonville, Alabama. This solvent could be ready for wider development in the 2025-2026 time scale, he said.

For CO_2 utilisation, an interesting technology is biological methanation, where specialized microorganisms convert hydrogen and CO_2 into methane.

Another interesting project is electrochemical hydrogen compression. Mr Barkey describes this as "very early stage" technology. Baker Hughes signed a "strategy collaboration agreement" with HyET Hydrogen, the developer of the technology, in December 2023.

The technology uses a membrane, with an electrical force. The hydrogen molecule is split into protons and electrons. The proton goes through the membrane, the electron goes around it through an electrical circuit. Only protons can pass through the membrane. On the other side of the membrane, it rejoins with the electron, but at double the pressure. For a detailed explanation see "Electrochemical hydrogen compressor" on Wikipedia.

A further interesting technology under development at Baker Hughes is a gas turbine which can run on 100 per cent hydrogen.

The development process

For every technology developed by Baker Hughes, a comprehensive 'technology discovery process' takes place. There is due diligence for both the technology and the market, looking at potential market size and the advantage the technology will have over competition, if there is any. Once a commitment is made to invest in the technologies, Baker Hughes develops a commercialisation plan and a plan to develop the technology over multiple generations.

Regulators commonly ask for the "best available technology", so if you are producing the best available technology that is a good commercial place to be.

"For each of these technologies we believe we have strong competitive advantage," Mr Barkey said. "They are all interesting and exciting."

"[But] you never quite know what moves the competitors will make, that's the joy of business, you know they won't stand still."

More information

www.bakerhughes.com

Decarbonising industrial emissions: material selection at MNZ

Material selection and corrosion control methodologies are critical to ensure safe operation of CCS projects under all potential operating conditions. Matt Browell-Hook, Energy Transition Director for Spirit Energy provides insights based on experience developing the Morecambe Net Zero (MNZ) project.

Spirit Energy's Barrow Terminal will have the capacity to accept CO2 by pipeline, ship and rail

The energy industry is currently going through its biggest change in living memory, and there is a significant push towards decarbonising the UK's industries to create a greener future. With set targets to be net-zero by 2050 and with the release of the UK Government's comprehensive CCUS vision last year, attention is turning to transform the oil and gas industry.

Morecambe Net Zero (MNZ) has the potential to be one of the largest carbon stores in the UK and Europe, offering industrial emitters a world-leading decarbonisation solution while creating new low carbon jobs and investment opportunities across the North West of England. Spirit Energy's carbon store is one of the first round of carbon storage licences issued by the North Sea Transition Authority (NSTA) in 2023 and in targeting at scale, industrial carbon storage by 2030.

The store will have the capacity to accept CO_2 by pipeline, ship and rail, and secure the future of thousands of jobs in carbon-intensive industries across the UK. MNZ's strategic position in the North West of England means that emitters from the industrial heartlands in the most remote corners of the UK will be able to access a low-cost storage solution that can assist in achieving their Net Zero goals.

The scale of its storage potential has already attracted the attention of major emitters, such as the Peak Cluster consortium of four leading cement and lime manufacturers and an energy from waste plant, recognising that MNZ offers them a permanent, safe, and secure net zero carbon storage solution. This partnership guarantees a genuine emissions reduction of 4 million tonnes of industrial CO_2 from today's UK total.

The Peak Cluster is made up of four of the UK's leading cement and lime producers; Tarmac, Breedon, Lhoist and Aggregate Industries. Collectively, these cement and lime production sites across Derbyshire, Staffordshire and Cheshire are responsible for 40% of cement production in the UK. The Peak Cluster pipeline will connect the emissions produced by these plants to the Morecambe Net Zero (MNZ) carbon storage facility supporting them on the pathway to Net Zero well ahead of the UK's 2050 deadline.

With decades of experience operating the Morecambe Bay gas fields, and backed by two of the world's largest energy companies, Spirit Energy is developing the carbon store to accept up to 25 million tonnes of carbon per year, with an expected capacity in the region of 1 billion tonnes over its operational life.

The Morecambe Bay gas fields have long played an integral role in the UK's energy security – at one stage providing 14% of all domestic gas supply. Now these supply levels have depleted, Spirit Energy is refocusing its business to explore how these exceptional natural assets can be repurposed to support the transition to a net zero future. The result is the transformation of the gas fields into the MNZ store – a world-leading carbon storage hub which will store CO2 deep underground in the existing subsurface structures of the gas fields.

The MNZ project has completed its pre-FEED reference case design for CO2 gathering system, onshore and offshore facilities requirements. When undertaking this phase of the work we have taken the approach as set out in here for careful material selection through both pipelines, plant and equipment.

Designing modern, safe and affordable carbon transport and storage infrastructure is a growing priority in the UK with the award of 21 carbon storage licences but is not a new concept for traditional hydrocarbon engineering.

Under normal operating conditions, a gas gathering system pipeline feeding the offshore facilitates is considered dry (< 50 ppm mol water), and therefore CO2 corrosion is not considered a threat. However, if there were to be an upset at the upstream facilities that led to offspec CO_2, entering the gathering system, with presence of free water, then it is likely that corrosion will occur in Carbon Steel (CS) wherever liquid water is present because of its reaction with CO2 to form a high concentration of carbonic acid. Further, other impurities can lead to the production of free water.

Given the nature of most gas gathering systems currently under consideration, long above or below ground pipeline solutions operation either in gas phaseor in dense phase carbon steel pipelines become the most traditional route for a design basis. The development of a network code specification for CO2 in transportation and storage schemes has been undertaken and published by the Department of Energy Security and Net Zero.

This code was codeveloped by the department, industry, supply chain and academia in order to provide a consistent standard for CO2, maximising both the economic capture of emissions at capture plants and maximise the anticipated operation life, with economic design solutions for the transportation systems.

However, beyond the pipeline it's likely that in operation there will be both planned and unplanned events lead to depressurization of equipment containing compressed CO2 which will result in a drop in temperature below the normal operating temperature. This is particularly important given the very low temperatures CO2 can achieve when expanding.

The lowest metal temperature is based on process conditions after depressurization (the blow-down temperature). In the case of vessels, the MDMT may be higher than the blow-down temperature by taking into consideration the operating temperature and material heat capacity. This is critical to account for in design to ensure material embrittlement and fracture is adequately assessed in the chosen design.

Material selection should not be solely reliant upon lived experience though, and given the overwhelming driver to safely reduce the capital costs of CCUS projects, Non-metallic Reinforced Thermoset Plastics (RTR) such as Glass Reinforced Epoxy (GRE) and Glass Reinforced Plastic (GRP) are materials which should be considered and have a number of advantages over metallic piping including low material cost and resistance to some corrosive impurities.

When investigating these materials, the major factor when specifying thermosetting GRE pipe systems is the quality and care of installation. Industry experience has shown us that low quality installation has resulted in premature failure at field joints during hydrotesting and in service.

In design of the CCUS system, the primary corrosion control for equipment in CO_2 service is the effective dehydration upstream of the gathering system, that meets CCS Network Code CO2 specification, thereby ensuring that no free water is present within the storage and transportation facilities.

Material selection provides the means of corrosion control by selection of appropriate materials for each duty in each operational / upset scenario. However, this does not always represent the most economic means, so additional corrosion control techniques maybe required. For external corrosion, coatings and in some cases cathodic protection shall be used to provide the assurance that the design life for onshore, offshore, and subsea facilities will be met.

Internal coatings can be utilised as a means of controlling internal corrosion. However, selection of internal coatings need to be on a case-by-case basis as the coating system is very dependent on the process application expected for the design reference case. Examples include CS storage tanks for water where the application of the lining mitigates against the need for a high corrosion allowance, but different coatings may be required for potable water, sea water and distilled water applications.

It is worth noting that internal flow coatings for piping and pipeline are not necessarily appropriate for CO2 transport due to negligible improvement in flow assurance i.e., internal coatings used to optimize flow characteristics in the pipeline and the risk of corrosion at exposed girth welds that cannot be covered and potential issues with permeation and damage to coatings during any decompression operational activities.

When considering material selection and corrosion control methodologies it is important to ensure that all potential operating conditions including process start-up, normal operation and upset scenarios are considered. For carbon storage projects it's critical that low temperature design conditions including normal operation and relief and depressurisation cases are considered in any design.

The author would like to acknowledge Phil Robson, Xinming Hu & John Woods for Wood PLC.

More information

www.spirit-energy.com

www.woodplc.com

EU NZIA and an obligation on oil companies to store

Under the European Union's Net Zero Industry Act, companies selling oil and gas will have an obligation to store CO2 themselves. There is also a highly ambitious EU storage target. A CATO webinar explained.

The European Union Net Zero Industry Act (NZIA) has an amendment requiring that EU oil and gas producers, and other entities "selling" oil and gas, will have an obligation to do a certain amount of CO2 storage themselves, or face sanctions, said Eadbhard Pernot, Policy Manager, Carbon Capture with the Clean Air Task Force (CATF).

He was speaking at a webinar organised by CATO (CO2 Afvang, Transport en Opslag), a Dutch carbon capture research organisation on Dec 11.

Denmark, Netherlands and Romania were opposed to the rule making CO2 storage an obligation. In the case of Denmark and the Netherlands, "maybe they felt it wasn't needed," Mr Pernot said.

There are exemptions to the obligation if a state already has CO2 storage activities undertaken or planned by companies which are not oil and gas operators. This could be used to balance the obligation on operators. There is also an exemption if it can be shown that there is little demand for CO2 storage, so oil and gas companies do not need to build storage which will not be utilised.

The proposal was adopted by the European Council on Dec 7 2023, after discussions over Autumn 2023 in the EU Parliament and its subcommittees.

Supporting clean technologies

The NZIA was originally proposed in March 2023, stemming from EU's Green Deal Industrial plan, to support manufacturers of clean technologies in the EU. The aim is that the EU's manufacturing capacity should approach 40 per cent of its annual deployment needs by 2030.

It covers "strategic net zero technologies", defined as solar (PV and thermal); electrolysers and fuel cells; onshore and offshore wind; sustainable biogas and biomethane; batteries and storage; CCS; heat pumps and geothermal energy; and grid technologies.

These technologies are selected based on their technology readiness level, their contribution to decarbonisation and competitiveness, and the resilience of the energy system, said Zoe Kapetaki of TNO's Department for energy and materials transition based in Delft.

One objective is that manufacturing and development projects related to them can be granted a "priority status", which could help expedite project development. Other objectives include facilitating access to market, enhancing skills, cutting red tape and accelerating permitting, attracting and supporting investment.

The impetus partly came from EU getting a sense of threat from the US Inflation Reduction Act, that all low carbon development funding could be enticed into the US. And also concerns that CCS projects were so far confined largely to the North Sea, Mr Pernot added.

The growing interest in CO2 removal (capture from the air) also changed the conversation, because there is a recognition that it is needed to achieve net zero targets, because it will be impossible to eliminate all emissions. CO2 removal will also require a CO2 sequestration infrastructure, he said.

With European Union elections in 2024, it will be very hard to agree new legislation in 2024, so the end of 2023 was the last opportunity to bring in the legislation before 2025, he added. The Emission Trading Scheme (ETS) is expected to be the most important tool to make projects 'bankable', but prices are still not high enough or stable enough to satisfy investors, he said.

Storage targets

The Act includes a target of 50mtpa of CO2 to be injected within the EU by 2030, which cannot be combined with enhanced oil or gas recovery. Is this target feasible? Ms Kapetaki notes that the projects in France, Bulgaria, Poland, Belgium, Finland and the Netherlands, with start dates of 2025 to 2028, add up to about 12.5 mtpa, of which 7.5mpta are in the Netherlands.

If all existing planned projects were executed, there could be 17 mtpa being stored by 2030, about a third of the target. A further concern is that most of the current projects are in the North Sea, and there is a need to develop storage sites to serve southern Europe.

The NZIA asks that member states and exploration and production companies "make public" all their geological data related to storage sites. The regulations also include measures to ensure "fair and open access" to CO2 storage, Mr Pernot said. The EU will need to address 'cross chain risk', a regulatory structure for how risks are shared between capture, transport and storage providers. The UK "has done a lot of work" on this, he said.

Storage potential

CATF has assessed Europe's CO2 storage potential in a study published in July 2023. It found the largest theoretical storage is in Bulgaria and Norway. Norway was included because its emission trading scheme is connected with the EU one, which could mean its storage could be part of an EU storage target, although it is not in the EU. UK was not included in the study because its own emission trading scheme is not connected to the EU's.

The study did find that subsurface data relevant to CO2 storage for UK and Norway was "fantastic" in comparison with other countries, because of the oil and gas production there, Mr Pernot said.

More information

co2-cato.org/news/webinar-nzia/

Transforming concrete from a carbon problem to a carbon solution

Carbonaide aims to capture and store 500 megatons of carbon dioxide by 2050 by transforming it into a carbonate material that can be used to supplement traditional concrete.

As the climate continues to warm, so does the demand for technologies that can reduce CO2 emissions and/or efficiently remove CO2 from the atmosphere. Proposed solutions for sequestering CO2 are plentiful, but there are serious issues around how to verify the claims made by the promoters of these innovations. Accurately measuring the veracity of claims has become a key issue in the private sector's Voluntary Carbon Market (VCM), which is increasingly emphasising the need to monitor, verify, and report the amount of CO2 that is actually captured and stored.

Carbonaide, a Finnish company serving the concrete industry, has a clear answer to this challenge – and it's market-ready. Carbonaide's technology utilises CO2 to produce a carbonate mineral. With support and cooperation from the measurement technology company Vaisala, Carbonaide's solution is practical and straightforward, and underpinned by accurate monitoring.

Carbonaide's first pilot plant in Hollola Finland where the CO2 mineralised product is being made (Image: Carbonaide, photo by Vesa Kippola)

Big challenges call for smart solutions

Climate changing CO2 emissions come from many sources, but the concrete industry alone emits 8% of global CO2, mostly in the form of emissions from standard Portland cement manufacturing. As a major global contributor of greenhouse gas emissions, the concrete industry is under enormous pressure to lower its carbon footprint. A single ton of Portland cement creates an astounding 800–900 kilograms of CO2 emissions, and with regulations increasingly tightening around concrete production emissions, efficient technologies to reduce the CO2 emissions from concrete are in high demand. The challenges are several-fold: How to remove CO2? Where to store it? How to do this affordably? And – just as importantly – how to accurately measure performance?

Simply stated, Carbonaide's expertise is in the transformation of concrete from a large emission source into a carbon storage sink. The company's CEO is Tapio Vehmas, an analytical chemist by training with more than 20 years of experience in the concrete sector. He is one of the co-founders of Carbonaide, alongside COO Jonne Hirvonen. As Vehmas puts it, "Our goal is quite focused – to create a more sustainable future with cutting-edge tech that doesn't just reduce the carbon emissions of concrete, but also stores more CO2 than it emits throughout its lifetime."

Explaining the Carbonaide proposition, Vehmas says, "As experts in both carbon curing and sustainable carbon dioxide value chains, we offer an effective and robust decarbonisation technology for pre-cast concrete manufacturers. With our technology, a concrete manufacturer can reduce cement consumption in daily production and also decrease the carbon footprint of its products by mineralising CO2 into concrete."

Carbonation is traditionally considered as a degradation mechanism of hardened concrete. In Carbonaide technology, carbonation is reversed into beneficial mineral formation during the concrete hardening process. Carbonate mineral formation enables the utilisation of CO2 as a supplementary cementitious material and provides permanent storage of gaseous CO2.

Carbonaide COO Jonne Hirvonen is eager to talk about the advantages of their production-ready innovation and the ways his team has benefitted from Vaisala's advanced measurement tools. "Our unique advantage is that we accurately measure and control the carbon-curing process. Just as importantly, we have pushed our product to be as easy as possible to install and start using. The majority of our measurements are CO2 levels – and the quality of online measurement data is a top priority for us."

Hirvonen continues, "Unlike many, our carbonation can be efficiently and accurately verified by process measurements, without the need to constantly sample the concrete products. One early challenge we faced was that CO2 is usually measured in either ppm levels or for workplace safety purposes – but our range requirement is very wide. For this reason, we needed new solutions that did not impose risks on the quality of our measurements. At this point it became clear that Vaisala could play an important role in our solution."

Carbonaide's initial requirements were quite simple. As they developed their process, they understood that significant measurement needs would arise, so they were eager to go with a partner who really understood this. Hirvonen is also keen to emphasise that partnering with Vaisala was not only useful in the initial development stages. "If your business is expected to grow, you should only work with partners that are able to help at both the early stages, and also later, during implementation on a larger scale."

As Vaisala's Product Manager Antti Viitanen states, "Sustainability is less about grand claims, and more about proven numbers. To make decarbonisation a reality, reliable measurement data is an absolute must."

Decarbonising the future

Both Hirvonen and Vehmas believe that it's not only their concrete manufacturing customers that demand accurate measurements and high quality – but also the entire construction sector. As Hirvonen puts it, "There is no option to do things clumsily. Our industry only accepts robust, credible solutions, because buildings have to last for decades."

Regarding Carbonaide's own plans for the future, Vehmas says, "Our goal is to sequester 500 megatons of carbon dioxide by 2050, and we don't see any major obstacles preventing that from happening. We now have industrial scale processing capabilities, and there is a clear demand for our product. In fact, if the world's entire cement production were to use our production process, 1.5 Gigatons of carbon dioxide could be captured. This is hugely significant because global energy-related CO2 emissions in 2022 were just over 36.8 Gigatons."

More information

www.vaisala.com

www.carbonaide.com

EU will miss 2050 climate targets by a decade, urgent action on CCUS needed

Nascent technologies such as hydrogen and carbon capture need urgent action in the forms of investment, demand certainty, and policy commitment, with progress varying across the EU27, according to a new report from Wood Mackenzie.

Despite ambition across its members, the European Union won't meet climate targets until well into the 2060s, as focus shifts to energy security and economic stability.

The report 'EU27: Energy Transition Outlook' is part of Wood Mackenzie's ETO research series which maps three different routes* through the global energy transition with increasing levels of ambition.

On its current trajectory, the EU's emissions are expected to fall short of its net zero pledges at 684 million tonnes per annum (Mtpa) by 2050, despite unity between members to meet the EU 2050 net zero target, which falls under the European Green Deal.

To meet global net zero goals, the EU would need to reach net zero by 2048 in order to offset other regions that will still be emitting throughout the following decade, according to Wood Mackenzie's net zero 2050 scenario.

"The EU remains a leader in the energy transition with ambitious, legally binding targets, but a turbulent start to the decade has thrown up several obstacles, shifting focus to energy security and economic stability while pushing net zero targets lower on the agenda," said Lindsey Entwistle, senior research analyst at Wood Mackenzie, and lead author of the report.

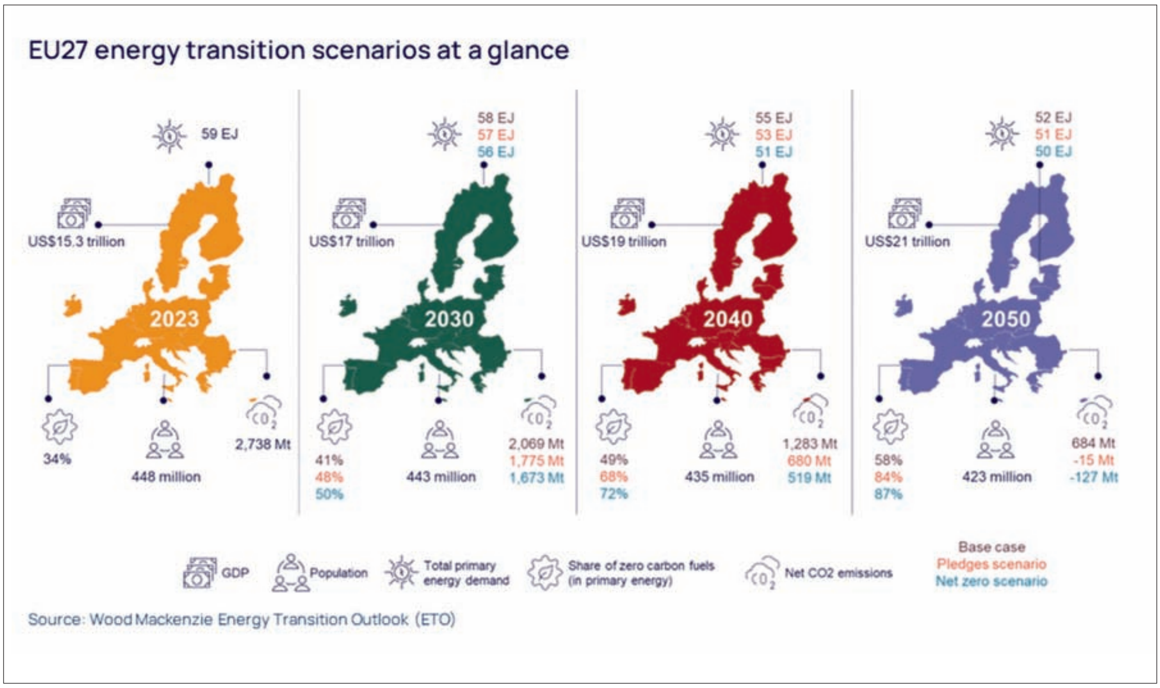
Entwistle added: "The good news is that these goals align for the EU in the longer-term and the wider industry is seeing the Union double down on efforts to streamline policy and strengthen cross-border infrastructure for power, carbon capture and low-carbon hydrogen. Targeted investment in these areas could accelerate the EU's transition and achieve net zero by 2050."

The pace of renewables rollout is constrained

Electricity demand is forecasted to increase to 2.5 times from current levels, with 82% of domestic power supply forecasted to be renewable by 2050 in Wood Mackenzie's base case. Renewables capacity increases by an additional 70% in the net zero scenario, requiring an extra 10 gigawatts (GW) per year compared to Wood Mackenzie's base case.

Smaller economies require support with electrification through funding for critical infrastructure, low-carbon power supply and public incentives. Wood Mackenzie base case projections highlight a wide gap between levels of electric vehicle (EV) and heat pump adoption. Sweden is at the higher end, with 88% EV share and 78% heat pump penetration expected by 2050, while Bulgaria is expected to reach just 35% and 33% respectively.

"Reducing bottlenecks is critical to deploying the extra 10GW of renewables capacity per year that is required to enable sufficient electrification of demand sectors. Policy makers are keenly aware of this, and half of the Projects of Common Interest identified in 2023 are related to international power, grids, and infrastructure. The TEN-E policy and the Grids Action Plan both aim to ease power infrastructure bottlenecks through targeted investment and collaboration across members," stated Entwistle.



EU27 members are united under the EU 2050 net zero target. Germany and the Nordic countries have more ambitious targets of 2045: Wood MacKenzie's analysis shows that more members need to accelerate their efforts to achieve global net zero by 2050

New technologies receive varying support – hydrogen and CCUS in focus

In Wood Mackenzie's base case, hydrogen is forecasted to grow to nearly 10% of industrial energy demand by 2050 in the EU, displacing the equivalent of 16% of today's fossil fuel consumption in the sector and reducing more than 100 million tonnes (Mt) of CO_2 emissions.

Hydrogen infrastructure projects account for 40% of Projects of Common Interest (PCIs) in 2023, helped by the launch of the Hydrogen Bank's first auction round of €800 million.

Entwistle said: "Hydrogen Bank's auction is a strong response to the US' Inflation Reduction Act and the swift execution shows that the EU is serious about competing in the global hydrogen economy. But with 10Mtpa of imported low-carbon hydrogen required in our base case and 18Mtpa in our net zero scenario by 2050, the real export opportunity lies in EU expertise and low-carbon manufacturing of electrolysers, fuel cells and their components."

"Norway, Denmark, Finland, and Spain are well positioned to become key exporters for regional hydrogen trade within the EU, and are expected to reach more than 5.5 Mtpa net export capacity by 2050," Entwistle added.

While few members have set domestic targets for carbon capture or storage, there are 14 PCIs that focus on carbon capture, utilisation, and storage (CCUS) infrastructure, and the EU Innovation Fund has poured €1.7 billion into CCUS since 2021. The Danish Greensand demonstration project began North Sea storage in 2023, exporting CO_2 from Belgium via ship.

The consortium expect the FID for the full-scale project in 2024. This is a promising start but there is a long way to go to scale up CCUS cross-border carbon transport and storage, stated the report.

Entwistle said: "Despite being late to the game, the EU has now been very clear about the importance of CCUS in its net zero strategy. The latest announcement of a 280 Mtpa capture target by 2040, as part of the Net Zero Industrial Act, is ambitious considering some members' historic reluctance to embrace the technology."

"There is no doubt that the EU views CCUS as essential to tackling the hard to abate emissions without impeding the industrial sector, where gross emissions are expected to exceed 270 Mtpa by 2050.

The EU will rely on the ability to export captured CO_2 to neighbouring countries like Norway and the UK, with abundant North Sea storage, and there are several live projects developing the necessary pipelines and export infrastructure," Entwistle added.

The EU continues to have the highest global carbon prices, at 2.5 x the average for developed economies. But prices need to increase from 2027 onwards at twice Wood Mackenzie's forecast rate in order to facilitate the widespread adoption of nascent technologies that is required to achieve net zero.

Progress varies between members

Germany and the Nordic countries have more ambitious targets of 2045, while more members need to accelerate their efforts to achieve global net zero by 2050, stated the report.

Nordic members already use a large share of renewables in generating power, mainly a combination of wind, solar and hydro, alongside a high uptake of nuclear in Sweden and Finland. Wood Mackenzie figures show that Sweden operates 100% low-carbon generation (66% renewable) and Finland with 98%, while Poland uses 66% fossil fuels for power generation, followed by Germany at 47% and Romania at 44%.

The report also highlights variation regarding nuclear power policy, with several members planning to phase it out entirely or have already done so. While France, Poland and Romania are investing in new conventional nuclear plants as well as establishing themselves as up-and-coming small modular reactors (SMR) supply and customer bases.

More information

www.woodmac.com

www.projectgreensand.com

Cement industry: escaping the CO2 trap

The EU Commission's Carbon Management Strategy announcement highlights the significance of carbon capture techniques, such as Direct Air Capture, in achieving the net-zero target. This is especially relevant for emissions-intensive industries, such as cement production.

Cement is a widely used building material in residential, industrial, and infrastructure projects, such as roads and bridges, due to its durability and versatility. The cement industry is a notable player in global construction and contributes significantly to the economic development of many countries. However, it also produces CO2 as an unpleasant by-product.

The cement industry significantly contributes to greenhouse gas emissions, accounting for approximately eight percent of global industrial emissions. The primary source of CO2 emissions is the combustion of fossil fuels to generate the high temperatures (approximately 1400-1500 degrees Celsius) required for the clinker-burning process.

Furthermore, the decarbonisation reaction of limestone during the burning process significantly contributes to the release of CO2. Roughly 400 kilograms of CO2 are emitted per tonne of cement manufactured.

NeoCarbon technology reuses the heat that cooling systems normally evacuate, so minimal additional energy is used to capture CO2 from the air. It can be retrofitted to many waste heat stream types and is fully scalable

However, the demand for infrastructure and housing is increasing in many countries, and renewable alternatives such as wood are not always a viable long-term solution.

Therefore, we remain dependent on cement production, making it crucial to find a solution to reduce CO2 emissions in this sector.

Air as a Resource: Direct Air Capture (DAC)

There are ongoing political and social discussions regarding various processes and technologies aimed at controlling emissions. These include green hydrogen, green cement, and Direct Air Capture (DAC), a promising technology that removes CO2 directly from the atmosphere. Unlike other carbon capture technologies that only reduce emissions from production facilities, DAC aims to remove CO2 directly from the ambient air, independently of specific emission sources such as power plants or industrial facilities.

DAC uses various chemical-technical processes to absorb CO2 from the ambient air and make the isolated CO2 available for storage or utilisation in industrial processes.

NeoCarbon has developed a novel reactor which significantly improves the efficiency of DAC, clearing the way to a scalable approach. Using a combination of heat and vacuum applied to this optimised reactor, as well as a very specific sorbent, NeoCarbon can capture CO2 from ambient air with much less energy than the current state-of-the art.

The process works in a two-step cycle: first, flowing ambient air through the reactor, in which the sorbent has been arranged in a highly optimized setup using advanced manufacturing techniques. This way, the reactor can contain a lot of sorbent material in a limited volume to allow for a high amount of CO2 to be trapped, while still being able to easily flow the vast volume of air required to capture large quantities of CO2.

Indeed, the concentration of CO2 in the atmosphere, while extremely detrimental to our climate, is only 0.04% or one molecule in 2,500. Capturing billions of tons of CO2 thus requires processing immense airflow.

In a second step, the vacuum is applied to allow for the captured CO2 to stay pure, and the sorbent is heated up. Here again, NeoCarbon's advanced reactor design optimises for efficient heat delivery directly to the sorbent, enabling lower sorbent deterioration, lower heat losses, and faster capture cycles.

Once the sorbent has released all its trapped CO2, the first step of the cycle can then start again.

DAC's Crucial Role in the Cement Industry

DAC can play a significant role in reducing emissions in the cement industry. Currently, there is insufficient renewable energy to produce cement at the high temperatures required, and sustainable alternatives are still under development. DAC can be adapted almost anywhere, unlike other technologies that depend on specific externalgeological conditions. The CO2 captured by DAC can be used as a raw material and added to the concrete, which can both help to make it stronger and store the CO2 in the long term.

This eliminates the need for geological storage. Although the concept sounds simple, implementing conventional DAC technologies can be challenging due to the high associated costs, particularly in terms of energy consumption.

Additionally, many providers struggle with the scalability of Direct Air Capture, as it often requires building infrastructure and allocating resources from scratch, which can be both costly and time-consuming.

Retrofitting as a Solution

Fortunately, advanced DAC technology exists that can utilise the waste heat flows available in existing industrial sites through a process known as retrofitting. The main cost driver of DAC is generating the required heat. However, utilising waste heat significantly reduces the energy requirement and, therefore, the costs of the process.

In practical terms, this approach can capture approximately 1.3 billion tonnes of CO2 annually, making a significant contribution to global climate targets. The technology is currently available and can be used in the near future. Since no new infrastructure is needed and companies can thereby reduce costs, this approach of DAC is essential, particularly in the cement industry.

NeoCarbon's second unique advantage is its focus on such a retrofit approach: by engineering a plug-and-play integration system which ensures a seamless and easy access to the waste heat produced by these industrial sites, capture modules can be deployed extremely rapidly to tap into this unused resource.

This leads to additional energy savings for NeoCarbon, and a DAC implementation that can complement particularly well other emission reduction system such as point-source capture (or preventing most emissions from chimneys or fume stacks to be released), potentially paving the way to carbon-negative factories.

DAC plays a crucial role in combating climate change, mainly when used in conjunction with other carbon capture technologies and strategies. The United Nations Intergovernmental Panel on Climate Change (IPCC) has identified DAC technology as having the most tremendous potential to achieve the required scale.

Integrating DAC into the cement industry offers promising prospects and benefits, both in terms of reducing CO2 emissions and enhancing the industry's long-term competitiveness.

To maximise these potentials, investing in research, development, and implementation is necessary. It is already evident that no single technology can achieve the desired goal.

Therefore, all technologies must be equally promoted because achieving net-zero is not just a desirable outcome, but a priority for everyone.

Big Plans ahead

Future plans involve building a first full-scale novel reactor product by early next year, and starting serial production in 2025, to be able to reach the first 500+ tons per year installations in late 2025.

From there, NeoCarbon wants to scale both the average installation size, and the number of sites to reach a million tons per year of total capture potential by 2030. This would also be achieved by leveraging partnerships. Neo Carbon could license their technology internationally, allowing partners to handle manufacturing and maintenance, and enabling rapid global hypergrowth with low capital expenditure (CAPEX).

More information

www.neocarbon.tech

CCS in Steel: Kickstarting Europe's Steel Industry Decarbonisation

Bellona has published a Brief looking at the iron & steel industry, which accounts for 5% of EU CO2 emissions due to fossil fuel dependence and must transition to low-emission processes to meet demand in a net zero world.

In the IEA Net Zero Scenario, steel production emissions will need to decrease to 1 ton of CO2 per ton of steel by 2030 to reach net-zero in 2050.

The use of Carbon Capture and Storage in steel is an option to cut emissions quickly in the following ways:

• The capture and storage of emissions from conventional blast furnaces in the short term.

• The capture and storage of emissions from DRI furnaces on fossil gas in the short to medium term.

• The creation of blue hydrogen for direct hydrogen reduction furnaces by capturing and storing CO2 emissions from existing hydrogen production through CH4 in the short to medium term.

• The capture of remaining emissions from metallurgic processes and off-gasses of electric arc furnaces even with direct hydrogen reduction with green hydrogen in the long term.

In conclusion, the case for CCS in steel is more compelling and necessary for 2030, with its relevance as a decarbonisation pathway diminishing in 2050 in favour of other technologies such as green hydrogen.

More information

eu.bellona.org

Germany takes a major step forward with Carbon Management Strategy

The German government has published key points of its Carbon Management Strategy, cementing the importance of CCS in achieving Germany's goal of reaching climate neutrality by 2045.

"As Europe's largest economy and biggest emitter, all evidence points to the fact that carbon capture and storage will need to be deployed on a significant scale if Germany is to reach its climate targets," said Lee Beck, CATF's Senior Director, Europe and Middle East. "The Carbon Management Strategy is a significant first step to deploying carbon capture and storage, which German governments must now deliver on."

The German Carbon Management Strategy comes after industrial producers and leading NGOs, including CATF, began calling on the German government to produce a strategy in 2021. As leading scientific evidence shows, carbon capture and storage will need to be deployed on a significant scale in Germany if it is to reach climate neutrality.

"The Strategy sets in motion several key actions for enabling carbon capture and storage in Germany, including the legislative revisions needed to establish CO2 pipeline networks and allow offshore storage of CO2 under Germany's North Sea," said Toby Lockwood, CATF's Technology and Markets Director, Carbon Capture.

"Following the example of some other EU Member States, carbon contracts for difference will be used to cover the funding gap still faced by the hard-to-abate sectors that will rely on carbon capture and storage to decarbonise."

Deployment of carbon capture and storage will be particularly important for Europe's largest industrial producer. Major regions like North Rhine-Westphalia host key industries such as cement, lime, chemicals, and steel, which must decarbonise. As CATF outlined last year, a Carbon Management Strategy is a core pillar of Germany's effort to transform its industrial sectors to climate neutrality.

While the publication of the Carbon Management Strategy is a welcome development, it is essential that the first CO2 infrastructure projects reach final investment decisions. Developing the first cluster projects and ensuring access to CO2 storage for German industrial producers are crucial to cut emissions while preserving key German industries.

CCS Europe welcomes announcement

The announcement that Germany will support the deployment of carbon capture technology to reduce emissions from hard-to-abate industrial sectors has been warmly welcomed by advocacy body CCS Europe.

Chris Davies, director of CCS Europe, said the news had been long-awaited but marked a breakthrough that would help change perceptions about the technology across Europe.

"The government of the largest industrial power has recognised that it cannot meet its CO2 reduction goals without carbon capture.

"This sends a powerful message to governments throughout Europe that they must develop CCS deployment strategies if they are to achieve industrial decarbonisation."

"Industries like lime, cement, steel, chemicals aluminium and waste-to-energy release CO2 in ways that no amount of renewable electricity can prevent. The gas must be captured.

The German announcement comes in the same month that the European Commission published a Communication on Industrial Carbon Management. This stated: "In general, governments across the EU still need to recognise carbon capture and storage a s a legitimate and necessary part of the solution to decarbonise."

More information

www.catf.us

www.ccs-europe.eu

Lessons learned: case studies of successful and failed CCUS projects

The report from the Industrial Energy Transition and Decarbonization (IETD) Consortium (formerly the CO2CC Program) provides a comprehensive review of the technical, economic, policy and social risks that CCUS projects face including a detailed set of recommendations for future CCUS developers that should increase the chances of successful project execution.

TCGR's report Lessons Learned: Case Studies of Successful and Failed Carbon Capture, Utilization, and Storage (CCUS) Projects lays the groundwork for success of future CCUS projects by extracting lessons learned from four select case studies chosen to represent the spectrum of outcomes from the numerous CCUS demonstrations and projects that have been implemented globally to date.

The report:

• Develops a list of project features or attributes that could pose a serious risk and lead to failure

• Presents four case studies that succeeded or failed for different reasons, and that had different project outcomes, including the Petra Nova CCS project in Texas

• Summarises lessons learned thus far and provides recommendations for implementors of future CCUS projects

The report presents alternative CCUS deployment paradigms that could accelerate execution, such as a hub strategy or the wholesale splitting of the CCUS value chain to enable different consortia to develop different parts of the enterprise (for example, transport-only or storage-only service providers that operate under a fee-for-service model).

The report also provides models for regulatory frameworks that substantially clarify implementors' share of the storage burden by addressing key issues like access to pore space; the tenure of sequestration leases; standards for everything from well injection to monitoring, verification, and accounting (MVA); and long-term liability for stored CO2.

The report identifies two major problems: first, despite the expected need for CCUS technologies, investments have not kept pace with the large role that is envisioned for the technology. Nonetheless, investments by industry and government since the turn of the century have been in the billions, which raises a second problem: despite these investments, there have been a substantial number of failed projects, with no consensus regarding the reasons for failure (or success). In fact, most proposed projects fail at different points of their execution, as recent analyses of CCUS have noted.

The purpose of the report is to focus on the second problem, so that the next wave of capital flowing into the industry facilitates greater success in project execution and (ultimately) GHG emissions reduction. It introduces and discusses a non-exhaustive list of the challenges facing CCUS, before presenting several case studies of success or failure over the previous decade. It summarises several major categories of risk that must be mitigated, where they exist, for the successful execution of CCUS projects, before concluding with a set of recommendations and a restatement of the report's main messages.

Key takeaways from the report

• CCUS projects face a range of technical, economic, policy, political, and social risks. The elimination of all risks is not possible or necessary for a substantial expansion in CCUS to materialize. However, executives and project managers who are cognizant of these risks and work diligently to mitigate them could increase the likelihood of successful project execution and make the development of CCUS projects both techno-economically and socio-politically sustainable.

• CCUS projects, even in the future, are likely going to be megaprojects (>$1 billion), which are inherently more likely to fail. Nonetheless, experts know why they fail: they are fragile and require "extraordinarily robust" planning, open and two-way communication, stakeholder alignment with a common vision, and an excellent project management team. This will remain a challenge for future projects, but it is neither an unknown nor insurmountable one.

• If the goal is CO2 emissions reduction, projects that employ mature technologies that sit at high levels of both technology and integration readiness are more likely to succeed. They are also more likely to be deployed on budget and on time. Projects that employ new technologies are more susceptible to the risk of cost growth. Nonetheless, the demonstration of new technologies that promise reduced costs or energy use should be highly encouraged and supported by industry, but they should be conducted as pilots rather than overpromising stakeholders, regulators, and the public in terms of capture rates.

• Some lessons are less novel than others, but even those that are "known" are too infrequently implemented by project developers, including on their flagship projects, as the Kemper experience demonstrates. Except for incentive credibility and the institution of a robust regulatory framework, both of which require policy action and for which models exist, CCUS developers can begin integrating all other lessons into future project planning to increase the likelihood of success. A fortuitous policy window has opened, one that could help demonstrate that CCUS has a role to play in greenhouse gas emissions reduction; it is up to industry to develop projects that avoid the mistakes of the past and deliver on net-zero commitments that are now universally accepted.

More information

More information about this report and other deliverables of the IETD Consortium can be found at:

www.catalystgrp.com/tcg-resources/member-programs/industrial-energy-transition-and-decarbonization-ietd-consortium/

Plans for Solent UK CCS cluster launched with report

Plans have been revealed for a CCS cluster in Southampton (UK), based around ExxonMobil's Fawley petrochemical complex, the largest integrated refinery and chemical complex in the UK.

It produces over 10 per cent of the UK's consumption of jet fuel, and diesel and petrol which fuels 1 in 5 vehicles on UK roads. The refinery also generates 3.5m m3 a day of gas, as a by-product of the refining process.

The refinery has pipeline connections to the airports Heathrow, Gatwick and Birmingham, for supplying aviation fuel.

The Solent cluster includes plans for a blue hydrogen plant, with an estimated capacity of 1.4 GW. It could be in operation in 2030. A secondary expansion phase could increase capacity to 2.8 GW, and come online in 2035.

There are also plans two green hydrogen plants with a combined capacity of 400 MW, and an Energy from Waste plant connecting to the carbon capture.

There are plans to manufacture Sustainable Aviation Fuel (SAF) at the site. Further details have not been made public, but the SAF could be made from either the blue or green hydrogen.

CO2 would be stored offshore, in aquifer sites in the English Channel. It could store 10m tonnes CO2 per year by 2035. The site has safety advantages over oil and gas reservoir storage, in that it is "relatively unperforated" with wells, said Paul Greenwood, UK chairman of Esso (ExxonMobil).

It would be possible to build a CO2 import terminal connected to the cluster. 115 companies are involved in the project so far.

The project would need government funding or other suitable policy support to go ahead. While ExxonMobil has committed to invest enormous sums to low emission energy sources over the next five years (including $3bn committed over 2021 to 2025), the money will only be invested in projects which it is able to make profitable, said Paul Greenwood, chair of Esso (ExxonMobil) UK Ltd.

Project participants are working with UK government to find a policy structure which could make the project financially viable. The socio-economic report stated that infrastructure under consideration for the initial projects would represent around £11.9bn investment by 2035.

Maritime terminal

A low carbon maritime fuel terminal is being planned for the cluster.

The terminal would be able to provide low carbon methanol, or a fuel based on blue or green ammonia or hydrogen.

Southampton is the UK's second largest port, handling 1.5m TEU a year, 1.7m cruise ship passengers and 820,000 cars. The Fawley Marine Terminal adjacent to Southampton handles 2,000 shipping movements each year.

Together with neighbouring Portsmouth, a major Navy port, the region sees 200,000 large vessel movements a year.

Low carbon methanol would be produced as an intermediate stage of making SAF. This could either be all converted to aviation fuel, or sold to shipping. The maritime industry could also be supplied with the blue /green hydrogen, or ammonia made from that.

Labour party perspective

An event was held at the UK House of Commons on Feb 19 to launch a report about the social and economic benefits of the project.

At the event, Dr Alan Whitehead, Shadow (Labour party) Minister for Energy Security, and a MP for part of the City of Southampton, said that the Labour party will be "completely committed" to CCS if, as widely expected, it wins the next election.

CCS can "make sure those parts other parts can't reach are properly decarbonised.," he said.

"For a very long time CCS discussions have been, 'this is going to be a niche'. Now it is at the centre of a lot of things we are doing," he said.

"We just want CCS to go ahead as quickly as possible, in as many places as possible, with the right support from government."

"I am very envious of what is going ahead on Teesside. How quickly they are going to move, just how much they have achieved, where they are sited, on the track 1 process.2

"The Southampton Cluster is potentially a real opportunity to develop another hub for collection transport and storage of carbon."

Also, "we don't want to be sending all our carbon to Norway or somewhere else," he said.

Faster government money

At the event, Lord Callanan, UK Minister for Energy Efficiency and Green Finance, was asked by Ruth Herbert, CEO of the Carbon Capture and Storage Association, if more government funding could be available sooner.

The funding is needed to develop more storage sites so the country has injection capacity when the current sites cannot take any more, expected in the early 2030s. Characterising and developing sites currently takes several years.

Lord Callanan replied that it took an enormous amount of negotiation with the UK Treasury government department to persuade them to agree to spend the currently committed £20bn on CCS.

"We have to see what it delivers first," he said. "We can't got back and ask for further funding until we can see what we got for £20bn. It is unrealistic to ask for further commitment."

More information

Read the Solent Cluster report:
www.thesolentcluster.com

Projects and policy news

Equinor's H2H Saltend project given green light

www.equinor.com/energy/h2h-saltend

Equinor's H2H Saltend is a 600-megawatt low carbon hydrogen production plant with carbon capture, one of the first of its kind and scale to be granted planning permission in the UK.

The decision comes at a vital time, as the project prepares for a potential application into the Government's forthcoming 'Cluster Sequencing Track-1 Expansion' process, which is expected to launch this year and will select decarbonisation projects in both the Humber and Teesside that can connect to the East Coast Cluster's carbon capture transport and storage infrastructure by around 2030.

Due to be operational around the end of the decade and sited at the energy intensive Saltend Chemicals Park, to the east of Hull, H2H Saltend will help to reduce the park's emissions by up to one third. To achieve this, low carbon hydrogen will be used in chemical processes by both Saltend-based and other nearby companies, as well as directly replacing natural gas in several industrial facilities reducing the carbon intensity of their products.

Hydrogen from H2H Saltend will also be blended with natural gas at Equinor and SSE Thermal's on-site Triton power station. The amount of CO2 captured and safely stored in sub-sea aquifers as a result will be around nearly 900,000 tonnes per year, equivalent to taking about 500,000 cars off the road annually.

H2H Saltend is a catalyst project for the wider decarbonisation of the Humber, including helping to link regional CO2 pipelines from Easington in East Yorkshire across northern Lincolnshire and to Drax in North Yorkshire. The infrastructure, which NEP confirmed ownership of in January 2024, will capture and transport carbon dioxide for safe sub-sea storage as part of the East Coast Cluster development.

Three projects along this pipeline route - H2H Saltend, Drax BECCS and Keadby Carbon Capture Power Station – now have planning consent, making the Humber unique in its offering of mature decarbonisation projects.

These proposals aim to make the Humber, the UK's most carbon intensive industrial region, net-zero by 2040. In addition, H2H Saltend will deliver value for money by building a foundation for the energy transition in the Humber area, leading to more job opportunities for local people and supply chain contracts. It will help to establish East Yorkshire as a leading light in the transition to a net zero economy.

The project also forms part of Equinor's 'Hydrogen to Humber' ambition to deliver 1.8 gigawatts of low carbon hydrogen production within the region, nearly 20% of the UK's national 2030 target. These proposals seek to develop a hydrogen transport and storage hub network linking key sites primarily on the north bank of the Humber including Saltend, Easington and the Aldbrough Storage facility, via dedicated hydrogen pipelines.

The H2H Saltend planning application was submitted to the East Riding of Yorkshire Council in July 2023. There have been three public consultation events in East Yorkshire and Hull since 2021 to present the project throughout the planning process, in addition to regular dialogues with local authority and parish councillors. No objections to the application were raised by any statutory body.

The UK Government is expected to launch the Track-1 Expansion competition from 2024. It is the next step of the Cluster Sequencing process, following selection of the East Coast Cluster as a Track-1 Cluster and subsequent selection of a first phase projects in March 2023, when Humber projects were unsuccessful.

enfinium proposal to decarbonise largest energy from waste site in UK

www.enfinium.co.uk

The CCS project for Ferrybridge 1 and 2 facilities has been designated as a 'Project of National Significance' by the Secretary of State for Energy Security & Net Zero.

Installation of CCS at the enfinium site could result in over 1.2 million tonnes of carbon dioxide being captured every year, of which around 600,000 tonnes would be 'carbon removals'. The project would rapidly accelerate green economic growth and decarbonisation of West Yorkshire in line with the region's ambition to achieve Net Zero by 2038.

The Ferrybridge 1 and 2 facilities in Knottingley, West Yorkshire, represent the largest energy from waste site in the UK, transforming over 1.4 million tonnes of unrecyclable waste into enough homegrown energy to power around 350,000 homes every year.

enfinium has previously announced an ambition to lead an investment of up to £800 million over the project lifecycle in CCS at Ferrybridge.

The confirmation from the UK Government on 20th February – known as a Section 35 direction – is an important step in the planning and consenting programme for CCS at Ferrybridge, with statutory consultation due to take place later this year ahead of the submission of an application for Development Consent to the Planning Inspectorate in late 2025.

The Direction from the Secretary of State notes that the proposal "would provide and support the decarbonisation of the largest energy from waste site in the UK, with the potential to deliver over a million tonnes of CO2 savings per annum, equating to 6.5% of the government's annual carbon capture and storage ambition."

Mike Maudsley, CEO of enfinium said, "This designation is an important step in realising our ambition to turn Ferrybridge into one of Europe's biggest carbon removal projects."

Direct Air Capture's role in the urgent call to lower escalating emissions

Every year, over 40 gigatons of CO2 are released into the atmosphere, posing a significant challenge to achieving the global goal of reaching net zero by 2050 through emissions reduction alone. One of the paramount objectives in the DAC industry is the strategic reduction of the cost per tonne of CO2 removal. RepAir believes its electrochemical DAC solution can provide this paradigm shift.

Industries such as air travel, as well as those deemed "hard to abate," including cement, iron, and steel production, generate carbon dioxide emissions through process reactions that cannot be entirely eliminated by transitioning to renewable energy sources. Even if all industries capable of adopting renewable energy were to do so, a persistent 10-20% gap[1] of unpreventable emissions would remain.

Additionally, historical carbon dioxide emissions, stemming from global fossil fuel combustion and industrial processes since the industrial revolution, stresses the need for substantial progress through offset measures. All these reasons outline an urgent need for a comprehensive global carbon-negative strategy, that includes removing excess carbon dioxide out of the atmosphere to mitigate the escalating climate crisis.

According to a report by the International Energy Agency (IEA), the cost of direct air capture (the end-to-end cost of CO2 removal including final storage) will need to fall from $600 to $1,000 per tonne of CO2 today to below $200 per tonne and ideally closer to $100 per tonne by 2050, and preferably earlier.[2]

Central to this pursuit is the difficult challenge faced by DAC companies, as they attempt to curtail costs to align with the industry benchmark of $100 per tonne.

Additionally, a pivotal facet integral to the cost equation involves the imperative need for scalability to be economically viable. Conventional DAC solutions have yet to develop a technology that is economically viable at scale that addresses factors, such as, low energy consumption, continuous functionality, location flexibility, minimal maintenance requirements, and overall cost-effectiveness in both setup and operation.

Next Generation DAC Technologies

In recent years, efforts to enhance conventional Direct Air Capture (DAC) methods have seen significant strides, with advancements spanning from the utilization of novel materials like Metal Organic Frameworks (MOFs) as adsorbents with improved efficiency and stability, to improved engineering design concepts, such as rotating filters. While these endeavors have been ongoing for the past decade, the emergence of electrochemical-based DAC approaches represents a paradigm shift within this landscape.

Electrochemical methods, including electrodialysis (liquid-membrane), liquid pH swing techniques, and RepAir's electrochemical cell-based solution, offer promising avenues to address the inherent limitations, such as energy efficiency and cost-effectiveness, of existing DAC technologies. Among these, RepAir Carbon stands out as a transformative solution, strategically engineered to tackle key challenges at a gigaton scale, emphasizing low energy consumption and a fast path to seamless scalability.

Notably, RepAir's approach distinguishes itself by operating in a solid-state configuration, sidestepping the logistical complexities associated with liquid handling and maintenance. Additionally, its robustness against the presence of other atmospheric gases sets it apart from other emerging electrochemical alternatives.

RepAir's Technology

RepAir's Direct Air Capture (DAC) design represents a leap forward in carbon removal technology, offering a viable solution for the immediacy of the climate crisis.

The technology behind RepAir's DAC system involves a series of electrochemical principles. Like a battery, the process employs two electrodes placed on either side of a selective separator creating a cell. These cells are 'stacked' to multiply the carbon-removal capacity. Atmospheric air is drawn into the cathode, where an electrical current generates hydroxide ions that bind to CO2 molecules, forming carbonate and bicarbonate ions. Only these ions cross the separator into the anode, wherein the binding process is undone, the hydroxides are consumed, and pure CO2 gas is drawn out. Achieving a continuous process is realized by systematically switching cell polarity approximately every few hours.

Lab results demonstrate impressive energy efficiency with only 650 kWh per ton of CO2 removed (@400 ppm) which is significantly lower as compared to other DAC technologies. Electrochemical processing enables operation at ambient temperatures, distinguishing it from solvent-based or solid-based capture methods that often require high temperatures and significant water usage.

RepAir's low energy consumption and efficient, continuous process, leads to minimal operating expenditures (OpEx). Additionally, the straightforward, modular design further contributes to its scalability, resulting in low capital expenditures (CapEx). This combination positions RepAir's solution as highly conducive to large-scale production, offering maximum potential for swift and sustainable implementation.

RepAir's advantages

Our electrochemical technological approach offers key differentiators that yield notable benefits compared to other carbon capture solutions:

1. Global Energy Review 2021 – Analysis - IEA - https://www.iea.org/reports/global-energy-review-2021
2. https://www.bcg.com/publications/2023/solving-direct-air-carbon-capture-challenge

Low Energy Consumption: RepAir's DAC consumes 70% less energy than conventional solutions, with core units exhibiting energy consumption of less than 0.6 MWh per ton CO_2, including regeneration. This results in a total energy consumption of less than 1 MWh/tCO_2, while emitting less than 50kg of CO_2 for every ton removed.

Continuous Process: Unlike DAC technologies operating on a capture and release system, our continuous process enhances efficiency by providing a streamlined carbon capture solution. Continuous separation is achieved through the swift collection of separated CO_2 in a matter of seconds during polarity switching.

Modular Design: Capacity expansion is achieved by stacking multiple cells into a single stack and combining several stacks into a basic module unit, streamlining both manufacturing and scalability.

Scalability: Facilitated by a low-cost approach, our solution will be easy to scale up with estimated figures well below $100 per ton. Additionally, the system's compact footprint of approximately 15 tCO_2/m3 underscores its efficiency and scalability.

Flexible Deployment: With a modular design akin to building blocks, our technology allows for large-scale production with minimal capital expenditures (CapEx). This versatility enables deployment in various environments, particularly advantageous when located near sequestration facilities and areas with access to renewable energy sources like solar or wind farms.

Liquid-Free Technology: RepAir's technology eliminates issues associated with liquid usage in other technologies, resulting in minimal maintenance requirements, enhanced safety, and environmental responsibility.

No Platinum Group Metals (PGM) or Rare Materials: RepAir's electrochemical solution is based on abundant materials, eliminating the need for expensive rare-earth metals or Platinum Group Metals (PGM), enhancing affordability and sustainability.

No Heating Requirement: The electrochemical process achieves regeneration without the need for heating, further streamlining operations and reducing energy consumption.

No Consumables: The process operates without the need for streaming consumables in any form, ensuring long-term sustainability and cost-effectiveness.

RepAir's Direct Air Capture (DAC) Field Prototype

Renewable Electricity Usage: Driven solely by renewable energy sources, our process ensures high net capture and overall efficiency.

RepAir's Present and Future

Recently RepAir took the technology out of the lab and on to the roof with the launch of our outdoor field prototype, demonstrating the technical performance of our carbon capture solution in an operational environment for the first time. This marks a shift in RepAir's electrochemical solution to Technology Readiness Level (TRL) 6, a significant step forward on the road to scale up and market viability.

The launch of the prototype serves as an excellent tool for R&D to continuously assess results and implement necessary changes, driving the development of an optimal product. Additionally, we are focused on elevating the performance of crucial technological metrics, including enhancing the lifespan of our core technological elements. We aim to refine our system design and optimize process control for increased efficiency and scaling up our core technology for commercial scale.

In production, our strategy involves establishing in-house manufacturing capabilities for key elements of our core technology. Simultaneously, we are building a robust supply chain comprised of high-quality manufacturers. Building this infrastructure is essential to support mass production of various elements within our systems, ensuring a seamless and efficient manufacturing process. Next year we plan to collaborate with world-class Engineering, Procurement, and Construction (EPC) partners to design and construct projects. Additionally, engagement with global manufacturing partners is underway to ensure high standards in terms of quality, quantity, and cost-effectiveness.

On the commercial front, RepAir is actively engaging sequestration partners to create a comprehensive solution throughout the value chain. Simultaneously, we are recruiting offsetters for the purchase of carbon credits.

Conclusion

RepAir's groundbreaking electrochemical approach not only addresses the fundamental drawbacks of conventional DAC methods but also offers a multitude of benefits critical for adapting a carbon-negative strategy.

With significantly lower energy consumption, unparalleled scalability, and flexible deployment options, RepAir's technology presents a paradigm shift poised to transform the carbon capture landscape.

More information

www.repair-carbon.com

Using light to capture CO2 requires less energy than other methods

Researchers at ETH Zurich are developing a new method to capture CO2 involving molecules that become acidic when exposed to light.

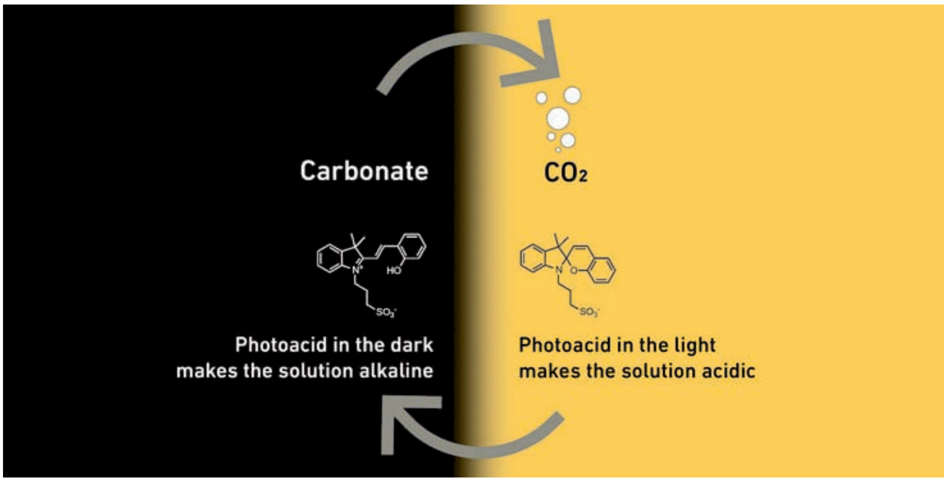
They have developed a special mixture of different solvents to ensure that the light-reactive molecules remain stable over a long period of time. Their new process requires much less energy than conventional technologies.

Led by Maria Lukatskaya, Professor of Electrochemical Energy Systems, the scientists are exploiting the fact that in acidic aqueous liquids, CO2 is present as CO2, but in alkaline aqueous liquids, it reacts to form salts of carbonic acid, known as carbonates. This chemical reaction is reversible. A liquid's acidity determines whether it contains CO2 or a carbonate.

To influence the acidity of their liquid, the researchers added molecules, called photoacids, to it that react to light. If such liquid is then irradiated with light, the molecules make it acidic. In the dark, they return to the original state that makes the liquid more alkaline.

This is how the ETH researchers' method works in detail: The researchers separate CO2 from the air by passing the air through a liquid containing photoacids in the dark. Since this liquid is alkaline, the CO2 reacts and forms carbonates. As soon as the salts in the liquid have accumulated to a significant degree, the researchers irradiate the liquid with light. This makes it acidic, and the carbonates transform to CO2.

The CO2 bubbles out of the liquid, just as it does in a bottle of cola, and can be collected in gas tanks. When there is hardly any CO2 left in the liquid, the researchers switch off the light and the cycle starts all over again, with the liquid ready to capture CO2.



Photoacids and differences between dark and light enable a cyclic process for the capture and release of CO2. (Graphic: ETH Zurich)

It all depends on the mixture

In practice, however, there was a problem: the photoacids used are unstable in water. "In the course of our earliest experiments, we realised that the molecules would decompose after one day," says Anna de Vries, a doctoral student in Lukatskaya's group and lead author of the study.

So Lukatskaya, de Vries and their colleagues analysed the decay of the molecule. They solved the problem by running their reaction not in water but in a mixture of water and an organic solvent. The scientists were able to determine the optimum ratio of the two liquids by laboratory experiments and were able to explain their findings thanks to model calculations carried out by researchers from the Sorbonne University in Paris.

For one thing, this mixture enabled them to keep the photoacid molecules stable in the solution for nearly a month. For another, it ensured that light could be used to switch the solution back and forth as required between being acidic and being alkaline. If the researchers were to use the organic solvent without water, the reaction would be irreversible.

Doing without heating

Other carbon capture processes are cyclical as well. One established method works with filters that collect the CO2 molecules at ambient temperature. To subsequently remove the CO2 from the filters, these have to be heated to around 100 degrees Celsius. However, heating and cooling are energy-?intensive: they account for the major share of the energy required by the filter method. "In contrast, our process doesn't need any heating or cooling, so it requires much less energy," Lukatskaya says. More than that, the ETH researchers' new method potentially works with sunlight alone.

"Another interesting aspect of our system is that we can go from alkaline to acidic within seconds and back to alkaline within minutes. That lets us switch between carbon capture and release much more quickly than in a temperature-?driven system," de Vries explains.

With this study, the researchers have shown that photoacids can be used in the laboratory to capture CO2. Their next step on the way to market maturity will be to further increase the stability of the photoacid molecules. They also need to investigate the parameters of the entire process to optimise it further.

More information

www.ethz.ch/en.html

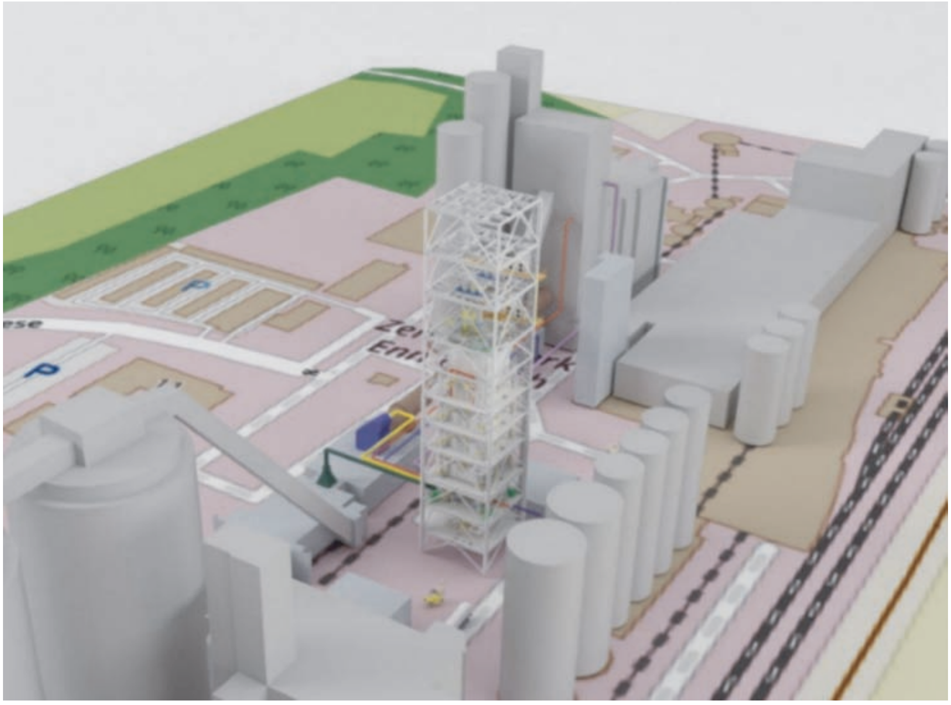
Leilac-2 to be constructed at Heidelberg Materials' cement plant in Germany

The Leilac-2 project aims to demonstrate a replicable module that can efficiently capture up to 100,000 tonnes per year of unavoidable process CO2 emissions released during cement and lime production.

The retrofittable module is designed to be integrated into an operational cement plant with minimal downtime and operate on a range of fuels.

Leilac's unique technology seeks to enable the affordable abatement of unavoidable CO_2 process emissions in cement and lime production. With no additional chemicals or processes, its indirectly heated calcination approach aims to efficiently separate CO2 for use or storage.

Following Heidelberg Materials' decision to end clinker production in Hanover, Germany, Calix's subsidiary, Leilac Limited, Heidelberg Materials and IKN, a Leilac-2 project partner, have conducted detailed technical and financial assessments of alternative sites for the project. This process has resulted in the selection of Heidelberg Materials' Ennigerloh cement plant in North Rhine-Westphalia, Germany as the new host plant for the Leilac-2 project.



Leilac-2 module located at Heidelberg Materials' Ennigerloh cement plant

Heidelberg Materials General Manager Germany, Christian Knell said, "Heidelberg Materials has again demonstrated its commitment to develop the Leilac technology and is pleased to host the Leilac-2 project at the Ennigerloh cement plant. Leilac continues to be an important technology solution for our industry-leading efforts to meet societies' net-zero commitments."

The Leilac-2 project has already delivered a robust detailed design ready for construction. The Ennigerloh site assessment found that the Leilac-2 design developed for the Hanover plant could be installed at the operational Ennigerloh plant with minimal delay and cost. The required additional engineering work is expected to be limited to site-specific permitting and integration and no increase in total project capital cost is expected.

Construction of Leilac-2 at Ennigerloh based on the existing engineered design is targeted to begin promptly following the conclusion of the permitting process.

The successful relocation of the Leilac-2 project to Ennigerloh will demonstrate the robust and transferrable nature of the Leilac technology and its ability to be quickly deployed at other operational cement plants. Ultimately, Leilac's technology is designed to be delivered through a blueprint model, for construction by local companies, using local resources.

Leilac CEO, Daniel Rennie said, "The Leilac technology represents a scalable and economical solution to address the carbon dioxide emissions that are produced unavoidably by the cement and lime industries, and the rapid demonstration of such solutions is essential to achieving our industrial decarbonisation goals."

"The swift and successful selection of Ennigerloh as the new Leilac-2 host plant is the result of the proactive, positive, and committed approach by Heidelberg Materials, the European Commission, and our partners, and the dedication of an exceptional collective project team."

"We look forward to continuing to work with all our partners to rapidly deploy efficient decarbonisation solutions at Ennigerloh and cement and lime plants around the world."

The Leilac Technology Roadmap to 2050 provides cost-effective pathways to carbon neutral industrial production of cement and lime in line with the Paris Agreement goals.

More information

www.leilac.com

www.calix.global

Capture & utilisation news

Elkem completes first smelter CCS pilot

www.elkem.com/sustainability/

Elkem, a producer of silicon-based materials, has completed its first pilot for carbon capture and storage at its plant in Rana, Norway.

The pilot recorded high capture rates of CO2, up to 95%, indicating technical viability of CCS in smelters.

Elkem's Climate Director, Trond Sæterstad, said, "We're excited to have completed our first pilot for CCS at our plant in Rana. Our high capture rates of up to 95%, combined with low amine degradation, show technical effectiveness of the technology. Now the challenge is to strengthen the business case for CCS, to make it commercially viable in an industry with global competition."

Flue gas from silicon smelters has fluctuating and low CO2 concentrations. The success in capturing this CO2 in the pilot provides invaluable learning for future developments. The CCS pilot was operational for approximately 3000 hours between November 2022 – June 2023.

"The key learnings from this pilot helps us know how to optimise our plants for potential future implementation of carbon capture," said Sæterstad.

Carbon Capture is included in Elkem's climate strategy towards reaching net zero emissions by 2050.

"Elkem aims to be part of the solution to combat climate change. Our mission is to provide advanced material solutions, shaping a better and more sustainable future. We will use the results from this pilot to continue maturing technical and commercial aspects of potential future CCS implementation."

"Lowering implementation costs and attracting competitive framework conditions are also critical components of this process," says Trond Sæterstad.

The project received financial support from Gassnova CLIMIT, and was a collaboration between Elkem and Mo Industripark, SINTEF, Alcoa, Celsa, Ferroglobe, SMA Mineral, Norcem, Norfrakalk, Arctic Cluster Team and Aker Carbon Capture.

Linde Engineering supplies CO2 liquefaction to Yara ammonia project

www.linde-engineering.com
www.yara.com/yara-clean-ammonia

Linde Engineering has signed a contract with global fertiliser manufacturer Yara to build a world-scale carbon dioxide liquefaction plant in Sluiskil, the Netherlands.

The Sluiskil project forms a key part of Yara's clean ammonia initiative, in which each year 800,000 tons of CO2 will be captured, liquefied, loaded onto special ships, and then subsequently locked away permanently below the seabed off the coast of western Norway.

"This collaboration with Yara confirms Linde Engineering's leading position in terms of technology and execution know-how for projects of this scale. It is also an important step on the path to net-zero for the fertiliser industry. Coastal CO2 hubs, which load liquid CO2 into ships for sequestration, are an asset in Europe's decarbonisation strategy with many more facilities in the planning stage," said Juergen Nowicki, Executive Vice President Linde plc and CEO of Linde Engineering.

The CO2 liquefaction plant will be built onsite next to Yara's existing ammonia plant. After start-up in 2026, it will be a part of one of the first commercial CCS ventures in Europe.

The plant will prepare the CO2 from Yara's ammonia plants for transportation. This will be achieved through processes including compressing, drying and liquefying using a refrigerant. The liquid CO2 will be stored in horizontal tanks with a total storage volume of about 15,000 m3, before shipping for sequestration.

As the CO2 source is not connected to the final storage location by pipeline, the processing and liquefaction of the CO2 by a corresponding Linde plant make economical transport possible in the first place – in general possible by ship, train, or truck.

"Yara, as a frontrunner, has found the project to be complex yet incredibly valuable," said Michael Schlaug, Vice President of Yara Netherlands. "The energy we've invested in it is more than worth it because we're paving the way for CCS as a technology in Europe and giving impetus to a clean hydrogen economy. Additionally, this investment signifies that the parent company sees our Sluiskil plant as a key asset within Europe. The investment also ensures the preservation of ammonia production and technological knowledge, decarbonization of the food chain, thus securing strategic autonomy for Europe."

Aker Carbon Capture wins US CO2 capture test campaign

www.akercarboncapture.com

CO280 Solutions and a leading pulp and paper company have awarded a carbon capture test campaign to Aker Carbon Capture for an undisclosed site on the Gulf Coast in the US.

This test campaign follows a successful pre-FEED performed for the same site. It will enable the full-scale implementation of multiple Just Catch 400 modular capture facilities with permanent storage, and the creation of carbon removal credits.

The company's mobile test unit will now be applied to the pulp and paper industry for the first time. The initial results from the campaign are expected towards the end of 2024, ahead of the project's expected final investment decision.

"With its strong cost and schedule advantages, our modular Just Catch 400 offering is an ideal fit for pulp and paper mills across the US. This test campaign signifies a milestone for Aker Carbon Capture's rapid expansion into the significant North American market," said Egil Fagerland, Chief Executive Officer at Aker Carbon Capture.

CO280 partners with pulp and paper companies to finance, own, and operate CCS projects that deliver carbon removal credits to the voluntary carbon market.

The US pulp and paper industry emits approximately 150 million metric tonnes of CO2 annually, primarily of biogenic origin. By capturing and storing these emissions permanently, one achieves negative emissions. Carbon removals provides an opportunity to not only compensate for hard-to-abate emissions, but also historical emissions, which is crucial to reaching net zero in 2050.

Offshore CO2 storage: a prerequisite for net zero

Governments and NGO's across the globe are coming around to the importance of CCS in achieving the goals of the Paris Agreement. By Martin van Onna, CEO, Strohm.

For years, people have challenged the concept of carbon capture and storage (CCS) and its relevance to achieving the ambitions laid out in the Paris Agreement. Rather than capturing CO2 and storing it underground, the argument goes that the focus should be on avoiding producing CO2 altogether by accelerating electrification and implementing green hydrogen to reduce the emissions of hard-to-abate industries. The thinking is that resources would be better spent crafting the energy system of the future, one that would be virtually, if not entirely, carbon free.

Last year served as a reality check though, making clear that everything that can be done to achieve net zero, has to be done - and CCS is a key contributor to achieving this goal. While the rollout of electrification and green hydrogen needs to accelerate, we see that the speed of electrification is hampered by the challenges of net congestion and balancing intermittent power sources with users. Green hydrogen on the other hand is moving slower than is required, due to market immaturity, the low technology readiness level of electrolysers and high costs; as a result, a number of green hydrogen project plans were scrapped in 2023.

These realities mean governments and NGOs are coming to understand that, besides pushing further with electrification and green hydrogen, CCS will have to move quicker as a recognised, important element to reach net zero. There are a number of elements that support the development of CCS, primarily around timing, cost, maturity, and necessity:

1. Timing: CO2 reduction can be achieved relatively quickly. There are many quick wins that can be achieved by targeting sectors where CO2 is currently emitted in large quantities, like refineries, fertilizer companies and electricity power stations, to name but a few.

2. Cost: The cost of CCS is well known and predictable, enabling a business case to be made with a high level of accuracy. It is also cost effective, especially when done at scale.

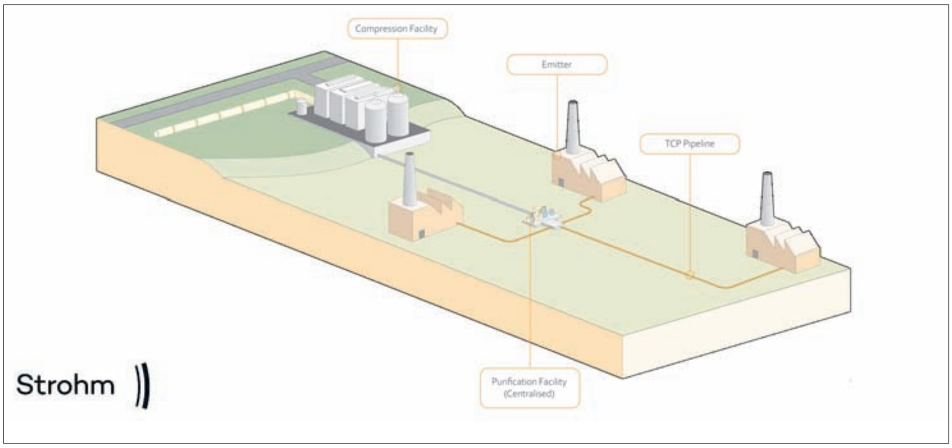


Figure 1: Central purification

The first wave of projects are expected to reach final investment decision (FID) this year without the need for subsidies. In Europe, the Emission Trading System (EU ETS) is a key tool for reducing greenhouse gas emissions cost-effectively - as a carbon market it creates an effective price mechanism for capturing and storing CO2.

3. Maturity: As CO2 injection has been done around the globe already for years, the technology is mature, well known and can be expanded relatively easily.

4. Necessity: In a mix of decarbonisation solutions, CCS is a necessity for tackling emissions where other options are limited, for instance due to a lack of maturity or cost.

With this, we have observed a growing realisation of the importance of CCS in keeping the Paris Agreement's goals alive. To achieve net zero, however, much more needs to be done. According to the latest IEA report on the subject, CCS will play a key role in the energy transition, but it needs to scale up and accelerate. Since 2018 momentum has increased, but now the CCS sector must show it can make good on its promises and deliver the decarbonisation needed to meet governments' net zero goals. If all announced projects are built, around 420 megatonnes of CO2 a year (MtCO2/annum) will be captured in 2030, which is more than eight times current capacity.

Still, that is only 40% of what is needed for the Net Zero Emissions by 2050 Scenario (NZE Scenario) of 1 gigatonne of CO2 a year (GtCO2/annum) - scaling up will be required, to put it mildly. Current project lead times average six years, but by adopting best practices there is scope to reduce this by around three to four years. Achieving 1 GtCO2/annum requires, on average, 160 MtCO2/annum of capture capacity to start the planning phase every year between 2023 and 2026. In 2022 this was achieved.

For storage, we need to look at offshore locations as the perfect place to permanently lock away CO2 without causing concern. In Europe, the North Sea basin with its swathes of aquifers and depleted gas fields is ideally positioned for storing large volumes of CO2. As a report from global energy consultancy Xodus explained: "The volume of CO2 being injected into the North Sea by 2050 will be equivalent to the natural gas currently being extracted from the basin. That scale of carbon capture, utilisation and storage will require some 100 reservoirs, more than 7,500 kilometres of new pipelines and dozens of onshore emissions capturing and gathering sites."

There are still operational challenges to overcome, both onshore around the gathering of emissions and offshore with the subsea injection. These difficulties both concern corrosion, albeit in different ways. The good news is that Strohm, and our Thermoplastic Composite Pipe (TCP), provides a solution to this challenge as the product simply does not corrode at all. Further, the flexibility of the product simplifies the offshore installation process, thereby meaning that projects can move from development to operation more swiftly.

First, let us explore the issues with onshore capture. CO2 is well known for its corrosiveness when contaminated. Where capture is carried out at locations with a high concentration of CO2, the resulting gas is often still contaminated with impurities, ranging from hydrogen sulfide (H2S) to water. Purifying CO2 to the extent required to be able to use carbon steel pipelines is extremely expensive, especially when done on small scale at the emitters' site - this disincentivises them to invest.

Transmission System Operators (TSOs) are therefore keen to use non-corrosive materials for the smaller gathering network - allowing emitters to avoid investing in purification and thereby accelerating adoption - before taking advantage of scale to purify the CO2 before it is injected into larger transmission lines - concepts depicted in Figures 1 and 2.

For this to work effectively, TCP is an enabling technology as it does not corrode at all and thereby allows the purification to be done centrally, rather than at distributed sites. Moreover, TCP can do this in the pressures and sizes that are required and anticipated by the TSO's. Unlike reinforced thermoplastic pipe, TCP can accommodate CO2 transport in both gaseous and critical phase at pressure and can be deployed in the sizes required by emitters.

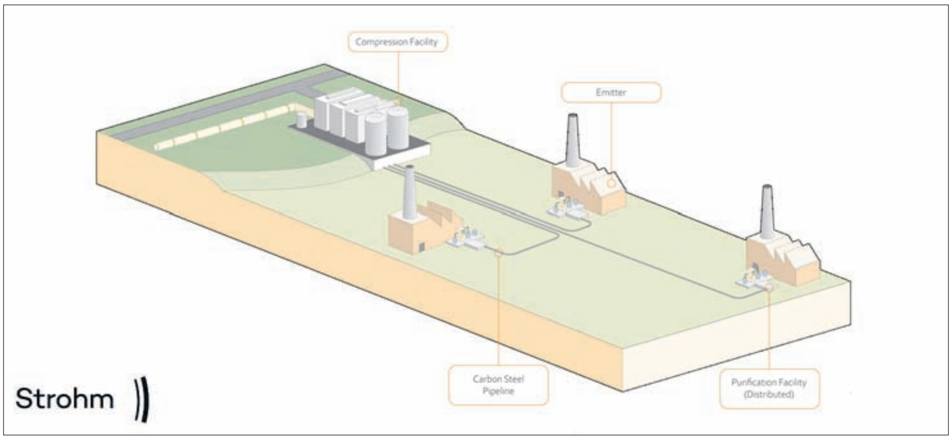


Figure 2: Distributed purification

Moving onto the offshore and subsea space, the large-scale injection of CO2 in reservoirs and aquifers requires large pipelines to export the gas from shore. These pipelines are typically designed in carbon steel and, as such, require dry CO2. Here, the challenge is around the infield infrastructure in cases where subsea wells and valves are used. Even the smallest amounts of seawater ingress, or water left behind after commissioning, will lead to severe corrosion challenges. Here again, TCP provides the solution. By using TCP to connect manifolds with injection trees, the last mile of transport is served by a fully non-corroding, flexible composite pipe.

Moreover, it is generally accepted that flexible pipes simplify the offshore installation and, through that, reduce the project lead time. This time saving is exactly what is needed to achieve the NZE Scenario; as the IEA explained, project lead times need to decrease from an average of six years to three or four years, by adopting best practices. Standardisation and the ability to use a large variety of installation vessels help to reduce the time it takes for a CCS project to reach the operational phase and begin locking away emissions. The flexibility that TCP brings, while being lightweight enough to allow developers to use small vessels and the horizontal lay method, all adds to the acceleration of offshore project execution. In turn this means that the environmental impact of delivering CCS at scale can be kept to a minimum. Indeed, research carried out by DNV has shown that TCP can reduce the total carbon footprint of a given offshore pipeline solution by more than 50% (see Figure 3).

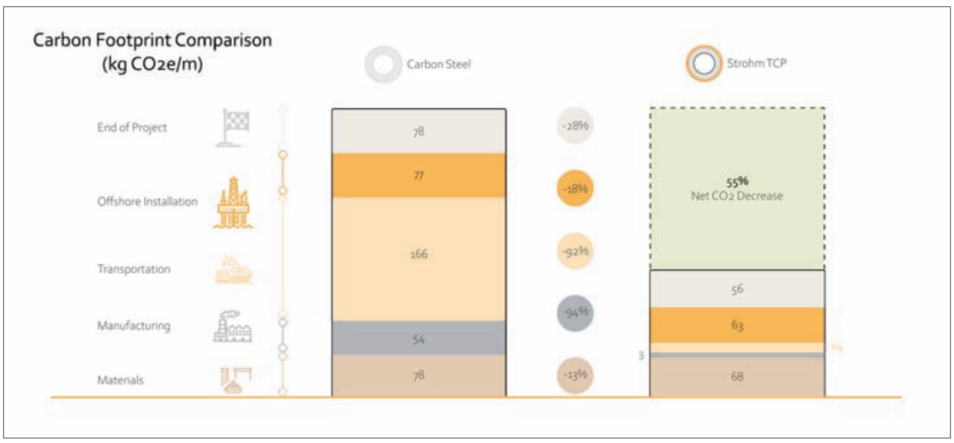


Figure 3: Carbon Footprint reduction

Now that CCS is generally accepted as one of the most vital cogs in the energy transition, there is little doubt that the scale and pace of deployment must significantly increase. With the offshore environment offering promising opportunities for large-scale CO2 storage, leveraging technologies such as TCP becomes paramount in overcoming operational challenges and accelerating project execution.

A non-corroding and flexible solution, TCP is the best option for the first and last mile of CO2 transport. It de-risks the project, in terms of technical risk, commercial risk and schedule, and means that CCS can be delivered with as little impact to the environment as possible. Embracing such innovations is the best way to make CCS a material contributor to achieving the overarching NZE Scenario.

More information

www.strohm.eu

Study on CO2 transport by ship in Europe

EU advisory organisation Zero Emissions Platform has published a report about the potential for maritime transport of CO2, estimating 10-20 vessels will be needed in Europe by 2030. By Karl Jeffery.

The Zero Emissions Platform, a EU advisory organisation, has published a report into the potential for maritime transport of CO2 between emitters and storage sites.

It estimates that 10-20 vessels will be needed by 2030 to serve projects which will be in operation by then. Far more carbon capture and storage projects are planned for the 2030s, so far more vessels will be needed over the longer term, but this was outside the scope of the study.

The study looked at the planned CCS projects, potential shipping routes, suitable vessel capacities and fleet sizes, potential interoperability issues, and regulatory and commercial barriers and enablers.

Companies represented in the working group included Storegga, Carbon Collectors, Energy Transition Advisory (co-chairs / authors); and Northern Lights, Harbour Energy, Slaughter and May, SIGTTO, Ecolog, Shell, Knutsen NYK, Equinor, Prime Marine, Neptune Energy, BP, and Navigator Terminals.

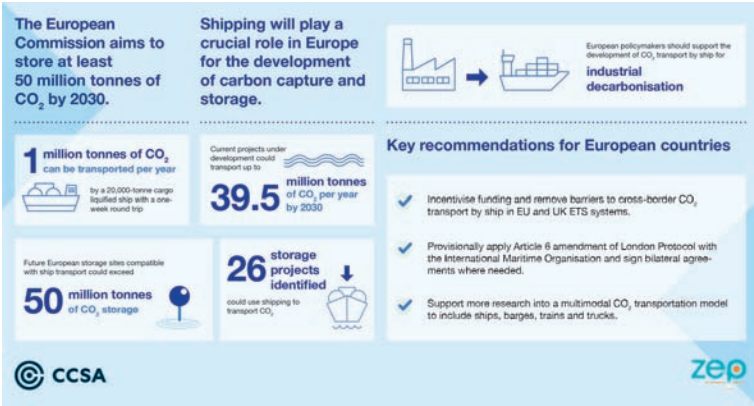
Shipping might not only be used to carry CO2 from a source to a sink; it may be used in future to carry CO2 from terminals to stores, or from one terminal to another. CO2 is more likely to be delivered from emitting sites to terminals by pipeline.

There are 'low volume' and 'high volume' transport scenarios, where high volume could be up to 40m tonnes CO2 transported a year.

For a comparison, the Northern Lights project of Norway, Europe's first CCS project, handles up to 1.5m tonnes CO2 a year in its first phase, so is 'low volume'.

The shipping service could be operated by the storage provider like a waste collection service. Alternatively, the emitter could provide a 'drop off' model, an example being an emitter selling and delivering CO2 for food use.

Three 'shipping conditions' were explored: low pressure (5-10 bar and -50 degrees C); medium pressure (15 bar and -27 degrees C); and high pressure (40-45 bar, 5-10 degrees C). The medium pressure option was chosen by Northern Lights.



The lower the temperature, the more energy needed for cooling, and more insulation needed. But higher pressure needs much thicker walled tanks, and lower temperature means higher density. The tolerances for impurities are also different at different pressures and temperatures.

CO2 specifications

The CO2 specifications for shipping are generally more stringent than pipeline specifications, said Haije Stigter, technical director of consultancy Carbon Collectors, and a co-chair and co-author of the report. So, it makes sense to do CO2 conditioning at the point the CO2 is loaded onto ships.

If there is a small amount of water mixed with the CO2, it will be corrosive; any hydrogen present can have an impact on material integrity. Sulphur and nitrogen oxides, oxygen and hydrogen sulphide are also corrosive.

If the CO2 contains methane, nitrogen, or hydrogen, they will not condense at the temperatures where CO2 condenses, so will remain as a gas.

To find the best solution might require a "complete techno economic analysis - source to sink," he said.

It will be desirable to keep the specifications as broad as possible, because the more restrictive they are, the more potential CO2 shipping options will be restricted out, and some emitters may find CO2 shipping cost prohibitive.

Challenges

SIGGTO, the Society of International Gas Tanker and Terminal Operators, is asking for international regulations for gas transport to be changed, because they were designed for carriage of flammable gases, while CO2 is inert.

There will need to be very reliable methods for metering and allocating the CO2 which is permanently stored, if it is used to enable emitting companies to avoid paying for emissions credits.

It may be necessary for governments to provide higher levels of subsidy to CO2 emitters which require maritime transport, because their costs will be higher than emitters who can connect to a CO2 pipeline network.

It would be helpful if EU-UK transport regulatory barriers could be overcome. These are the lack of integration between EU and UK emission trading schemes, and the London Protocol prohibiting transport of waste between countries without a special agreement between them, Mr Stigter said.

More information

Download the report, "Achieving a European market for CO2 transport by ship" (Jan 9, 2024) here:

www.zeroemissionsplatform.eu

This article was based on a webinar which is online here:

www.youtube.com/watch?v=JptJxWbqREU

Transport and storage news

EverLoNG onboard carbon capture shows promising results

www.everlongccus.eu

Initial results from the EverLoNG ship-based carbon capture (SBCC) prototype has shown that capture rates of at least up to 85% are achievable.

The EverLoNG SBCC prototype, developed in the Netherlands by Carbotreat, was installed on board the SEAPEAK ARWA, a LNG-powered carrier chartered by TotalEnergies, in September 2023.

This major milestone marked the first deployment anywhere of a 'full-chain' on-board system comprising capture, liquefaction and storage facilities.

This first testing campaign, which concluded mid-February 2024, focused on the performance of the capture system. It ran for over 1,000 hours during which the unit captured up to 250kg of CO_2 per day.

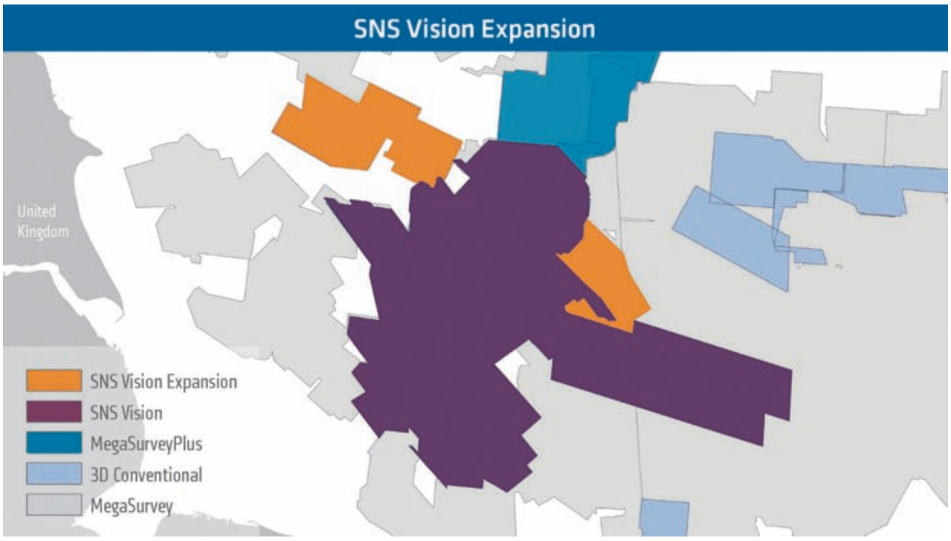
Initial results are very promising, showing that capture rates of up to 85% are achievable. With further system optimisation to come, researchers are confident of more.

As well as assessing the impact of SBCC on the ship's infrastructure and emissions, EverLoNG researchers are studying the effects of motion on CO_2 capture rates and of exhaust gas impurities on capture solvent performance.

With a dedicated operator on board to oversee operation of the system, the prototype and vessel designs also enable remote performance monitoring and supervision from shore. This enables a safer and more efficient learning campaign that is providing real-time data that will be shared publicly.

Following the SEAPEAK ARWA trial, the SBCC unit will be removed and installed on board the SSCV Sleipnir from Heerema Marine Contractors, where a second campaign of around 500 hours will take place.

The second campaign will see the full CCUS chain in operation. The captured CO_2 will be stored on board as a liquid in a container. The container will then be offloaded, and the CO_2 transported to an industrial site for utilisation, or stored permanently in the geological subsurface.



PGS North Sea data shows carbon storage potential

www.pgs.com

Data is now available from the SNS Vision project targeting exploration potential in the mature Southern North Sea gas province.

The final data supports exploration both for postsalt CO_2 storage potential in the Triassic Bunter sand formation and near-field exploration targets, said PGS.

SNS Vision covers open exploration acreage, as well as eight recently awarded CCS licenses. It provides reliable and consistent depth-migrated regional data for screening and evaluation of the carbon storage site, and includes additional deliverables that further support this.

Twenty-six datasets included in the project have benefited from depth imaging reprocessing, including a 2 millisecond broadband processing, modern deghosting, complex demultiple flow that is optimized for shallow water, and depth migration based on full waveform inversion (FWI).

This resulted in a seamless seismic data volume with improved resolution over approximately twelve thousand square kilometers that is suitable for both conventional exploration and CCS projects from shallow to deep.

Following the SNS Vision seismic reprocessing effort, the PGS team performed an automatic regional horizon interpretation to rapidly interpret the volume and particularly the CO_2 storage horizons, namely the Bunter Sand Formation interval.

Santos secures finance for Moomba CCS project

www.santos.com

The facilities, with a five-year tenor and totalling US$150 million, will be used to cover project costs incurred to date and to draw down upon as the project progresses to first injection targeted for mid-2024.

Santos CEO and Managing Director Kevin Gallagher highlighted the willingness of banks to fund energy transition projects at very competitive rates and said this indicated their recognition of CCS as a vital tool in reaching the world's net-zero ambitions.

The first phase of the Moomba CCS project is now 80 per cent complete and is targeting about US$24 per tonne lifecycle breakeven storage costs, which will make it one of the lowest-cost CCS projects globally and very competitive with other carbon-abatement technologies and opportunities.

The project will have capacity to store up to 1.7 million tonnes of CO_2 per year (with actual volumes depending on availability of CO_2 for storage). That's equivalent to delivering – every year – about 28 per cent of the total emissions reduction achieved in Australia's electricity sector last year.[2]

The Cooper Basin will play a significant role in the energy evolution as it transforms into a decarbonisation hub with the potential to produce low-carbon fuels and offer CCS services which could reduce emissions from critical fuels such as LNG and from hard-to-abate sectors such as steel, aluminium and cement.

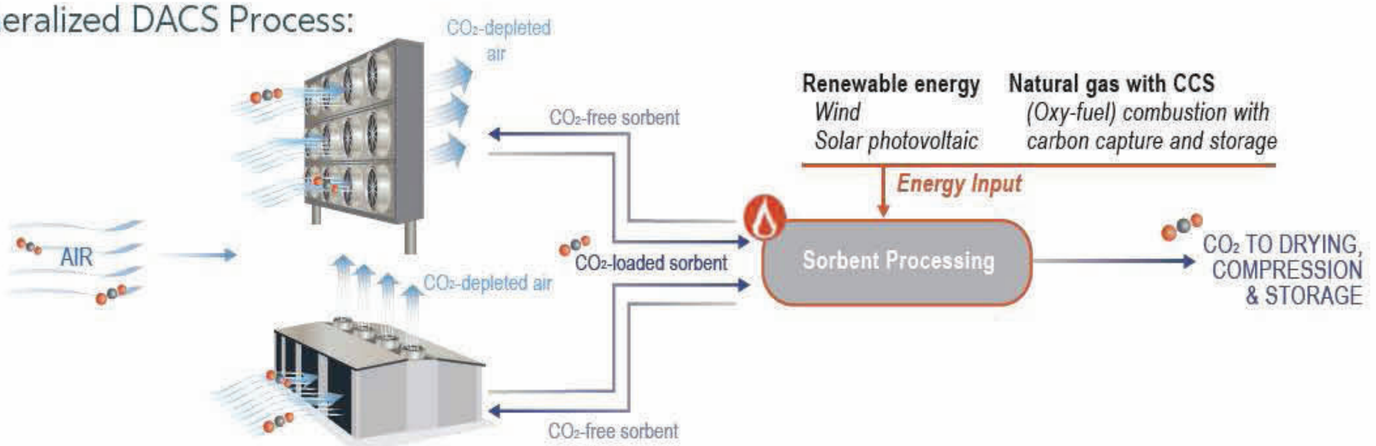
DIRECT AIR CAPTURE & STORAGE

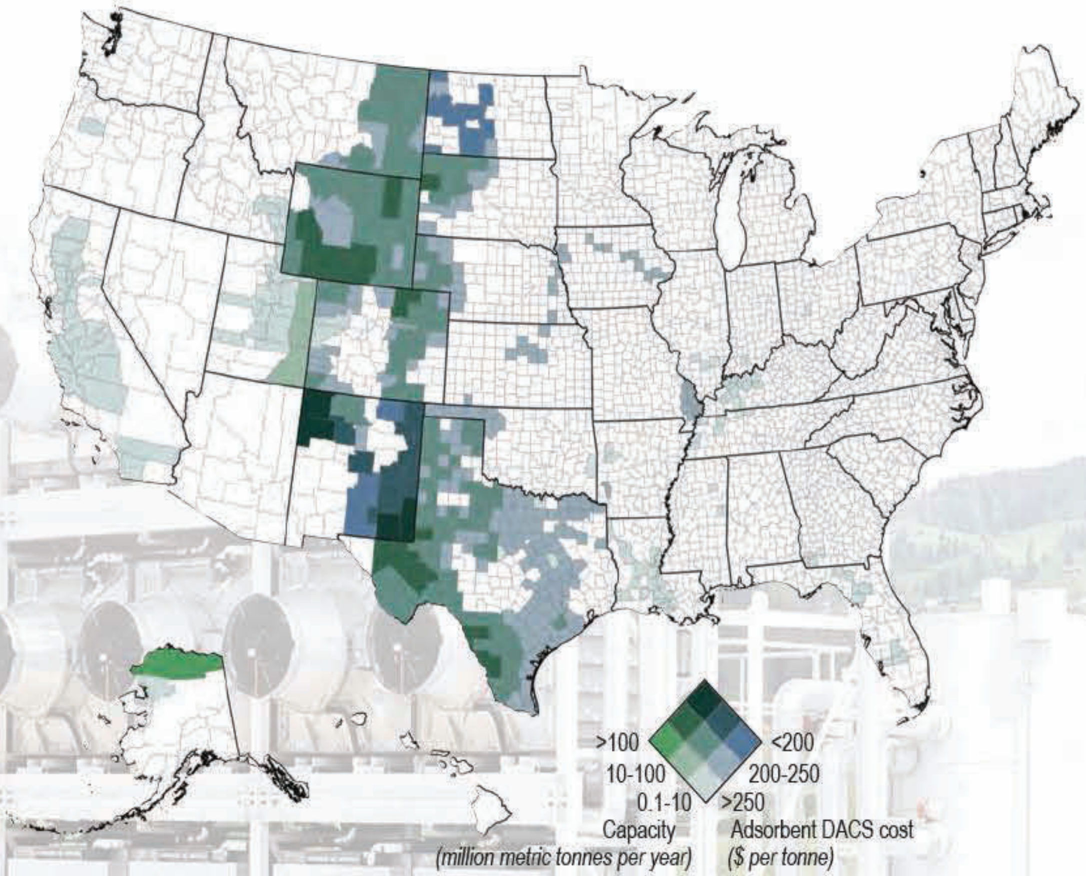
> "We have more than enough opportunities to deploy direct air capture with wind and solar energy to get us to the gigatonne scale of CO_2 removal and net-zero emissions."
>
> Dr. Simon Pang
> *Lead Author, DACS*
> *Lawrence Livermore National Laboratory*

Direct Air Capture with Storage (DACS) Paired with Renewable Energy

- Direct air capture uses mechanical or passive processes to remove carbon dioxide (CO_2) directly from the atmosphere.
- There is technical potential to remove several billion metric tonnes of atmospheric CO_2 each year with DACS. However, these are land, energy and capital-intensive technologies, and it is expected that social, ecological, regulatory and market factors will limit the total removal potential of DACS.
- To maximize efficiency and avoid competing with energy decarbonization, DACS should be sited where there is abundant renewable energy and close to suitable geologic CO_2 storage.

Generalized DACS Process:





Key Findings:

- Prioritizing DACS development in regions experiencing job loss in fossil fuel sectors can bring new jobs and economic resilience to these areas.
- DACS is a long-term CO_2 removal solution that will need to scale once all other decarbonization and CO_2 removal approaches have been maximized.
- Targeted near-term DACS deployment is critical to improving efficiency, reducing costs, and guiding the establishment of rigorous monitoring, reporting and verification standards for captured CO_2.

Every region has a story. Every region has an opportunity

To learn more about each carbon dioxide removal pathway, go to **Roads2Removal.org**