Carbon Capture Journal

CCUS in the U.S.

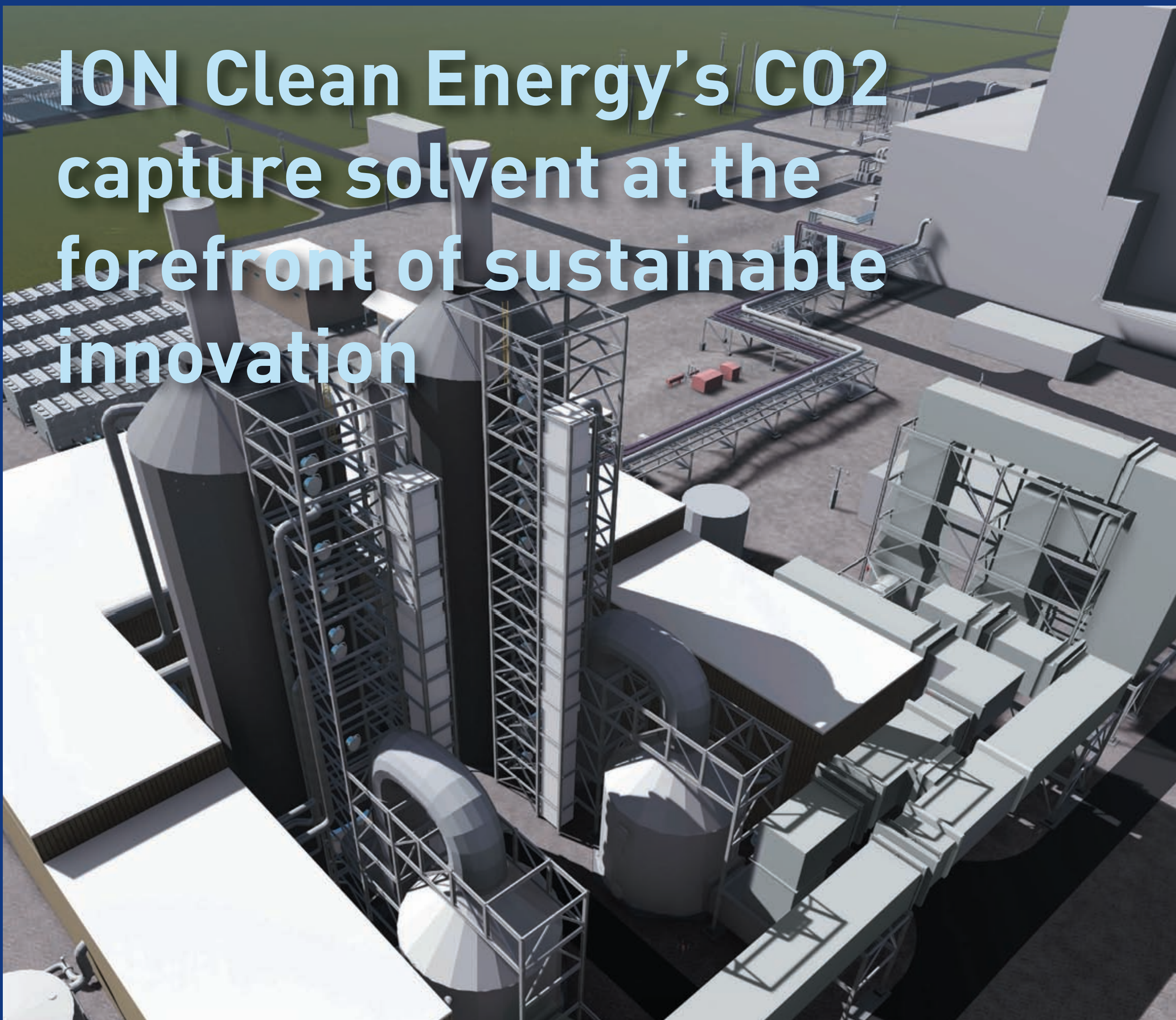
MIT: overcoming a bottleneck in carbon dioxide conversion

NETL sees major CCUS job growth potential

Carbon Hubs Atlas for U.S. Decarbonization

Mar / Apr 2022 Issue 86

ION Clean Energy's CO2 capture solvent at the forefront of sustainable innovation



Artificial leaf captures 100x more CO2 for power of a lightbulb

Could UK CCUS constitute a new source of sustained 'green growth'?

Open Impact Bonds: pricing and funding a carbon capture breakthrough

Catalyst turns carbon dioxide into gasoline 1,000 times more efficiently

Bellona joint call for action on CO2 infrastructure in Europe

The letter calls for a common vision and strategy to realise a CO2 transport and storage infrastructure that accelerates industrial decarbonisation and structural emission reductions.

A substantial part of the European basic materials production happens in industrial clusters in north-western Europe. The ARRRA (Antwerp-Rotterdam-Rhine-Ruhr Area) cluster produces 40 percent of all chemicals in Europe. Steel and cement companies also show a high degree of integration in this region. The mutual interdependence of companies operating in the cluster translates into common needs and comparable emission reduction challenges.

To act on climate change, fulfil their societal role and stay competitive in the future, companies in the ARRRA cluster must comply with the net-zero and circularity objectives of the European Green Deal. Given its highly interconnected nature, the cluster needs a renewed joint strategy towards net-zero emissions in 2050 (or 2045, as is the ambition of the German federal government) for all sectors. The cross-border nature of some of these industries calls for cross-border government efforts to decarbonise.

The letter, signed by a large group of civil society and private sector stakeholders from the Netherlands, Belgium and North-Rhine Westphalia, calls on the national and regional governments of the Netherlands, Belgium, Flanders, Wallonia, Germany, and North Rhine-Westphalia to accelerate and deepen their collaboration on industrial transformation planning.

Governments need to take the lead in foreseeing the cross-border infrastructure needed to make the large-scale emission reductions possible. As society relies on industry to decarbonise, the companies rely on the government to ensure the enabling infrastructure.

While the letter focusses on Carbon Capture and Storage as a part of the solution, the signatories acknowledge that companies have a portfolio obligation in the transformation towards net zero emissions. In such an 'and-and' approach, measures that decarbonise production processes, such as energy efficiency, electrification with renewable energy and circular production processes should be prioritised.

At the same time, they recognise that the development of Carbon Capture and Utilisation (CCU) for long-lived, (repairable, reusable) and recyclable products and Carbon Capture and Storage (CCS) are additional solutions to reach the 2030 and 2050 climate targets. An industrial transformation plan requires actions in all these domains, coupled with a finance strategy and plans to realise the required infrastructure.

Call for action

1. Set up a cross-border CO2 transport and storage infrastructure working group: This working group should facilitate ongoing knowledge exchange and joint planning between the relevant authorities, should develop a common vision, policy, and rulebook on the roll-out of cross-border CO2 infrastructure, and should align authorisation procedures in close consultation with private and civil society stakeholders. Ensure that the infrastructure is open access and prevent monopolies. The infrastructure should be future proof, multimodal and multi-purpose, so that it can also be used for Carbon Dioxide Removal (CDR) solutions to achieve negative emissions.

2. Take a leading role in defining the framework conditions for CCS: Survey the full scope of CCS-needs in the integrated ARRRA industrial cluster in the short, medium, and long-term, taking into account the risks for stranded assets and lock-ins.

3. Develop a common legal framework: Ratify the London Protocol and negotiate international agreements between the Netherlands, Belgium, and Germany for the transport of CO2 across borders in line with the London Protocol. Develop and exchange transparent, robust, and effective liability regimes for the allocation of leakage risks for CO2 transport and long-term storage facilities. Reflect this in coalition agreements and national climate plans, respecting existing national policies and CCS-conditions.

4. Provide the necessary funding framework: Set up a joint funding mechanism to help organize financial instruments at the local, national, and EU-level to address CO2 infrastructure needs, blending public and private financing. This mechanism should involve clear conditions for receiving funding and include a cap and end date for subsidies. Create a mapping of capture, transport and storage solutions and their respective costs to facilitate the long-term planning of CCS as a mitigation intervention by companies. Define which sectors qualify for funding, keeping in mind the following principles:

• Prioritise direct emission reductions over CCS and ensure that CCS does not hinder the development or deployment of other forms of emission reductions including electrification. Ensure that funding for CCS does not hinder the phaseout of fossil fuels.

• Companies applying CCS should include it as part of a long-term plan to reduce greenhouse gas emissions.

• The use of the CCS should be prioritized in the industrial sector.

5. Acknowledge and standardise the multimodal and multi-purpose nature of CO2 transport and storage infrastructure, the deployment of new infrastructure, as well as the retrofitting of existing onshore and offshore infrastructure where this is opportune. Ensure that different modes of transport (pipelines, ships, barges, trains, trucks) are planned according to their specific merits and that infrastructure is developed to serve different purposes over time.

6. Ensure that infrastructure can be expanded to connect to other industrial clusters further inland (for example in Germany and France).

More information

www.bellona.org

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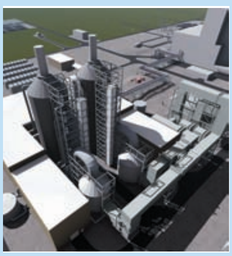

Front cover: ION Clean Energy conducted a 700 MW FEED study supported by U.S. DOE and conducted by ION, Sargent & Lundy, Koch Modular, and Siemens. The capture facility, including compression to pipeline specifications, included two 350 MW CO2 capture trains (pg. 2)

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Leaders - CCUS in the United States

Projects and policy

Capture and utilisation

Transport and storage

ION Clean Energy's CO2 capture solvent at the forefront of sustainable innovation

ION's focus has been to develop environmentally advantageous solvent technologies that have a high rate of carbon removal while significantly dropping the cost of CO2 capture. Most recently, ION has broadened its focus to include designing a solvent that can specifically excel in high O2 environments.

ION has been developing and improving its CO2 capture technology suite since 2008 and has risen to the forefront of innovation in the commercial post-combustion carbon capture space.

Market Dynamics

The current U.S. administration aims for a carbon neutral electricity grid by 2035 and the use of carbon capture to achieve these targets is now undisputable. While control of CO2 emissions has been largely focused on coal-fired power stations, there is increasing attention on other sectors of carbon emissions such as industrial and natural gas-fired emissions, as they are surpassing coal-fired emissions in the U.S. on an annual basis.

To this point, ION is amongst some of the most dynamic innovators in the CO2 capture space, rapidly understanding and responding to this market shift from coal-fired utilities to natural gas-fired power and industrial sources, which are increasingly becoming more attractive host sites for CCUS given the relatively young age of the facilities as well as the high-capacity factors.

Over the past few years, ION has proactively focused on developing a solvent that would be economic as well as environmentally advantageous in natural gas combined cycle (NGCC) environments. While ION's solvent technologies are highly desirable for many applications, they are especially well suited for NGCC and natural gas boilers because they are extremely stable in high O2 environments and have the ability to adapt and ramp with commercial dispatch of power stations.

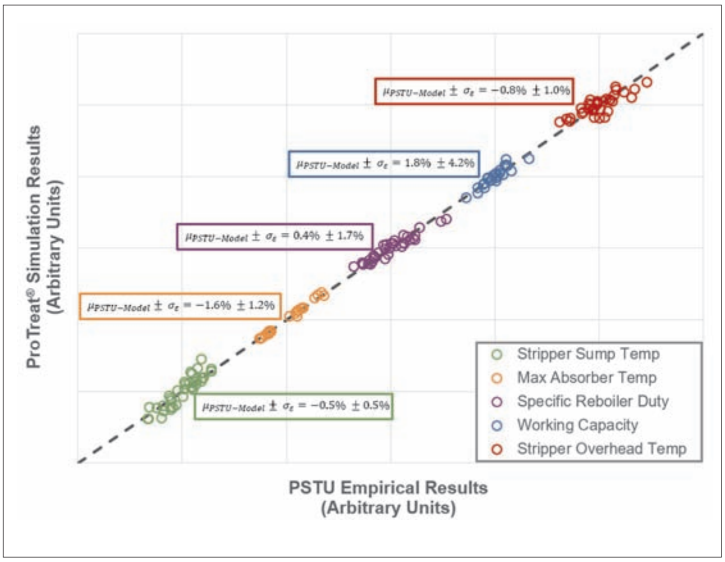

Figure 1 - Parity plot demonstrating excellent validation of ProTreat® process model versus empirical results at various operating conditions

In an environment where every tonne of CO2 captured is critical for capture economics, these key performance characteristics will drive CO2 emissions even lower for load-following facilities without impacting their dispatch rate. In addition to technical attributes, ION's technology also excels in overall CO2 capture economics with extremely competitive costs of capture at large scale.

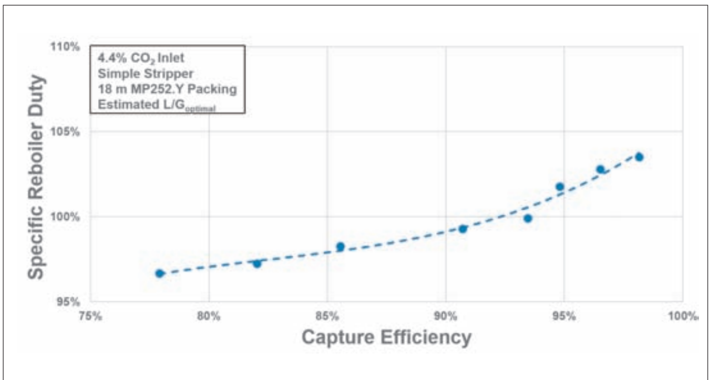

Figure 2 - Demonstrates 2-3% extra specific energy is required to raise the capture efficiency from 95 to 98%

ION's solvent technology has been successfully demonstrated at increasing capture plant size and on varied flue gas types totaling over 15,000 hours of testing, with support from U.S. Department of Energy, National Energy Technology Laboratory. Throughout these demonstrations, ION solvents met or exceeded per-

NCCC's PSTU in the foreground and the new gas-fired boiler in the background in Alabama. ION demonstrated capture rates in excess of 98% CO2. Photo provided as a courtesy from NCCC formance expectations, and ION's latest test campaign at the National Carbon Capture Center's (NCCC) Pilot Solvent Test Unit (PSTU) was no exception.

Through the NCCC testing, ION successfully demonstrated capture rates in excess of 98% CO_2 from NGCC flue gas conditions (4.4% CO_2), with very low extra specific energy consumption, negligible solvent degradation, and emissions levels below 1 ppm. Over the entire 4,000-hour campaign, no solvent make-up or reclamation was required, confirming the environmentally advantageous nature of the technology, and ION's ability to lower operational costs at commercial scale.

Key Differentiators

A key focus of the parametric testing performed during the NCCC campaign was further validation of ION's proprietary module within ProTreat®, a process simulation tool that ION uses to produce bespoke capture facility designs for individual customers. Figure 1 shows the extremely high degree of concurrence between the process simulation and the empirical results generated over a wide range of operating conditions.

Given these and similar results over a wide range of flue gas compositions, ION and its partners have developed significant confidence in the ability to design capture facilities for large commercial operations.

Another differentiating factor of ION's technology is its ability to achieve high CO_2 capture rates at a very low increase in energy consumption (Figure 2). Over 1,500 hours of steady-state testing at NGCC conditions, ION demonstrated stable operations of 95% capture without any setpoint changes (Figure 3).

Additionally, ION achieved 99% capture including dynamic operations testing where the process reached steady state immediately upon flue gas introduction (Figure 4). These performance characteristics are critical for deployment at commercial power stations that are regularly ramped up/down based on market demand.

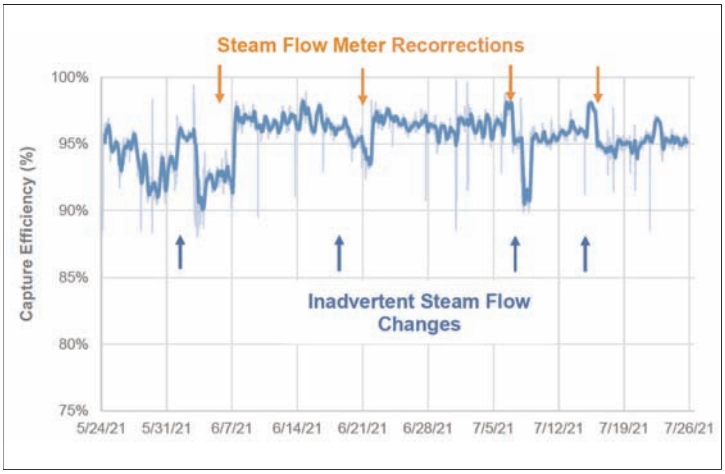

Figure 3 - Over 1,500 hours of steady-state testing on NGCC flue gas conditions, ION's technology consistently showed stable operations achieving ~95% capture, where only exceptions were due to steam flow meter recorrections that were resolved as required

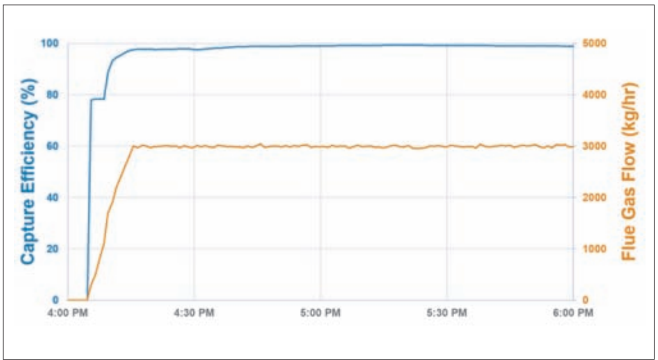

Figure 4 -Dynamic operations test showed that from warm start, ION's solvent was able to reach 99% capture efficiency immediately upon flue gas introduction into the system, a critical market need in the world of commercial dispatch (the perceived delayed response is a result of measuring equipment response time)

In summary, ION believes these exceptional solvent performance characteristics will enable wide-scale deployment in decarbonizing the power and industrial sectors. Point source capture technologies with the ability to achieve high CO_2 capture rates, such as ION's, will continue to be a focus for wide-scale deployment as their economics and overall emissions reduction impact is substantially better than other decarbonization approaches such as direct air capture.

Looking to the Future

In an effort to accelerate deployment, ION continues to build consortiums of subject matter experts, e.g., engineering, construction, financing, utilization, and sequestration, as ION recognizes that the development of CCUS projects is likely to be complex and time is of the essence to make the most meaningful impact towards climate targets.

With the support of these partnerships, ION has completed two Front-End Engineering & Design (FEED) studies with Nebraska Public Power District to understand the design and costing of both a 300 MW and 700 MW retrofit CO_2 capture system onto their largest coal-fired power station, Gerald Gentleman Station in Sutherland, NE, USA.

The cover image to this issue depicts results from the 700 MW FEED study supported by U.S. DOE and conducted by ION, Sargent & Lundy, Koch Modular, and Siemens. The capture facility, including compression to pipeline specifications, includes two identical 350 MW CO_2 capture trains fully integrated into Gerald Gentleman Station, Unit 2.

The costing evaluation from the FEED resulted in impressive capture economics of \$35 per tonne of CO_2 captured.

Most recently, ION was selected by Calpine, America's largest generator of electricity from natural gas and geothermal resources, to complete a FEED study for Delta Energy Center, an 857 MW NGCC power station in Pittsburg, CA, USA. This project was subsequently awarded U.S. DOE funding and the FEED is expected to be completed in early 2023.

ION continues to drive towards its mission of capturing 1 billion tonnes of CO_2 by 2050 and is currently evaluating commercial opportunities that align with its technical capabilities, where there are strong financial incentives to reduce carbon emissions and where plant owners are fully committed to decarbonize with the best available technology.

More information

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NETL CCS report sees major job growth potential

A buildout of America's evolving CCS technologies offer noteworthy job growth potential with no significant supply chain risks, according to an NETL-authored report released by Secretary of Energy Jennifer M. Granholm.

The report, titled "Carbon Capture, Transport and Storage, Supply Chain Review," was conducted by NETL to assess potential supply chain bottlenecks to CCS implementation. NETL researchers conducted a supply chain risk analysis by comparing raw material estimates against domestic and global production to search for opportunities and vulnerabilities.

The report's authors found that a major reason for the low risk to the supply chain is because CCS infrastructure can be supplied by components made in the U.S.

The report also concluded that a CCS industry build-out could result in creation of up to 1.8 million jobs largely in the Midwest, Appalachian and Southern States through construction, operation and maintenance of capture, pipeline and storage sites.

According to the report, "There are also numerous opportunities for research and innovation in the CCS space, including leveraging the captured carbon for additional revenue streams such as applications in liquid fuels, chemicals and plastics, and novel materials."

The U.S. is committed to achieving a 50-52 % reduction from 2005 levels in economy-wide net greenhouse gas pollution in 2030, creating a net-zero carbon emission power sector by 2035, and achieving net zero emissions economy-wide no later than 2050.

The United States is currently a global leader in carbon capture technology and projects. As of February 2021, the United States had 13 commercial-scale carbon capture facilities, half of worldwide capacity. Many technologies are available to support the eventual 2050 CCS buildout including solvent-based capture CO2 drying, steel pipeline transportation, and geologic storage.

The reports are part of a series of studies produced in response to Executive Order 14017 "America's Supply Chains," which directs the Secretary of Energy to submit a report on supply chains for the energy sector industrial base. The Executive Order aims to build more secure and diverse U.S. supply chains – facilitating greater domestic production, a range of supply, built-in redundancies, adequate stockpiles, safe and secure digital networks, and a world-class American manufacturing base and workforce.

Key Findings & Opportunities

CCS provides a near-term pathway to rapidly reduce the impacts of existing emissions-intensive infrastructure and processes, while zero-carbon alternative solutions (such as hydrogen power generation) mature.

CCS also carries low technological risk because the required infrastructure is already in widespread commercial use (the United States is a world leader in carbon capture technologies), as well as low supply chain risk, due to the required infrastructure relying on large amounts of common and readily available raw materials (such as steel, cement, and ammonia).

Opportunities

CCS presents considerable opportunities in the following areas:

• Growth in the American Economy and Workforce: The growth of the CCS market is expected to produce between 390,000 and 1.8 million good-paying union jobs in various industries, especially in fossil energy communities most affected by the transition to a net-zero economy.

These employment opportunities will include the fields of raw materials (steel and cement, among others); engineering and design (the design of carbon capture, pipelines, injection sites, and supervisory control and data acquisition), construction (retrofitting, pipeline development, injection sites, and trucking), and operation and maintenance (O&M). These employment opportunities will follow the value chain of CCS, largely in the Midwest, Appalachian, and Southern states for the construction and subsequent O&M of capture sites, pipeline sites, and storage sites.

• Development of Diverse Supply Chains: The United States remains a leader in CCS development and deployment, and CCS infrastructure can be supplied in large part by American-made components. There are also opportunities to develop diversified supply chains with U.S. allies and partners that play to the strengths of each country.

• Technological Innovations for Converting Captured CO2 into Valuable Products: There are several opportunities for research and innovation in the CCS space, such as leveraging captured CO2 for use in applications like liquid fuels, chemicals and plastics, and novel materials. This would add new revenue streams to the industry alongside existing 45Q tax credit incentives and restoring depleted oil and gas reservoirs for reuse.

Long-Term Use

The near-term uses of CCS infrastructure may be retired as zero-carbon alternatives are commercialized, but there are several long-term use-cases:

• Continued CCS: There may be future conditions where zero-carbon alternatives are technically impossible or impractical. A built-out CCS network would allow infrastructure and processes to continue while addressing emissions.

• Direct Air Capture and Storage (DACS): CCS infrastructure also enables a long-term solution for continuing to remove CO2 from the atmosphere. DACS will be easier to implement regionally if the CCS infrastructure is available for use.

• Other Pipeline Uses: Researchers are investigating opportunities to leverage CO2 pipelines to transport other fluids, including hydrogen. Additional research is required in the areas of hydrogen compression technology and large-scale pipeline conversion, especially when converting pipelines originally intended to transport CO2.

Policy Next Steps

To advance the growth and development of the CCS industry, policy recommendations and next steps are included in the report, "America's Strategy to Secure the Supply Chain for a Robust Clean Energy Transition". A high-level summary is included below.

• Accelerate early development of CCS infrastructure. Provide RD&D to address technical challenges and costs of carbon capture, storage, and transport.

• Incentivize CCS market growth. Incentivize CO2 infrastructure projects (pipelines and storage), including providing investment and permitting support.

• Incentivize domestic manufacturing of materials and equipment for the midstream by prioritizing and/or requiring materials to be produced domestically.

More information

www.energy.gov/policy/office-policy

netl.doe.gov

GE-led Carbon Capture Technology Integration Project receives funding

GE Gas Power's FEED study "Retrofittable Advanced Combined Cycle Integration for Flexible Decarbonized Generation" will receive over $5.5m in funding from the U.S. Department of Energy.

The funding is focused on CCUS for power generation applications with a goal of commercial deployment by 2030. GE Gas Power will work with Southern Company, Linde, BASF, and Kiewit to develop a detailed plan for integrating carbon capture technologies with a natural gas combined cycle plant to capture approximately 95 percent of carbon dioxide emissions generated.

GE and partners will conduct a FEED study on Alabama Power's James M. Barry Plant

The FEED study will be focused on Southern Company subsidiary Alabama Power's James M. Barry Electric Generating Plant, located in Bucks, Alabama, which is powered by two GE 7F.04 gas turbines, part of GE's 7F gas turbine fleet, the largest gas turbine fleet in North America. GE will research advanced technology and control concepts to integrate the combined cycle power plant with Linde's Gen 2 carbon capture solution based on BASF OASE® blue technology. The project will also include gas and steam turbine equipment enhancements to improve the carbon capture process, with a goal of reducing the impact of the carbon capture process on the power plant's output, performance, and equipment cost.

With the goals of reliability, load flexibility, and significant reduction in carbon emissions, this retrofittable solution can be applicable to other power plant sites and serve as a template for lowering carbon emissions across more than 1,500 F-Class gas turbines worldwide, which currently deliver up to approximately 280 gigawatts of electricity daily.

Due to the complexity of the integration of CCUS technologies into an existing natural gas power plant, this FEED study – a detailed blueprint and operating business guide - will represent a pre-requisite for future construction projects and it can accelerate commercial deployment of other projects. With proven expertise in natural gas combined cycle plant engineering, operability, and plant integration, GE will lead the full-scale integration of the study with the goal of preserving the attributes of a natural gas combined cycle plants that are critical to enable a renewable energy-based future including dispatchability, lower carbon intensity, high flexibility and reliability, and low capital cost.

More information

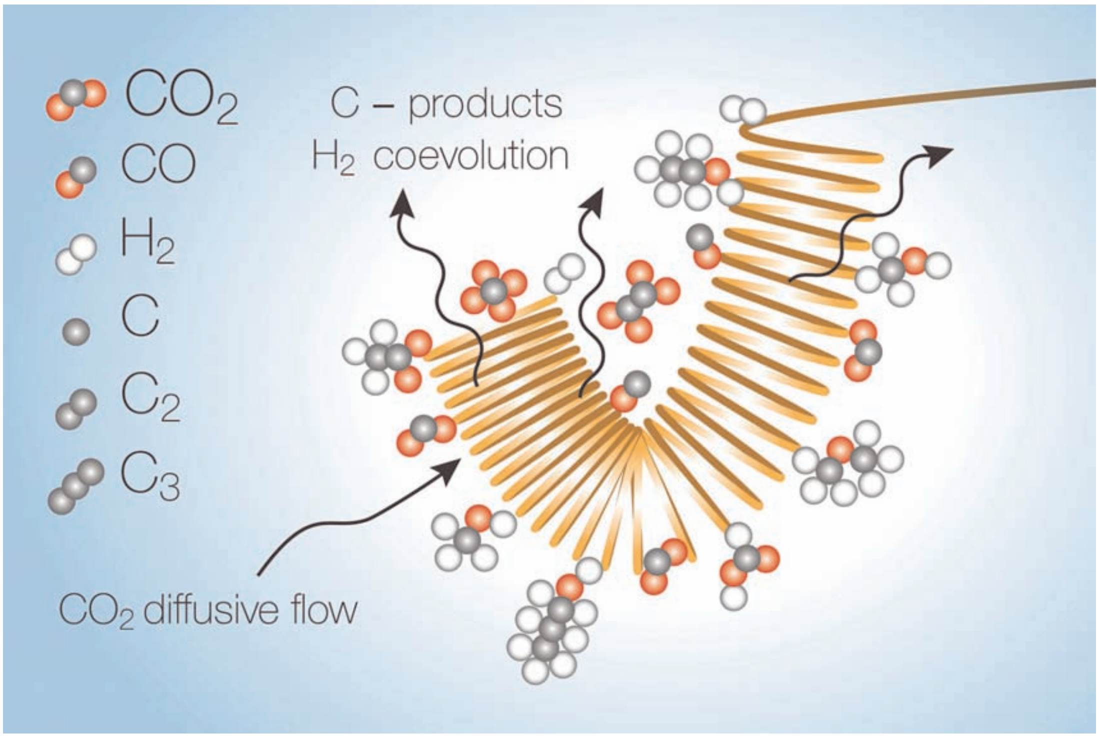
www.ge.com/gas-power

Overcoming a bottleneck in carbon dioxide conversion

MIT study reveals why some attempts to convert the greenhouse gas into fuel have failed, and offers possible solutions.

If researchers could find a way to chemically convert carbon dioxide into fuels or other products, they might make a major dent in greenhouse gas emissions. But many such processes that have seemed promising in the lab haven't performed as expected in scaled-up formats that would be suitable for use with a power plant or other emissions sources.

Now, researchers at MIT have identified, quantified, and modeled a major reason for poor performance in such conversion systems. The culprit turns out to be a local depletion of the carbon dioxide gas right next to the electrodes being used to catalyze the conversion. The problem can be alleviated, the team found, by simply pulsing the current off and on at specific intervals, allowing time for the gas to build back up to the needed levels next to the electrode.



MIT researchers have identified a problem that tends to limit chemical processes for turning carbon dioxide into fuel or other useful chemicals — and ways of addressing that problem.
Image: Courtesy of the Varanasi Lab

The findings, which could spur progress on developing a variety of materials and designs for electrochemical carbon dioxide conversion systems, were published today in the journal Langmuir, in a paper by MIT postdoc Álvaro Moreno Soto, graduate student Jack Lake, and professor of mechanical engineering Kripa Varanasi.

"Carbon dioxide mitigation is, I think, one of the important challenges of our time," Varanasi says. While much of the research in the area has focused on carbon capture and sequestration, in which the gas is pumped into some kind of deep underground reservoir or converted to an inert solid such as limestone, another promising avenue has been converting the gas into other carbon compounds such as methane or ethanol, to be used as fuel, or ethylene, which serves as a precursor to useful polymers.

There are several ways to do such conversions, including electrochemical, thermocatalytic, photothermal, or photochemical processes. "Each of these has problems or challenges," Varanasi says. The thermal processes require very high temperature, and they don't produce very high-value chemical products, which is a challenge with the light-activated processes as well, he says. "Efficiency is always at play, always an issue."

The team has focused on the electrochemical approaches, with a goal of getting "higher-C products" — compounds that contain more carbon atoms and tend to be higher-value fuels because of their energy per weight or volume. In these reactions, the biggest challenge has been curbing competing reactions that can take place at the same time, especially the splitting of water molecules into oxygen and hydrogen.

The reactions take place as a stream of liquid electrolyte with the carbon dioxide dissolved in it passes over a metal catalytic surface that is electrically charged. But as the carbon dioxide gets converted, it leaves behind a region in the electrolyte stream where it has essentially been used up, and so the reaction within this depleted zone turns toward water splitting instead. This unwanted reaction uses up energy and greatly reduces the overall efficiency of the conversion process, the researchers found.

"There's a number of groups working on this, and a number of catalysts that are out there," Varanasi says. "In all of these, I think the hydrogen co-evolution becomes a bottleneck."

One way of counteracting this depletion, they found, can be achieved by a pulsed system — a cycle of simply turning off the voltage, stopping the reaction and giving the carbon dioxide time to spread back into the depleted zone and reach usable levels again, and then resuming the reaction.

Often, the researchers say, groups have found promising catalyst materials but haven't run their lab tests long enough to observe these depletion effects, and thus have been frustrated in trying to scale up their systems. Furthermore, the concentration of carbon dioxide next to the catalyst dictates the products that are made. Hence, depletion can also change the mix of products that are produced and can make the process unreliable.

"If you want to be able to make a system that works at industrial scale, you need to be able to run things over a long period of time," Varanasi says, "and you need to not have these kinds of effects that reduce the efficiency or reliability of the process."

The team studied three different catalyst materials, including copper, and "we really focused on making sure that we understood and can quantify the depletion effects," Lake says. In the process they were able to develop a simple and reliable way of monitoring the efficiency of the conversion process as it happens, by measuring the changing pH levels, a measure of acidity, in the system's electrolyte.

In their tests, they used more sophisticated analytical tools to characterize reaction products, including gas chromatography for analysis of the gaseous products, and nuclear magnetic resonance characterization for the system's liquid products. But their analysis showed that the simple pH measurement of the electrolyte next to the electrode during operation could provide a sufficient measure of the efficiency of the reaction as it progressed.

This ability to easily monitor the reaction in real-time could ultimately lead to a system optimized by machine-learning methods, controlling the production rate of the desired compounds through continuous feedback, Moreno Soto says.

Now that the process is understood and quantified, other approaches to mitigating the carbon dioxide depletion might be developed, the researchers say, and could easily be tested using their methods.

This work shows, Lake says, that "no matter what your catalyst material is" in such an electrocatalytic system, "you'll be affected by this problem." And now, by using the model they developed, it's possible to determine exactly what kind of time window needs to be evaluated to get an accurate sense of the material's overall efficiency and what kind of system operations could maximize its effectiveness.

The research was supported by Shell, through the MIT Energy Initiative.

More information

varanasi.mit.edu

pubs.acs.org

Artificial leaf captures 100x more CO2

Engineers at the University of Illinois Chicago have built a cost-effective artificial leaf that can capture carbon dioxide at rates 100 times better than current systems for less power than a lightbulb.

Unlike other carbon capture systems, which work in labs with pure carbon dioxide from pressurized tanks, this artificial leaf works in the real world. It captures carbon dioxide from more diluted sources, like air and flue gas produced by coal-fired power plants, and releases it for use as fuel and other materials.

"Our artificial leaf system can be deployed outside the lab, where it has the potential to play a significant role in reducing greenhouse gases in the atmosphere thanks to its high rate of carbon capture, relatively low cost and moderate energy, even when compared to the best lab-based systems," said Meenesh Singh, assistant professor of chemical engineering in the UIC College of Engineering and corresponding author on the paper.

Using a previously reported theoretical concept, the scientists modified a standard artificial leaf system with inexpensive materials to include a water gradient - a dry side and a wet side - across an electrically charged membrane.

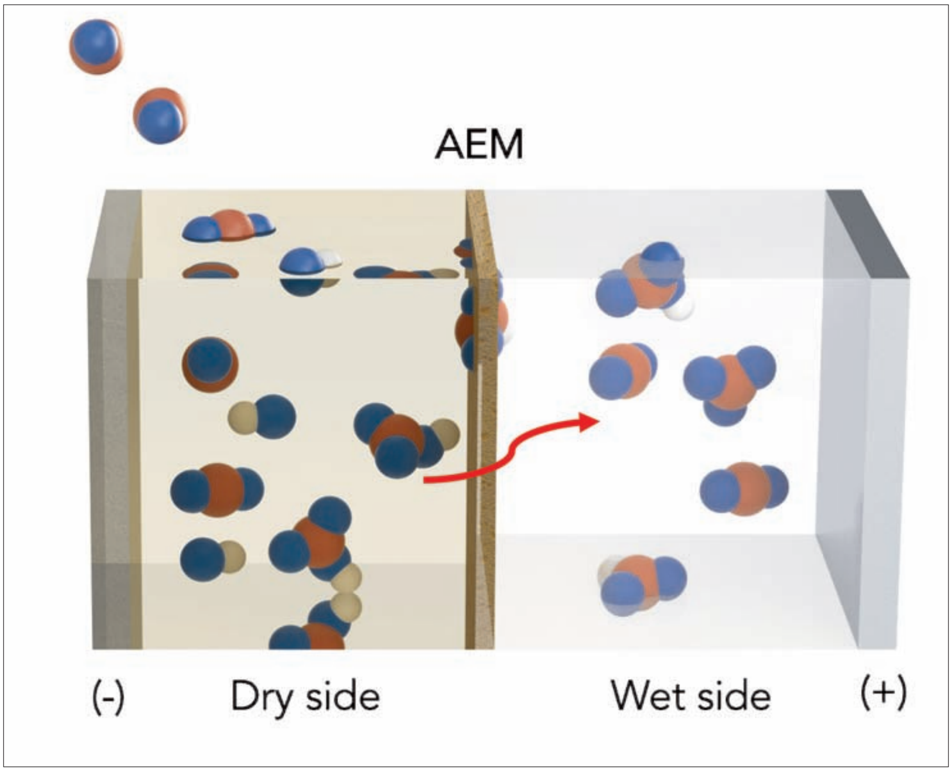


Illustration of a carbon capture process designed by UIC College of Engineering scientists. Carbon dioxide from air or flue gas is absorbed by a dry organic solution to form bicarbonate ions, which migrate across a membrane and are dissolved in a liquid solution to concentrated CO2. Carbon atoms are shown in red, oxygen atoms are shown in blue and hydrogen atoms are shown in white. (Credit: Aditya Prajapati/UIC)

On the dry side, an organic solvent attaches to available carbon dioxide to produce a concentration of bicarbonate, or baking soda, on the membrane. As bicarbonate builds, these negatively charged ions are pulled across the membrane toward a positively charged electrode in a water-based solution on the membrane's wet side. The liquid solution dissolves the bicarbonate back into carbon dioxide, so it can be released and harnessed for fuel or other uses.

The electrical charge is used to speed up the transfer of bicarbonate across the membrane.

When they tested the system, which is small enough to fit in a backpack, the UIC scientists found that it had a very high flux - a rate of carbon capture compared with the surface area required for the reactions - of 3.3 millimoles per hour per 4 square centimeters. This is more than 100 times better than other systems, even though only a moderate amount of electricity (0.4 KJ/hour) was needed to power the reaction, less than the amount of energy needed for a 1 watt LED lightbulb. They calculated the cost at $145 per ton of carbon dioxide, which is in line with recommendations from the Department of Energy that cost should not exceed around $200 per ton.

"It's particularly exciting that this real-world application of an electrodialysis-driven artificial leaf had a high flux with a small, modular surface area," Singh said.

"This means that it has the potential to be stackable, the modules can be added or subtracted to more perfectly fit the need and affordably used in homes and classrooms, not just among profitable industrial organizations. A small module of the size of a home humidifier can remove greater than 1 kilogram of CO2 per day, and four industrial electrodialysis stacks can capture greater than 300 kilograms of CO2 per hour from flue gas."

The UIC scientists report on the design of their artificial leaf and the results of their experiments in "Migration-assisted, moisture gradient process for ultrafast, continuous CO2 capture from dilute sources at ambient conditions," which is published in Energy & Environmental Science.

The research is funded by a grant (DE-SC-0022321) from the U.S. Department of Energy. A patent application titled "Artificial photosynthetic systems for integrated carbon capture and conversion" has been filed by the Office of Technology Management at UIC.

More information

www.uic.edu

pubs.rsc.org

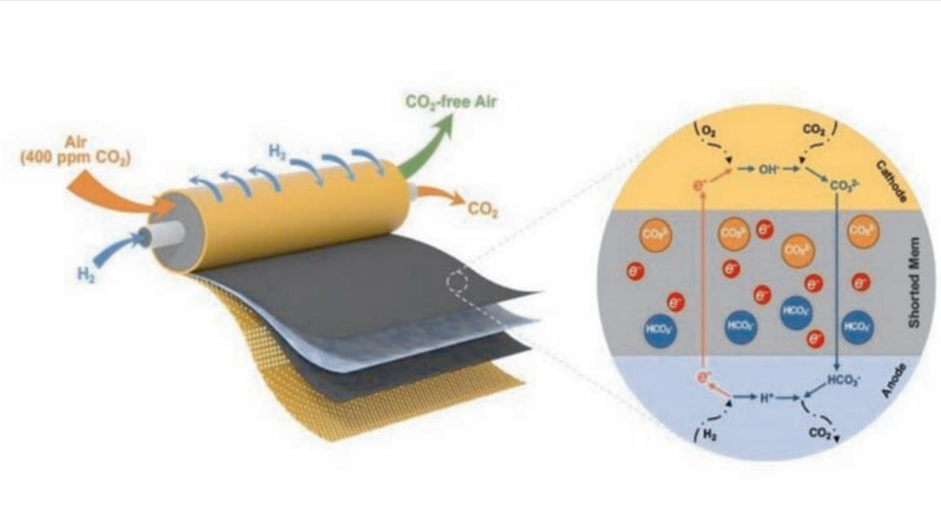
Method to capture 99% of CO2 from air

University of Delaware engineers have demonstrated a way to effectively capture 99% of carbon dioxide from air using a novel electrochemical system powered by hydrogen.

It is a significant advance for carbon dioxide capture and could bring more environmentally friendly fuel cells closer to market. The research team, led by University of Delaware Professor Yushan Yan, published their results in Nature Energy.

Fuel cells work by converting fuel chemical energy directly into electricity. They can be used in transportation for things like hybrid or zero-emission vehicles.

Yan, Henry Belin du Pont Chair of Chemical and Biomolecular Engineering, has been working for some time to improve hydroxide exchange membrane (HEM) fuel cells, an economical and environmentally friendly alternative to traditional acid-based fuel cells used today.



The UD research team’s spiral wound module takes in hydrogen and air through two separate inlets (shown on the left) and emits carbon dioxide and carbon dioxide-free air (shown on the right) after passing through two large-area, catalyst-coated shorted membranes. The inset image on the right shows, in part, how the molecules move within the short-circuited membrane

But HEM fuel cells have a shortcoming that has kept them off the road — they are extremely sensitive to carbon dioxide in the air. Essentially, the carbon dioxide makes it hard for a HEM fuel cell to breathe.

This defect quickly reduces the fuel cell’s performance and efficiency by up to 20%, rendering the fuel cell no better than a gasoline engine. Yan’s research group has been searching for a workaround for this carbon dioxide conundrum for over 15 years.

A few years back, the researchers realized this disadvantage might actually be a solution — for carbon dioxide removal.

“Once we dug into the mechanism, we realized the fuel cells were capturing just about every bit of carbon dioxide that came into them, and they were really good at separating it to the other side,” said Brian Setzler, assistant professor for research in chemical and biomolecular engineering and paper co-author.

While this isn’t good for the fuel cell, the team knew if they could leverage this built-in “self-purging” process in a separate device upstream from the fuel cell stack, they could turn it into a carbon dioxide separator.

“It turns out our approach is very effective. We can capture 99% of the carbon dioxide out of the air in one pass if we have the right design and right configuration,” said Yan.

They found a way to embed the power source for the electrochemical technology inside the separation membrane. The approach involved internally short-circuiting the device.

"It's risky, but we managed to control this short-circuited fuel cell by hydrogen. And by using this internal electrically shorted membrane, we were able to get rid of the bulky components, such as bipolar plates, current collectors or any electrical wires typically found in a fuel cell stack,” said Lin Shi, a doctoral candidate in the Yan group and the paper’s lead author.

Now, the research team had an electrochemical device that looked like a normal filtration membrane made for separating out gases, but with the capability to continuously pick up minute amounts of carbon dioxide from the air like a more complicated electrochemical system.

In effect, embedding the device’s wires inside the membrane created a short-cut that made it easier for the carbon dioxide particles to travel from one side to the other. It also enabled the team to construct a compact, spiral module with a large surface area in a small volume. In other words, they now have a smaller package capable of filtering greater quantities of air at a time, making it both effective and cost-effective for fuel cell applications. Meanwhile, fewer components mean less cost and, more importantly, provided a way to easily scale up for the market.

The research team’s results showed that an electrochemical cell measuring 2 inches by 2 inches could continuously remove about 99% of the carbon dioxide found in air flowing at a rate of approximately two liters per minute. An early prototype spiral device about the size of a 12-ounce soda can is capable of filtering 10 liters of air per minute and scrubbing out 98% of the carbon dioxide, the researchers said.

More information

www.udel.edu

Carbon and Hydrogen Hubs Atlas for US Decarbonization

The Great Plains Institute Atlas identifies areas that offer the capacity to help expand and accelerate emissions reductions and carbon removal through focused coordination, deployment, and policy. From a blog by Dane McFarlane.

The development of carbon and hydrogen hubs is a crucial strategy for achieving economies of scale in the deployment of decarbonization technologies and associated infrastructure. Hubs are an opportunity to meet midcentury climate goals, retain and create high-wage energy, industrial, and manufacturing jobs, and provide environmental and economic benefits to local communities.

A few key takeaways from the atlas are:

• Carbon management and zero-carbon hydrogen are needed at scale to achieve our climate goals.

• Carbon and hydrogen hubs can focus planning, coordination, policy, and investment regionally to bring these required solutions to scale.

• Supportive federal and state policy is critical to scale up carbon management and zero-carbon hydrogen technologies and associated infrastructure.

Carbon and hydrogen hub opportunities span the United States

GPI has identified 14 hubs across eight regions of the United States. Carbon and hydrogen hub development opportunities are well distributed across the country, and the regions designated as potential hubs through this analysis are by no means exclusive. Since industrial production and emissions occur throughout the country, carbon capture, hydrogen production, and direct air capture facilities will need to be deployed wherever beneficial and feasible.

Why the focus on carbon and hydrogen together? According to global climate modeling scenarios by the United Nations Intergovernmental Panel on Climate Change (IPCC) and the International Energy Agency (IEA), we must reach net-zero emissions by midcentury to keep the average global temperature rise to 1.5°C to 2°C above preindustrial levels. Carbon management and hydrogen will play a vital role in meeting these emissions reduction goals in the United States and globally, particularly in hard-to-decarbonize sectors like industry and manufacturing.

IPCC and IEA modeling makes clear that large-scale carbon management is needed to meet midcentury global temperature targets, including through carbon capture retrofits of industrial facilities and power plants, and direct air capture facilities. In the latter half of this century, nearly all global modeling scenarios require economywide deployment of negative emissions technologies, such as direct air capture and bioenergy with carbon capture, to achieve net atmospheric carbon removal. These carbon management and storage technologies account for up to 12 gigatons of negative emissions annually by 2050, offsetting about 50% of midcentury annual global emissions, in the IPCC's illustrative 1.5°C scenarios.

Greenhouse gas emissions from industrial energy use and production processes are hard to decarbonize through traditional renewable energy, electrification, and energy efficiency options. Many industrial products cannot be made without fuels that provide high-intensity heat or energy. Moreover, even with the decarbonization of energy inputs, many industries still release large volumes of carbon emissions as an inherent part of the chemistry of their key industrial processes, such as in steel, cement, and chemicals production.

Process emissions make up a significant share of total emissions in many sectors, and have extensive associated fuel use. The entire industrial sector represents about 23 percent of the United States' total of 6.5 gigatons of annual greenhouse gas emissions.

For those carbon-intensive industrial and transport applications where carbon capture is not feasible, hydrogen can act as a versatile energy carrier that, when produced with zero-carbon energy sources, can enable deep decarbonization. These applications include the use of hydrogen as an alternative to high-energy industrial fuels and blending hydrogen into existing natural gas systems. The IEA estimates that the production and use of zero-carbon hydrogen will be responsible for 13 percent of total annual emissions reductions by 2050.

In some key sectors, the technology and processes of carbon management and hydrogen production remain nascent. Economywide and at-scale commercial demonstration of these technologies and their associated infrastructure is thus essential to enabling widespread deployment sufficient to meet our climate obligations.

Carbon and hydrogen hubs as launch points for early investment

The co-located energy production, industrial and manufacturing capacity, and geologic storage resources of a hub region offer the potential to create economies of scale from investments in shared infrastructure. A hub approach also affords the opportunity to build an integrated value chain and marketplace for producers and consumers of hydrogen and captured carbon emissions.

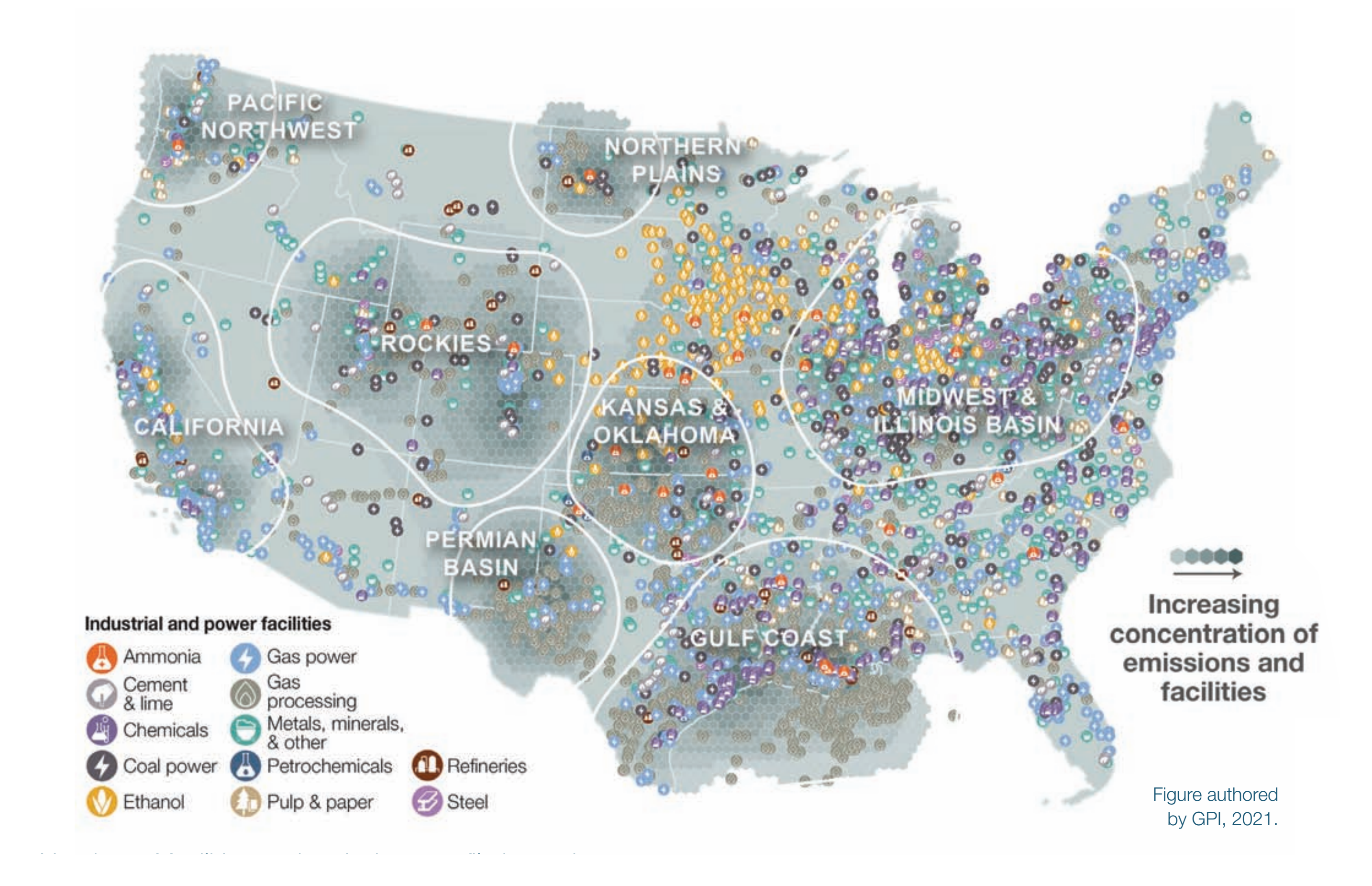
GPI identified potential regional carbon and hydrogen hubs based on the following criteria:

• High concentration of large industrial facilities with significant emissions

• High quantities of fossil fuel use for on-site industrial energy production

• Presence of facilities qualifying for the federal 45Q tax credit for carbon capture retrofit, as well identified feasible near- and medium-term capture opportunities

• Current reported production of hydrogen and ammonia



Regional Opportunities for Hub Development - The atlas identifies eight regions where concentrated industrial activity coincides with opportunities for permanent geologic carbon storage

• Large saline and fossil geologic formations for permanent carbon dioxide (CO2) storage

• Existing multimodal commodity distribution infrastructure, such as freight railroads, barge waterways and ports, and interstate highway routes for freight trucking

• Existing conventional energy distribution infrastructure for hydrogen blending and established rights-of-way for low-impact CO2 and hydrogen transport infrastructure

Carbon capture and storage opportunities

GPI identified 542 facilities as prime candidates for carbon capture retrofit over the next 10 to 15 years. These facilities represent a launching point for investment in carbon capture and storage, where the economics of capture appear favorable for near-term investment. Additional 45Q-eligible facilities that are expected to continue operating and provide employment through midcentury should also be considered opportunities for retrofit after this initial 10-15 year period.

Near-term candidates for carbon capture deployment are largely clustered in the regional hubs identified in this atlas. Their geographic concentration further optimizes the potential project economics of these targets for carbon capture retrofit by enabling coordination between facilities and subsequent economies of scale in developing shared transport and storage infrastructure.

According to the US DOE, the US has vast physical capacity to permanently store thousands of years of US emissions at current levels in secure saline geologic formations. However, local site characterization will be needed to identify suitable CO2 injection sites for project development. Site access and cost of injection also factor into geologic storage access for a given project.

Locating carbon capture and direct air capture in areas with existing saline storage capacity can minimize transport costs, land use, and local impact. However, not all potential carbon capture and direct air capture must be co-located to saline formations. Shared transport infrastructure can achieve beneficial economies of scale, enabling investment break-even for industrial capture retrofit and direct air capture deployment, even when longer distance transport to a final storage site is required.

Federal policy is increasingly favorable for carbon and hydrogen hub development. Congress has recently enacted groundbreaking bipartisan legislation, including reform and expansion of the 45Q tax credit in 2018 to incentivize carbon capture, direct air capture, and carbon utilization projects, as well as passage of the infrastructure bill last year. The infrastructure bill provides over $20 billion in funding to demonstrate carbon management and hydrogen technologies at scale, build out transport and storage infrastructure, and develop regional hydrogen and direct air capture hubs.

More information

Read the full blog post and download the report for free at:

betterenergy.org

Engineered bacteria convert captured CO2 into chemicals

Researchers led by Northwestern University and LanzaTech have harnessed bacteria to break down waste carbon dioxide to make valuable industrial chemicals.

In a new pilot study, the researchers selected, engineered and optimized a bacteria strain and then successfully demonstrated its ability to convert CO2 into acetone and isopropanol (IPA).

Not only does this new gas fermentation process remove greenhouse gases from the atmosphere, it also avoids using fossil fuels, which are typically needed to generate acetone and IPA. After performing life-cycle analysis, the team found the carbon-negative platform could reduce greenhouse gas emissions by 160% as compared to conventional processes, if widely adopted.

The study, "Carbon-negative, scaled-up production of acetone and isopropanol by gas fermentation," was published in the journal Nature Biotechnology.

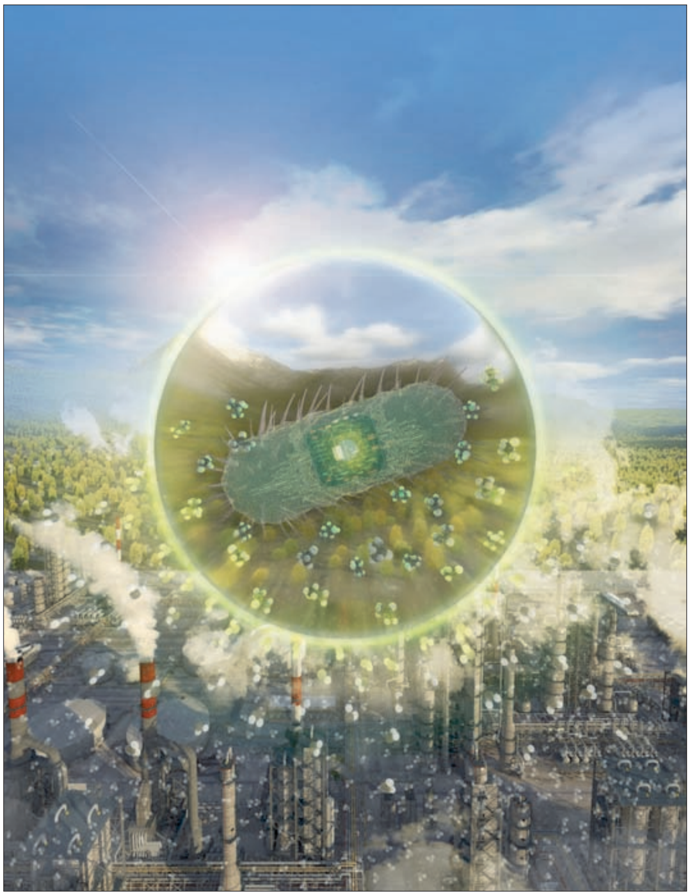
"The accelerating climate crisis, combined with rapid population growth, pose some of the most urgent challenges to humankind, all linked to the unabated release and accumulation of CO2 across the entire biosphere," said Northwestern's Michael Jewett, co-senior author of the study. "By harnessing our capacity to partner with biology to make what is needed, where and when it is needed, on a sustainable and renewable basis, we can begin to take advantage of the available CO2 to transform the bioeconomy."

Jewett is the Walter P. Murphy Professor of Chemical and Biological Engineering at Northwestern's McCormick School of Engineering and director of the Center for Synthetic Biology. He co-led the study with Michael Koepke and Ching Leang, both researchers at LanzaTech.

Necessary industrial bulk and platform chemicals, acetone and IPA are found nearly everywhere, with a combined global market topping $10 billion. Widely used as a disinfectant and antiseptic, IPA is the basis for one of the two World Health Organization-recommended sanitizer formulas, which are highly effective in killing the SARS-CoV-2 virus. And acetone is a solvent for many plastics and synthetic fibers, thinning polyester resin, cleaning tools and nail polish remover.

While these chemicals are incredibly useful, they are generated from fossil resources, leading to climate-warming CO2 emissions.

To manufacture these chemicals more sustainably, the researchers developed a new gas fermentation process. They started with Clostridium autoethanogenum, an anaerobic bacterium engineered at LanzaTech. Then, the researchers used synthetic biology tools to reprogram the bacterium to ferment CO2 to make acetone and IPA.



Engineered bacteria can produce valuable chemicals from waste CO2. Image: Justin Muir

"These innovations, led by cell-free strategies that guided both strain engineering and optimization of pathway enzymes, accelerated time to production by more than a year," Jewett said.

The Northwestern and LanzaTech teams believe the developed strains and fermentation process will translate to industrial scale. The approach also could potentially be applied to create streamlined processes for generating other valuable chemicals.

"This discovery is a major step forward in avoiding a climate catastrophe," said Jennifer Holmgren, LanzaTech CEO. "Today, most of our commodity chemicals are derived exclusively from new fossil resources such as oil, natural gas or coal. Acetone and IPA are two examples with a combined global market of $10 billion. The acetone and IPA pathways developed will accelerate the development of other new products by closing the carbon cycle for their use in multiple industries."

More information

www.northwestern.edu

www.nature.com

Catalyst turns carbon dioxide into gasoline 1,000 times more efficiently

Stanford University engineers are working to turn CO2 into other useful chemicals, such as propane, butane or other hydrocarbon fuels that are made up of long chains of carbon and hydrogen.

Matteo Cargnello, a chemical engineer at Stanford University, is working to reverse the proliferation of greenhouse gases.

“We can create gasoline, basically,” said Cargnello, who is an assistant professor of chemical engineering. “To capture as much carbon as possible, you want the longest chain hydrocarbons. Chains with eight to 12 carbon atoms would be the ideal.”

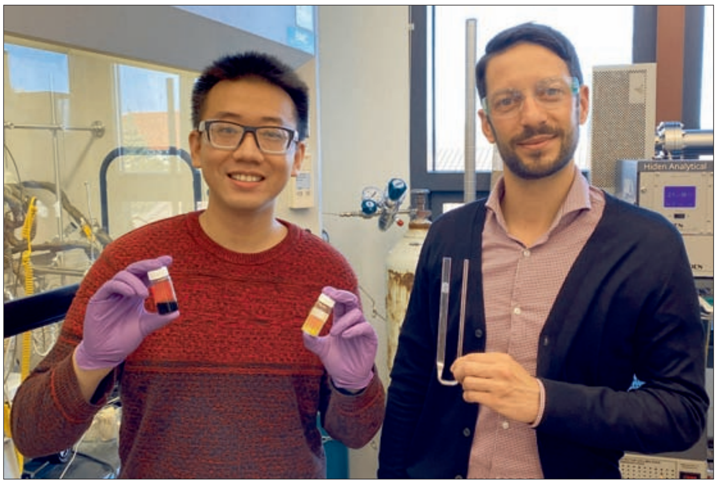
A new catalyst, invented by Cargnello and colleagues, moves toward this goal by increasing the production of long-chain hydrocarbons in chemical reactions. It produced 1,000 times more butane – the longest hydrocarbon it could produce under its maximum pressure – than the standard catalyst given the same amounts of carbon dioxide, hydrogen, catalyst, pressure, heat and time.

The new catalyst is composed of the element ruthenium – a rare transition metal belonging to the platinum group – coated in a thin layer of plastic. Like any catalyst, this invention speeds up chemical reactions without getting used up in the process. Ruthenium also has the advantage of being less expensive than other high-quality catalysts, like palladium and platinum.

Cargnello and his team describe the catalyst and the results of their experiments in their latest paper, published this week in the journal Proceedings of the National Academy of Sciences.

Cargnello and his team took seven years to discover and perfect the new catalyst. The hitch: The longer the hydrocarbon chain is, the more difficult it is to produce. The bonding of carbon to carbon requires heat and great pressure, making the process expensive and energy intensive.In this regard, the ability of the new catalyst to produce gasoline from the reaction is a breakthrough, said Cargnello. The reactor in his lab would need only greater pressure to produce all the long-chain hydrocarbons for gasoline, and they are in the process of building a higher pressure reactor.

Gasoline is liquid at room temperature and, therefore, much easier to handle than its gaseous short-chain siblings – methane, ethane and propane – which are difficult to store and prone to leaking back into the skies. Cargnello and other researchers working to make liquid fuels from captured carbon imagine a carbon-neutral cycle in which carbon dioxide is collected, turned into fuel, burned again and the resulting carbon dioxide begins the cycle anew.



Chengshuang Zhou holds vials of ruthenium, left, and the coated catalyst, while Matteo Cargnello holds the pipe used for the reaction experiments. (Image credit: Mark Golden)

The key to the remarkable increase in reactivity is that layer of porous plastic on the ruthenium, explained lead student author Chengshuang Zhou, a doctoral candidate in Cargnello’s lab, who conducted the search and experimentation needed to refine the new coating. An uncoated catalyst works just fine, he said, but only produces methane, the shortest chain hydrocarbon, which has just a single atom of carbon bonded to four hydrogens. It’s not really a chain at all.

“An uncoated catalyst gets covered in too much hydrogen on its surface, limiting the ability of carbon to find other carbons to bond with,” Zhou said. “The porous polymer controls the carbon-to-hydrogen ratio and allows us to create longer carbon chains from the same reactions. This particular, crucial interaction was demonstrated using synchrotron techniques at SLAC National Laboratory in collaboration with the team of Dr. Simon Bare, who leads Co-Access there.”

While long-chain hydrocarbons are an innovative use of captured carbon, they are not perfect, Cargnello acknowledges. He is also working on other catalysts and similar processes that turn carbon dioxide into valuable industrial chemicals, like olefins used to make plastics, methanol and the holy grail, ethanol, all of which can sequester carbon without returning carbon dioxide to the skies.

“If we can make olefins from CO2 to make plastics,” Cargnello noted, “we have sequestered it into a long-term storable solid. That would be a big deal.”

Other co-authors – all at Stanford – are Simon Bare, distinguished staff scientist, SLAC National Accelerator Laboratory; Stacey Bent, vice provost for graduate education and postdoctoral affairs and professor of chemical engineering; Adam Hoffman, associate scientist, SLAC; postdoctoral scholars Arun Asundi, Emmett Goodman, Jiun Hong and Baraa Werghi; and PhD student Sindhu Nathan.

More information

www.stanford.edu

Could CCUS in the UK constitute a new source of sustained 'green growth'?

The Centre for Energy Policy (CEP) at the University of Strathclyde argues that labour market and business model challenges, combined with the trade-offs involved in different public funding approaches, make the national and regional economy-wide impacts of introducing CCUS in the UK difficult to predict. By Karen Turner, Julia Race and Antonios Katris.

A very different landscape

Since we last wrote about 'Making the Macroeconomic Case for CCS' in this journal back in 2016, much has changed in both wider UK climate policy and the approach to CCUS, as well as across the wider economy and political landscape.[1] The fundamental need to examine a broader set of costs and benefits from CCUS emerging and accruing across the UK economy in ways that align with HM Treasury's need to ensure fiscal responsibility as we considered back in 2016 remains. For example, in linking the service role of CCUS in supporting the decarbonisation and/or transition of different activities. However, the conditions and context have changed radically.

Firstly, the UK has arguably taken a globally leading role in being the first nation to legislate for 'net zero' in 2019 – aligning with recommended limits on mid-century global warming of 1.5 degrees Celsius. An increasing number of nations have followed this lead both before and after the delayed COP26 held in Glasgow in November 2021 under the UK's continuing Presidency. Here the role of CCUS in both delivering the extent of deep emissions reductions and enabling 'net zero' to emerge at a wider economy and international levels is arguably crystallising, and potentially providing new economic opportunities, for those nations with the capability and resource base to deliver CO2 transport and sequestration services.

Secondly, within the UK, the central focus of CCUS policy and deployment has shifted to enabling competitive decarbonisation within and sustaining (and ideally growing) the (direct and indirect) GDP and employment contributions of the nation's regional industry clusters. UK Government strategy in this regard set out in a series of documents emerging through the 2017 Industrial Strategy and moving from the 2018 CCUS Action Plan through to the Prime Minister's 2020 'ten-point plan for a green industrial revolution'. The first stages of deployment are now emerging via the CCUS Cluster Sequencing Process, where CCUS for power and hydrogen complement the industrial decarbonisation core (spread across six UK regional clusters).

Thirdly, and providing the main challenges that our own economy-wide research is designed and able to provide intelligence and evidence on, the economic landscape has changed radically. The (so far) elusive constant is the need to design and implement a commercially viable business and policy model for industrial capture that enables what is implicitly early mover activity on CCUS in internationally competitive firms, many operating in the context of complex global supply chains where markets for more costly 'green' products are yet to emerge.

Crucially, the capture business model challenge and the potential to realise 'green growth' and 'just transition' potential through repurposing some of the existing oil and gas industry and supply chain activity in the UK to deliver transport and storage services are also increasingly challenged by national and global economic conditions.

Here, a combination of domestic labour supply constraints will interact with wider global supply chain challenges in impacting both the timely deployment of CCUS projects and the economic landscape in which public policy and industry decision makers must operate. An exacerbating factor will be the emerging cost-of-living crisis and its impacts on both fiscal conditions and the economic well-being and attitudes of people and businesses in near and mid-range timeframes.

Central insights from CEP's research on the likely medium to long-term impacts of industrial capture and UK transport on storage on the macroeconomy

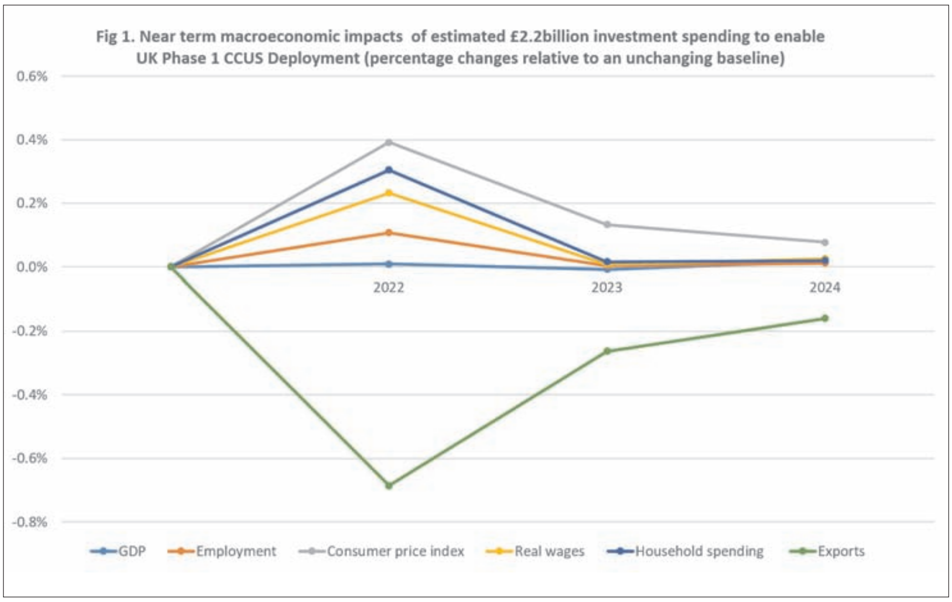
Several studies have suggested that CCUS could bring clear benefits to the wider UK economy, including sustained net gains to GDP and employment.[2] However, it is not clear that any or all of these studies take account of the constraining effects of the issues set out above, or of how the adoption of different funding models may affect outcomes. For example, there is a risk of potentially displacing activity elsewhere in the economy through directly affecting real household spending power (through taxation), or by impacting employment or other sources of income generation where the international competitiveness regional industry activity is adversely affected by increased costs.

Our research uses economy-wide scenario analyses to consider the potential impacts of different public funding models: (i) when government is likely to play a role in guaranteeing demand for what may initially be an oversized infrastructure-intensive transport and storage industry, and/or (ii) the impact of an 'industry pays' approach to carbon capture. [3] We analysed a case where CCUS is introduced to four of the six UK regional clusters,

1. See 'Making the Macroeconomic Case for CCS', by Karen Turner and Julia Race, published in the Nov/Dec 2016 issue of Carbon Capture Journal.
2. For example, the report commissioned by CCSA titled 'Economic Analysis of UK CCUS', published in July 2021, available from www.ccsaorganisation.org
3. See our 2021 report titled 'Moving early in Carbon Capture and Storage : Opportunities and Challenges for Delivering Green Growth and Just Transitions', co-authored with Oluwafisayo Alabi, Christian Calvillo, Antonios Katris, Jamie Stewart and Kim Swales, at https://strathprints.strath.ac.uk/78347/, which contains reference details for underlying peer reviewed research.

which now include the Phase 1 clusters identified by the UK Government in October 2021, plus the Scottish cluster. Two central findings emerged:

1. Deployment of CCUS could lead to sustained 'green growth' where it involves introduction of new CO2 Transport and Storage (T&S) industry activity to the economy. We found that net positive impacts for UK GDP (up to 0.1% over what it would otherwise be by 2040) and employment (up to a sustained gain of 17 thousand jobs) are possible across all time frames once the new T&S industry is fully deployed. Note that these may be considered healthy but relatively modest returns compared to what may be predicted by more commonplace economic 'multiplier' analysis.



This is because our analysis takes account of wage responses in supply constrained labour markets, where the consequent cost and price pressures (across all sectors) will act to erode gains. Moreover, net GDP and employment (combined with increased tax revenues) could be further eroded or entirely offset, with distributional and 'just transition' challenges emerging, if UK households as taxpayers or industry must bear the costs of guaranteeing demand for new T&S services. The worst outcomes were observed where industry is required to meet all costs and the international trade response to any consequent rise in UK output prices is high. In this case our findings suggest that the brunt of losses may be borne in the host economies where job losses and knock-on impacts on local spending are likely to be concentrated.

2. Operational carbon capture brings an additional challenge to the industry, requiring firms to use additional equipment to produce the same output. This translates to reduced capital efficiency of industrial firms with implications for returns on capital at the current production location. Crucially, the need to pass on increased capital costs through output prices is likely to have implications for the relative competitiveness of UK cluster firms in international markets.

Here our applied work focussed on the case of UK Chemicals where we found that capital efficiency reductions of up to 30% in that industry alone could trigger a sustained contraction in GDP of up to 0.12% per annum at a cost of more than 14 thousand jobs. However, where public support focuses on enabling capture firms to make 'early mover' relative efficiency gains in using CCUS as a decarbonisation solution, we found that wider economy losses could be limited, with potential for some net gains in activity and employment at an industry level.

The crucial takeaway is that deploying CCUS, like any large-scale decarbonisation action and/or source of 'green growth' brings potential to deliver some degree of wider economy gains in some or all timeframes. However, where there are new costs involved that must be met somehow, and where expansion occurs in an economic landscape where there are constraints on funding and labour in particular, policy makers need to fully understand the trade-offs involved under different scenarios and alternative interventions, such as identifying and supporting efficiency and productivity gains to mitigate or, ideally, offset pressures. This is crucial if the best potential outcomes are to be pursued in terms of maximising emissions reductions, whilst limiting costs and realising benefits, where possible, in different parts of the economy across nearer and longer-term timeframes.

New insights from initial research on the near-term impacts of investment activity to support the deployment of the UK Phase 1 CCUS clusters

In terms of nearer term returns from deployment project activity in CCUS, our initial research – conducted prior to the October 2021 announcement of Phase 1 of the CCUS Cluster Sequencing Process in the UK – had to make assumptions regarding the level and timing of up-front investment. Now we know that some relatively substantial levels of investment spending will be required within the next 3 years if the Phase 1 Hynet and East Coast CCUS clusters (Merseyside, Teesside, Humberside) are to become operational by 2025.

We have recently extended our initial research to focus on whether this may have some disruptive wider economy impacts in this near-term timeframe, particularly in the context of currently very challenging labour supply conditions, not least with multiple relatively large-scale CCUS projects potentially competing for the services of skilled workers in the initial construction and pre-deployment stages.[4]

We estimated the up-front investment spending required to enable deployment of the Phase 1 clusters (creating capacity to capture all industrial emissions generated in these regional clusters) to be in the order of £2.2billion spread roughly evenly over the years 2022, 2023 and 2024. Figure 1 shows the estimated impacts (assuming no other changes across the UK economy) where real wage rates adjust in the supply constrained UK labour market as demand for all kinds of labour rise. Gains in employment are concentrated in construction supply chains, which draw workers from other sectors and/or from the existing pool of unemployed workers.

The percentage change results help illustrate that small net gains in UK GDP (maximised at just under £160million in 2022) are a balance of increased total household spending (enabled by increased employment and real wage rates) and falling exports. However, crucially in the context of the current cost-of-liv-

4. Our new research is initially reported in a CEP policy brief available to download at https://strathprints.strath.ac.uk/79477/

ing crisis, note that the increase in the consumer price index, CPI (reflecting the price pressures that generally constrain expansion) is greater in all three years than the real wage growth, meaning that purchasing power will be eroded, potentially with important distributional implications not reflected in our results for total UK household spending.

However, perhaps of most concern for the CCUS projects themselves will be the how the wage pressures reflected in our results may combine with supply constraints in specialised areas of the UK labour market that the projects themselves must draw on to complete work within the 2025 timeframe for deployment as planned.

Moreover, where other infrastructure projects are likely to be competing for the same pools of specialised labour, the actual labour cost impacts may exceed the average impacts reflected in our real wage results (where nominal costs to firms will be higher, as indicated by our CPI results).

More economic research is required

Of course, the quantitative results of our scenario simulation analyses are, like any type of modelling, dependent on the data and information we can inform them with. As more specific and accurate information begins to emerge on required investments, capacity, and funding models for UK CCUS, scenarios and estimates of potential impacts can be updated and improved. However, at this stage, the main insight and message emerging is that there is potential for CCUS to constitute a new source of 'green growth' in the transitioning UK economy.

However, if benefits are to be maximised, and the distribution of wider economy costs balanced to ensure that the burden is not disproportionately borne by businesses, workers, and households in particular regions or income groups, there is crucial need for coordination across different areas of public policy development and implementation, with particular focus on supporting UK industry to develop competitive advantage in emerging 'green' markets.

More information

www.strath.ac.uk

Open Impact Bonds: pricing and funding a carbon capture breakthrough

If not having efficient CCS costs taxpayers tens of billions in climate damages, then governments should offer billions to the first private entity producing efficient CCS. By Nathan Witkin.

Though it is innovative, the policy idea proposed in this article is relatively simple. Given that climate change costs major global economies billions each year, any of these governments should offer billions to the first private entity producing a solution. Similar policy ideas have been attempted but have problematically failed to directly connect the value to taxpayers with the amount offered to the first group of successful investors who find and fund an effective solution.

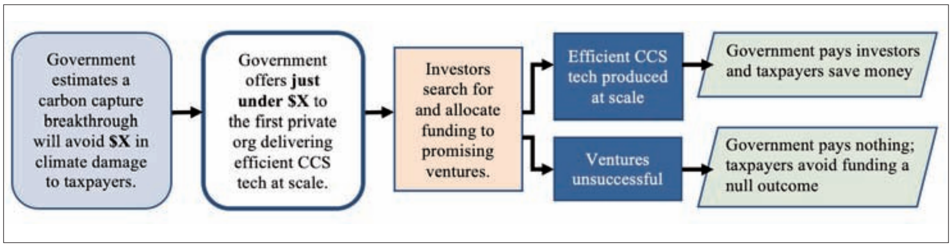


Figure 1: An open impact bond for a CCS breakthrough

This article will first present the economic and policy rationales for this idea. It will then provide evidence as to why this approach benefits taxpayers and how its closest policy analogues indicate this approach is uniquely promising and worthy of consideration.

Economic Analysis

In economic terms, the cost of not having efficient carbon capture should be the price society is collectively willing to pay for it. This approach is efficient on the macro scale and also common sense to the individual. If a broken window increases your home heating cost by £100, and you are not willing to change your energy usage, then you would save money by paying £99 for a new window.

However, when analogized to carbon capture and storage (CCS), this is not only a matter of wise, upfront investment. Because CCS benefits everyone, regardless of whether they invest their own money, there must be a mechanism compelling contributions. Fortunately, the normal power of a government to tax and spend can serve as this mechanism.

Policy Analysis

The resulting policy prescription involves a government defining the CCS technology the public is willing to purchase, assessing how much taxpayers would benefit economically in reduced climate damages, and then offering a slightly lesser amount in free-market competition. While the proposed policy presents similarities to past government efforts to spur CCS innovation through monetary incentives, there are crucial differences.

The proposed policy differs from competitions or X-prizes in that the money would only be paid if the submitted technology meets predefined criteria, ensuring taxpayers benefit by more than the prize amount. And while the goal is to attract investors – as with traditional impact bonds – the money could be earned by any competing entity, and not a single private entity engaged in an exclusive pay-for-success contract with the government. Furthermore, government competitions, philanthropic X-prizes, and traditional impact bonds do not base the amount offered on what taxpayers collectively save through successful delivery of the sought-after outcome.

Because the policy idea presented in this article is most similar to a social impact bond (described below) but is not structured under its characteristically exclusive contract, it is best described as an "open" impact bond.

Economic Evidence

This section demonstrates the economic need for an open impact bond and the economic power of using this policy to link the amount taxpayers save through efficient CCS to what governments should be willing to offer for it. To be clear, this open impact bond would pay a private entity if and only if it produces technology that removes carbon from the air at a measurably lower cost per ton than the carbon would otherwise create in climate damages.

In October of 2021, the World Economic Forum (WEF) issued a report indicating that a net-zero future would require approximately $50 trillion in investments over the next 25 years. Regarding the carbon capture industry, ExxonMobile recently estimated that a CCS hub with sufficient economies of scale would require $100 billion in investment. Furthermore, the Global CCS Institute projected the need for investment at $655 billion to $1.28 trillion between 2021 and 2050.

On the other side of this tall order for investors is very little incentive to make risky bets on the CCS ventures. That same WEF report calling for trillions in CCS investment also indicates that, without paying customers, market forces do not support the necessary private investment in net-zero technologies. This conclusion was voiced earlier by the Carbon Capture and Storage Association (CCSA) in a post-mortem analysis of the U.K.'s 2008-2015 CCS competitions. Evidence of this lack of market incentive is found in a 2021 analysis by Business Wire, valuing the global CCS industry at $1.5 billion and projecting growth to nearly $3 billion by 2025.

The mismatch between $100 billion needed for one CCS hub and $1.5 billion in worldwide investment characterizes a classic market failure. But this market failure is not unavoidable. Though there is almost no paying market for any product that would equally benefit customers and non-customers, investors and non-investors, CCS does offer measurable monetary benefits to society as a whole.

The collective economic benefit of efficient CCS technology is found in the avoidance of property damage from flooding, wildfires, and hurricanes caused by climate change. The U.S. National Oceanic and Atmospheric Administration (NOAA) reported the annual inflation-adjusted cost of weather events in the U.S. at nearly $20 billion per year in the 1980s and nearly $90 billion per year in the 2010s. Similarly, the European Environment Agency (EEA) estimated annual damage of €13 billion in floods, draughts, and heatwaves during the last decade. Furthermore, a collaboration of researchers estimated flooding damages in China would increase by 82% to USD$389 billion over the next 20 years.

Because climate change is currently creating billions of dollars in property damage to these developed economies – with the cost of inaction only estimated to increase – any of these societies should collectively value a CCS breakthrough with a very large price tag. The problem is that competitive free markets for innovative technologies are currently organized around individual consumers/investors, not the collective valuation by an entire society. However, a novel application of the impact bond concept may offer a solution, in this context.

Policy Evidence

If a CCS breakthrough could avoid tens of billions in property damage from climate events, then any developed society should offer this amount in an open impact bond to the first private entity producing such a breakthrough. This policy would motivate investors to seek out and fund promising R&D, allowing the private sector to manage risk while the public sector organizes public buy-in – each side doing exactly what they were designed to do.

While an open impact bond for efficient CCS seems intuitive, it is not currently available in any jurisdiction. And, though similar policies – social impact bonds and government competitions – have paved the way for this new policy idea, these existing policies exhibit particular flaws which further highlight the strength of the open impact bond.

According to a 2016 OECD report on the subject, a social impact bond (SIB) is a financing mechanism in which investors provide up-front capital for a social service and then the government repays the investors with a premium only if a predefined outcome is achieved. The main problem with SIBs are that they do not organize competition among different approaches, the conditions producing innovation under free-market capitalism. Instead, SIBs involve a contract between the government and a single private service-provider, sometimes taking years to negotiate, and then adding a layer of bureaucratic oversight to evaluate whether the outcome was achieved.

Because they are based on an exclusive contract between investor-backed private service providers and the government entity that would otherwise provide those services, SIBs have garnered growing criticism for being unnecessarily complex and ineffective. Under this approach, SIBs either (1) attract insufficient funding by not offering private rates of return or (2) offer a low-risk investment by paying private investors for services the government could offer more efficiently. An open impact bond avoids this inefficiency by simply defining the value to taxpayers of a particular innovation and then paying that amount to the first private entity producing that good.

Another similar policy idea is a CCS competition, providing a defined amount of government grants or philanthropic funds for groups submitting the best technology. In contrast to the open impact bond, these competitions appear to provide funding to the best applicant rather than to the first applicant whose submission meets the defined criteria. Furthermore, the amounts offered in these competitions are not based on or justified by the amount they benefit taxpayers, who ultimately fund them. Finally, these competitions have not served as reliable mechanisms for attracting private investment, as most vividly illustrated by the U.K. cancelling its most recent £1 billion CCS competition mere months before it would have been awarded.

Thus, an open impact bond for efficient CCS would offer billions to the first private entity producing this technology to a specified quality and scale. It would attract investors who otherwise face little incentive to pour private funds into CCS R&D, and it would only pay out if it produces technology that would save taxpayers a greater amount in mitigated climate change damages.

More information

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Report: time to act as momentum builds for CCUS and hydrogen

This year companies and governments will need to make good on the pledges they made on energy transition technologies, including CCUS and low-carbon hydrogen, says Wood Mackenzie.

In a new report, CCUS and hydrogen: 5 things to look for in 2022, the global energy consultancy points out the huge momentum behind both CCUS and low-carbon hydrogen in 2021, with announcements of new projects, policies and investment as COP26 spurred companies' net zero targets.

Wood Mackenzie highlights key issues for CCUS and low-carbon hydrogen in 2022 as companies and governments switch to delivery mode.

The project pipeline for both CCUS and low-carbon hydrogen saw record growth in 2021. Companies were galvanised by increased net zero targets, new policy support and technology advancements. The CCUS pipeline of announced projects grew seven-fold, with 50 new hub projects globally. The low-carbon hydrogen pipeline more than doubled, with green hydrogen projects making up 75% of the announcements.

Mhairidh Evans, principal analyst, CCUS and Emerging Technologies, and co-author of the report said, "We don't believe we will see the same growth rate for the CCUS and hydrogen pipelines in 2022.

"The coming year will be about maturing projects and securing funding. About 75% of the CCUS pipeline is in early development. For hydrogen, almost 40% of the project pipeline does not have an estimated date of operation and 25% does not have an estimated capacity. A mark of success for 2022 will be more projects in advanced development or under construction."

The report tracked 15 CCUS projects aiming for FID this year. If developed successfully, they will add approximately 35 Mtpa of new CO2 capture or storage capacity and will require investment of around US$18 billion. Large volumes of CCUS are not expected to come online in 2022.

More than US$66 billion was invested in hydrogen in 2021, with projects looking at every aspect of the value chain from R&D to refuelling infrastructure.

The report said more capital flow is needed for hydrogen production projects, requiring an uplift in offtake agreements. This could mobilise the US$3.5 billion– to US$22 billion necessary for hydrogen production projects to reach FID in 2022.

Mhairidh Evans said that in 2022, 33 projects - mainly in Europe and Asia - should begin operation, which will see 0.1 Mtpa of low carbon hydrogen and 50 ktpa of green ammonia enter the market.

Wood Mackenzie also looked at the implications of the United States' Build Back Better Act. Significant investment hangs on the act passing Congress this year, following on from the US$15 billion provided by the Infrastructure Investment and Jobs Act passed in 2021 to support CCUS and low-carbon hydrogen.

Flor Lucia De La Cruz, senior research analyst, Hydrogen & Emerging Technologies, and co-author of the report said, "2021 was a big year for policy announcements in CCUS and low-carbon hydrogen.

"We see 2022 as an important year for translating policy into reality, but it's a tough political ask in some countries and we expect drawn-out negotiations to mean delays.

"This year, COP27 will be held in Egypt and promises to be a radical turning point for climate policy in Africa. Africa has the opportunity to make a stand and showcase its unique advantages in renewables and green hydrogen."

Policy developments in Canada, Europe and South East Asia are also explored.

Technology scale-up will be crucial to maintain and build momentum for CCUS and hydrogen. Green ammonia has been hailed as one of the cheapest pathways to transport green hydrogen around the world but it, and hydrogen carriers in general, have their challenges.

Wood Mackenzie expects more technological solutions related to storage and chemical plant design in 2022. Direct Air Capture is expected to edge from wildcard to reality, with drivers including US$3 billion of funding through the US Infrastructure Bill, growing demand for e-fuels and the burgeoning voluntary carbon market.

Dynamic green ammonia plants will address hydrogen transportation issues

Green ammonia has been hailed as one of the cheapest pathways to transport green hydrogen around the world for its ability to leverage existing infrastructure and mature process technology. However green ammonia, and hydrogen carriers in general, have their challenges. Normally plants are designed to operate at a fixed plant load. Operating with fluctuating hydrogen supply requires hydrogen buffer storage which today is both expensive and not available at scale.

Haldor Topsoe has addressed this challenge by redesigning its ammonia plant to allow for fully dynamic operation and respond to fluctuating hydrogen supply. In 2022 we expect more technological solutions related to storage and chemical plant design to follow Haldor Topsoe's lead.

Can direct air capture edge from wildcard to reality for CCUS? To find out more, read CCUS and hydrogen: 5 things to look for in 2022.

More information

Download the full report at:

www.woodmac.com

ING report: How governments are tempting corporates with CCS

Carbon capture and storage is a key technology for the transition towards net-zero emissions by 2050. Governments around the world are shaping CCS support mechanisms to trigger far greater corporate investment. But we're still far from a world where CCS alone can steer the world to its stated climate goals. And it's not without controversy.

Summary of key points

- CCS projects are picking up globally
- CCS to play a unique role in the transition towards a net-zero economy
- The US: Benefitting from CCS tax credits and network effects
- Europe: Netherlands, UK, Germany and Nordics racing to the top
- Australia: Long-term investment and carbon credit rewards
- China: Five-Year Plan pushes for more CCS projects
- Japan: Leading on international collaboration and technology know-how
- CCS could become a $200+bn market annually
- There's still a huge gap to bridge

Projects are picking up globally

Companies around the globe are increasingly looking to deploy carbon capture and storage technology. They're acknowledging the huge potential of CCS in strengthening corporate sustainability efforts and decarbonising the global economy and we're already seeing a steady rise of such projects worldwide. Projects also feature a growing trend of diversification in both geography and point source capturing.

CCS to play a unique role in the transition towards a net-zero economy

The deeper decarbonisation there is in future energy scenarios from the International Energy Agency, the bigger the role CCS will play. Under the IEA's Announced Pledges Scenario (APS), where all governments' climate commitments are set to be met in full and on time, carbon capture capacity will grow to 350 Mt CO_2 per year by 2030. That's from the current 40 Mt CO_2 per year.

Estimated CCS capacity will surge further under the Net Zero Emissions Scenario by 2050 Scenario (NZE) to around 1.7 Gt CO_2 per year in 2030—almost five times bigger than under the APS. The IEA also forecasts that CCS will account for as much as 18% of the emissions reduction needed between 2030 and 2050 to get the world to net-zero emissions by the middle of the century.

CCS could become a $200+bn market annually

Despite these positive movements, government policies and initiatives so far aren't enough to scale up CCS to a level needed to get the world to net-zero by 2050. According to the IEA, the annual large-scale CCS capacity in industry and transformation needs to reach almost 1,150 $MtCO_2$ by 2030. That is a significant jump from the actual capacity of 40 $MtCO_2$ in 2021.

Additionally, the IEA forecasts that $205bn is needed annually by 2030 to be invested in CCS development for the world to stay on track to reach net-zero emissions by 2050, but according to Bloomberg New Energy Finance, the global investment in CCS fell slightly to $2.3bn in 2021.

There's still a huge gap to bridge

There's still a huge gap to bridge. And it's also important to remember that CCS is controversial among some environmentalists who regard it as technology that perpetuates fossil fuel exploration and detracts from efforts to eliminate it.

That said, three things need to happen before corporate investment in CCS can really take off:

First governments need to support the designation of storage hub areas and incentivise investments in either new or repurposed existing infrastructure to transport and store carbon as this is not easily done by the market. And there's more; governments need to focus on amending existing policies and licenses to allow (long term) carbon storage.

Second, governments need to establish policies that can enhance CCS projects' revenue streams making the CCS business case viable for companies. The EU Taxonomy, the US's Section 45Q credits, and the ETS mechanism in several countries have proven to be effective. But more generous incentives, clearer implementation guidelines, and established enforcement mechanisms are all needed to boost investment in CCS to desired levels, at least from a climate perspective.

Finally, increasing funding in research and development should be devoted to CCS, as more advanced technologies can more effectively capture and store CO_2, reduce project costs, and make the technology more scalable and profitable.

More information

Download the full report at:
think.ing.com

Decarbonization technology proven at Waste-to-Energy plant

Danish researchers have demonstrated that it is possible to remove most of the carbon dioxide from the emissions of a waste incinerator, and by demonstrating the viability of the process, the researchers believe that they have developed a key technology in the fight against climate change.

A pilot plant has been operational in Copenhagen for several months and a novel gas monitoring technology has enabled the optimization of plant efficiency.

If global leaders are to deliver on their commitments to achieve net zero, one of their key objectives will be to develop and exploit decarbonisation technologies such as carbon capture and storage (CCS) and carbon capture, utilisation and storage (CCUS). Researchers from the Technical University of Denmark (DTU) are therefore working with a highly innovative waste incineration plant in Copenhagen to develop a process that is able to capture carbon dioxide (CO2) from its emissions. The project is utilising advanced gas analyzers from Vaisala to measure carbon capture efficiency and therefore CCUS viability.

The Amager Bakke incineration plant in Copenhagen

The researchers have developed a pilot plant to remove CO2 from the emissions of the incinerator at the Amager Bakke Waste-to-Energy Plant, which is one of the largest combined heat and power (CHP) plants in northern Europe, with the capacity to treat 560,000 tonnes of waste annually. Developed by the Copenhagen-based waste management company ARC (Amager Ressourcecenter), which is jointly owned by five Copenhagen-area municipalities, the CHP plant features a number of innovations including a rooftop artificial ski slope, which is part of an outdoor activity centre known as CopenHill.

The pilot plant was developed to capture CO2 from the emissions of processes such as wastewater treatment, biogas production, anaerobic digestion and waste incineration. However, the researchers are also investigating the ways in which CO2 can be both captured and utilized. Prior to its installation at Amager Bakke, the pilot carbon capture plant was operated at a wastewater treatment plant. “The technology itself is not new,” explains Jens Jørsboe, a researcher from the DTU, “However, the focus of our work has been to lower the cost of carbon capture, so that it can become economically feasible.”

Exhaust gas from the Amager Bakke incinerator is passed through an electrostatic precipitator (ESP) to remove particulates, NOx compounds are removed by selective catalytic reduction (SCR) and a scrubber removes oxides of sulfur. High levels of CO2 remain in the flue gas and the main purpose of the pilot carbon capture plant is to investigate the feasibility of its capture. To achieve this, the gas is passed upwards through a column packed with beads and a monoethanolamine (MEA) solvent which scrubs the CO2 from the gas. The solvent is then passed to a desorber which removes the CO2, which is now almost pure, and regenerates the MEA for reuse.

As a research project the produced CO2 is currently still vented to air, but on a commercial basis there are many different industrial applications in which CO2 can be utilized. For example, CO2 can be reacted with hydrogen in the Sabatier process to produce methane (a gas fuel) and water, at elevated temperature and pressure, in the presence of a nickel catalyst. This can be a green method for manufacturing fuel if the hydrogen is generated by electrolysis using renewable energy – from solar, biogas or wind power for example.

CO2 is also used in a wide variety of other industries including food and beverages, refrigeration, medical, horticulture, firefighting, welding etc., so a variety of potential markets are available if CO2 can be produced on a commercial quality and scale.

Monitoring carbon capture efficiency

The optimization of the carbon capture process can only be achieved if CO2 concentrations can be continuously monitored both before and after the carbon capture process. It was fortunate therefore that the world's first inline CO_2, humidity and methane monitor was developed by Vaisala in Finland prior to the pilot plant construction.

Exhaust gases from incinerators can be corrosive and potentially explosive, so in the past it has not been possible to conduct in-line monitoring. Until recently, the only solution was to extract samples for analysis outside of the process, but this method is not suitable for process control and optimization, and has a number of inherent flaws, such as the need to remove humidity from the sample line and a requirement for frequent re-calibration.

The development of Vaisala's multi-gas probe, the MGP261, resolved all of these monitoring challenges, especially when it was followed by a sister product the MGP262, which was adapted for measuring high concentrations of CO_2 and was therefore ideal for the continuous inline monitoring of almost pure CO_2 after the pilot plant's desorber.

The pilot plant employs three Vaisala probes in total, with the MGP261 monitoring incoming incinerator exhaust gas, and the MGP262 measuring the purity of the extracted CO_2. The third probe is a Vaisala CARBOCAP® CO_2 probe, the GMP251, which checks the levels of CO_2 (after carbon capture) in the pilot plant's exhaust gas.

Unique monitoring technology

All three monitoring probes contain CARBOCAP® technology which utilizes an electrically tunable Fabry-Pérot Interferometer (FPI) filter. In addition to measuring the target species, the micromechanical FPI filter enables a reference measurement at a wavelength where no absorption occurs. When taking the reference measurement, the FPI filter is electrically adjusted to switch the bandpass band from the absorption wavelength to a non-absorption wavelength.

This reference measurement compensates for any potential changes in the light source intensity, as well as for contamination in the optical path, which means that the sensor is highly stable over time.

Within the MGP261 and the MGP262, humidity and CO_2 are measured with the same optical filter, and a second optical channel measures methane. In many ways, this combines the analytical power of a laboratory spectrometer with the simple, rugged design of an industrial process control instrument.

Commenting on the performance of the monitoring equipment, Jens Jørsboe says: "We have been delighted with the accuracy and reliability of the multigas probes; not least because they have enabled us to learn a great deal about the management of flue gas from waste incineration. Much is known about the emissions from fossil fuel combustion, but less information is available on the emissions from waste incineration.

"The technology employed by the Vaisala probes is also helping to minimise operational costs because by effectively calibrating themselves the probes' service requirements have been minimal and downtime is avoided."

Carbon capture in Copenhagen and globally

With the benefit of continuous inline monitoring, the researchers have been able to optimize carbon capture performance following an evaluation of twelve different pilot plant configurations. Having proven the viability of the carbon capture process, the next step was to evaluate the relative advantages of carbon storage and utilization.

Jens Jørsboe says, "At the moment, utilization of CO_2 is the more expensive option because of the costs associated with the required further refinement of the CO_2, so the owners of the Amager Bakke plant are planning to apply for 1.5 billion DKK ($230 million USD) for a CCS plant capable of capturing 500,000 tonnes of CO_2 per year – if the right regulatory framework and sufficient funding is provided by the Danish state. This plant would employ the same amine scrubbing process that has been proven by the pilot carbon capture plant."

The incineration of 1 tonne of municipal waste (MSW) is associated with the release of between 0.7 and 1.7 tonnes of CO_2, depending on the content of the waste. Consequently, energy generation from waste incineration is more carbon intensive than the burning of fossil gas, so carbon capture offers an opportunity to manage the growing requirement for municipal waste treatment without generating unacceptably high levels of GHGs.

Looking forward, Jens believes that this technology could be applied at every waste incinerator in the world, which according to the latest data from ecoprog represents around 2,500 WtE plants, with a disposal capacity of around 400 million tonnes of waste per year.

In addition, it should be possible to harvest residual heat, which could be transferred to local industry or to a district heating network.

Summarizing, Jens says: "The recent COP26 climate change conference in Glasgow highlighted the urgent need for technologies that can help reduce global emissions of greenhouse gases such as CO_2. Many countries have committed to Net Zero targets, so our work at the Amager Bakke Waste-to-Energy Plant provides an opportunity for them to invest in one of the ways in which that objective can be achieved.

Vaisala is a global leader in weather, environmental, and industrial measurements. Building on over 80 years of experience, Vaisala provides observations for a better world, with space-proof technology even exploring Mars and beyond. Headquartered in Finland, Vaisala employs approximately 1,900 professionals worldwide and is listed on the Nasdaq Helsinki stock exchange.

More information

www.vaisala.com

Report details UK's first large-scale low carbon hydrogen production plant

Vertex Hydrogen, a joint venture between Essar Oil UK and Progressive Energy, has released a report detailing the development of the UK's first ever large-scale low carbon hydrogen production plant.

The low carbon hydrogen will be used to decarbonise industry as part of the HyNet cluster across the North West of England and North Wales.

The report has been launched by consortium partners Essar, Progressive Energy, Kent and Johnson Matthey to share learnings as to how they are designing and developing the ground-breaking hydrogen production plant. Hydrogen is critical to the UK's future energy mix, providing a low carbon solution to fuel vital to heavy industry.

The plant, to be owned and operated by Vertex Hydrogen, is being engineered by Kent and will use UK company Johnson Matthey's best in class Low Carbon Hydrogen (LCH™) technology at Essar's Stanlow Manufacturing Complex in Ellesmere Port, Cheshire. The Front End Engineering Design (FEED) was funded by the Government's Department of Business, Energy and Industrial Strategy ('BEIS') hydrogen supply competition.

The report explains how natural gas, and refinery fuel gas, will be converted into low carbon hydrogen whilst capturing carbon dioxide to be permanently stored under the sea bed in Liverpool Bay. The hub will produce 1GW of low carbon hydrogen with the first production line starting in the mid 2020's.

Low carbon hydrogen will replace fossil fuels in industry across the North West England and North Wales, helping the UK to decarbonise towards our net zero commitments and positioning a hydrogen economy as a catalyst for low carbon growth. Industry in the region across the chemicals, ceramics, paper, glass and flexible power generation sectors have already made commitments to reduce their carbon footprint using low carbon hydrogen from HyNet. This includes a wide range of companies such as Tata Chemicals Europe, Encirc, InterGen, Solvay, Ingevity, Novelis, Pilkington Glass and Saica Paper.

The report follows Vertex's submission of the company's plans to BEIS last month to build the UK's first low carbon hydrogen production hub with the HyNet cluster as part of the Government's Cluster Sequencing process.

Chris Manson Whitton, Director of Vertex Hydrogen said, "Our joint team of engineers, project managers and technologists, drawn from the consortium partners, have been developing this ground-breaking project over the last two years."

"We understand how important it is for us to share the knowledge we have learnt over this time to facilitate others who are following in our footsteps. This will both ensure the UK maintains its leadership position at the forefront of the growing global hydrogen economy and enable us to move as quickly as possible towards net zero."

"The work completed to date on Vertex Hydrogen's hydrogen production plant project demonstrates that we already have the technologies and skills within the UK workforce to design and deliver this type of project successfully."

The UK's first low carbon hydrogen plant will sit at the heart of the HyNet low carbon cluster, the UK's leading industrial decarbonisation cluster. HyNet is vital for the North West of England and North Wales to hit their net zero targets by 2050, playing their part in the fight against climate change. By 2030, HyNet aims to be a significant contributor to the Government's target to produce 5GW of low carbon hydrogen for power, transport, industry and homes.

HyNet infrastructure will include:

• Hydrogen Production: At the heart of the HyNet cluster, 3 TWh per year of low carbon hydrogen production by 2025, rising to 30 TWh by 2030 at a 'hub' located at the Stanlow Manufacturing Complex consisting of four state-of-the-art hydrogen production plants, which will capture ~97% of by-product CO2 from processing natural gas and Refnery Off Gas (ROG) feedstocks.

• CO2 Transport and Storage: This hydrogen production will be linked to a Carbon Capture and Storage transport and storage system, designed specifcally to sequester CO2 produced by hydrogen production and other industrial sources into long-term geological storage in the depleted Liverpool Bay gas felds.

• Hydrogen Network: Hydrogen will be delivered to multiple end customers via the UK's frst hydrogen multi-consumer network, with circa 85 km of 'spine' pipeline in place by 2027 and up to a further 270 km of hydrogen network in place by 2030. The network is routed to supply large industrial and fexible power generators in the area and to enable injection into the existing natural gas Local Transmission System, allowing all customers to readily switch from natural gas to a carbon free fuel. Plant 1 will supply the Stanlow Manufacturing Complex and other nearby industrial sites via a dedicated hydrogen pipeline before the hydrogen network is complete.

• Hydrogen Storage: A complex of hydrogen storage salt caverns will be created in the Cheshire salt basin and connected to the hydrogen distribution network. The complex will be able to store around

1.3 TWh of hydrogen, to enable fuctuations in demand to be managed cost effectively, without sizing the production hub to meet peak regional demand.

• The FEED for HyNet CO2 Transport and Storage, as well as the Hydrogen Network and Storage, is currently being developed under UK Research and Innovation's Industrial Decarbonisation Challenge funding.

More information

vertexhydrogen.com

Projects and policy news

Sinopec completes China's first megaton scale CCS project

www.sinopec.com

The project will recover carbon dioxide from the tail gas of a coal-to-hydrogen plant and use the CO2 to enhance oil recovery in the Shengli Oilfield

The Qilu-Shengli Oilfield CCUS project will reduce carbon emissions by 1 million tons per year and increase oil production by 2,965 million tons in the next 15 years..

As China's largest full industrial chain CCUS demonstration base and industry benchmark, the Project is estimated to increase oil production by 2,965 million tons in the next 15 years. It is of great significance to China's scaled development of CCUS and building an "artificial carbon cycle" model to increase China's carbon emissions reduction capabilities as the country advances to achieve the "dual carbon" goals of reaching peak carbon emissions by 2030 and carbon neutrality by 2060.

The construction of the Project was initiated in July, 2021 and consisted of two parts – Sinopec Qilu's carbon dioxide capture and Shengli Oilfield's carbon dioxide transport and storage.

Sinopec Qilu has newly constructed a liquid carbon dioxide recovery and utilization unit with a capacity of 1 million tons per year, which includes a compression unit, refrigeration unit, liquefaction refining unit and supporting facilities to recover carbon dioxide from the tail gas of coal-to-hydrogen plant with a purification rate of over 99 percent.

Meanwhile, Shengli Oilfield is applying the principle of supercritical carbon dioxide's easy miscibility with crude oil to build 10 unattended gas injection stations in Zhenglizhuang Oilfield to inject carbon dioxide into the 73 wells nearby to increase crude oil fluidity and improve oil recovery while adopting a closed pipeline transportation of oil and gas to further enhance carbon dioxide sequestration rate.

Taking an early start of CCUS R&D and construction, Sinopec has developed its own CCUS technology system that has achieved good results in improving crude oil recovery and reducing carbon emissions, and some of the capture technologies is in leading position domestically and advanced level in the world.

Sinopec's low partial pressure carbon dioxide capture technology has been successfully applied in more than 50 units of devices across 16 provinces and cities in China, capturing more than 200,000 tons of carbon dioxide every year.

The company has tackled multiple key technological problems. By actively conducting mineral field tests in the East China and Shengli oilfields and developing high-pressure miscible flooding of carbon dioxide, Sinopec said it has effectively solved the problem of difficult water inject and oil well production in reservoirs of ultra-low permeability.

The company proposed an innovative "throughput displacement coordination" carbon dioxide injection development mode to carry out efficient development of sealed small block reservoirs. Sinopec has also built China's first exhaust gas displacement, cyclic utilization and storage base of high water-cut oil reservoir industrial refinery in Sinopec Zhongyuan Oilfield.

Backed by systematic investigation of China's large-scale carbon dioxide emission sources, Sinopec has researched and drafted a CCUS potential evaluation method and established the Sinopec source & sink database. To date, Sinopec has implemented 36 carbon dioxide flooding projects.

Sinopec is looking to advance the constructions and realize the industrialized development of CCUS. Sinopec will build a CCUS R&D center to focus on the cutting-edge technological breakthroughs including the integration of CCUS with new energy, hydrogen energy and biomass energy. The company will advance the technology applications such as the carbon dioxide production of high-value chemicals and carbon dioxide mineralization and utilization to make breakthroughs in the core technologies and solving the equipment bottlenecks in carbon capture, transportation, utilization and storage.

With the goal of building a carbon dioxide technological innovation system of "technology development-construction project demonstration and industrialization," Sinopec will extend the clean carbon sequestration industrial chain and build the foundation for carbon emission reduction technology innovation.

Between 2021 and 2025, Sinopec will build another megaton CCUS demonstration project in partnership with Sinopec Nanjing Chemical Industries Co., Ltd. in its affiliated Sinopec East China oil and gas fields and Sinopec Jiangsu Oilfield to achieve the industrialized development of CCUS and widen the prospects as China advances to achieve carbon peak and carbon neutrality.

ExxonMobil to invest $400mn at Wyoming CCS facility

www.exxonmobil.com

ExxonMobil has made a final investment decision to expand carbon capture and storage at its LaBarge, Wyoming, facility, expanding the project by up to 1.2 million metric tons of CO2 a year.

ExxonMobil completed front-end engineering and design work for the project in December 2021 and expects to issue the engineering, procurement and construction contract in March. Pending regulatory approvals, startup is estimated in 2025.

"Carbon capture and storage is a readily available technology that can play a critical role in helping society reduce greenhouse gas emissions," said Joe Blommaert, president of ExxonMobil Low Carbon Solutions.

"By expanding carbon capture and storage at LaBarge, we can reduce emissions from our operations and continue to demonstrate the large-scale capability for carbon capture and storage to address emissions from vital sectors of the global economy, including industrial manufacturing."

The expansion is part of the company's 2030 emission-reduction plans and supports the company's ambition to achieve net zero greenhouse emissions (Scopes 1 and 2) for its operated assets by 2050.

By capturing an additional 1.2 million metric tons of CO2 each year, ExxonMobil can reduce greenhouse gas emissions from its upstream operated emissions by 3%. The LaBarge facility currently captures nearly 20% of all human-made CO2 captured in the world each year.

In addition to producing natural gas, ExxonMobil's LaBarge facility is one of the world's largest sources of helium, producing approximately 20% of global supply. Helium is an essential component for health care equipment such as magnetic resonance imaging, high-tech products including fiber optics and semiconductors, and materials for space travel.

ExxonMobil established its Low Carbon Solutions business to commercialize low-emission technologies. It is initially focusing on carbon capture and storage, hydrogen and biofuels. Over the next six years, the company plans to invest more than $15 billion on lower-emission initiatives.

Talos leases land in Mississippi for CCS hub

www.talosenergy.com

Talos Energy has reached an agreement with a large Louisiana landowner to lease land along the Mississippi River industrial corridor for future CCS projects.

Talos has also signed an MoU with EnLink Midstream to provide integrated CO2 transportation solutions in the region. These announcements mark the first major CCS project in the Baton Rouge / New Orleans area, known as the "River Bend CCS" project, and the first with an integrated midstream solution dedicated to permanent sequestration activities.

Talos will be the project manager and operator of the injection, storage and monitoring and will be joined by its partner, Storegga Limited.

Talos President and Chief Executive Officer Timothy S. Duncan commented, "This project is unique because the Mississippi River corridor is such an important focus area for lowering industrial emissions, and by combining the right storage location and geology, real pipeline infrastructure and two credible and capable operators, the River Bend CCS project can be a model for optimizing those variables to achieve a successful integrated CCS project."

Highlights of the project include:

• Approximately 26,000 acres leased in Iberville, St. James, Assumption and Lafourche Parishes, one of the largest industrial regions in the United States with approximately 80 million metrics tons of CO2 emitted regionally per year

• One Hub-class sequestration project comprised of three distinct sites with a cumulative storage capacity of over 500 million metric tons and identified collectively as River Bend CCS

• Located in a superior geologic fairway containing a 3,000+ foot thick saline aquifer column with porosity and permeabilities ideal for sequestration activities

• Talos has also secured a right of first refusal on approximately 63,000 additional acres in the area for phased, future expansion in order to meet expected future market demand

• Expands the Talos CCS project portfolio to three sequestration projects, including two regional hubs and one point source, spanning the Texas and Louisiana Gulf Coasts.

Eni UK signs 19 agreements for CCS at HyNet North West

www.eni.com

A total of 19 MoUs have been signed with companies interested in the opportunity to have their emissions captured, transported and stored in Eni UK's depleted hydrocarbon reservoirs as part of HyNet North West project.

In January 2022 alone, Eni UK has signed 6 of these agreements, demonstrating the outstanding interest that UK industry has shown for the decarbonisation potential offered by the HyNet project, which benefits from the expertise and ideal location of Eni UK's infrastructure for transportation and storage.

Once operational, the HyNet North West project will transform one of the most energy-intensive industrial districts in the UK into the world's first low carbon industrial cluster.

In particular the project will provide important support to the UK's decarbonisation process by contributing 100% to the 10 million tons per year of CO2 storage capacity and 80% to the 5GW of low carbon hydrogen Government's UK-wide targets set for 2030.

The agreements signed to date include hard-to-abate sectors and will play a crucial role enabling decarbonisation initiatives in the North West of England and North Wales industrial cluster.

In October 2020, Eni UK was awarded a CO2 appraisal and storage license in Liverpool Bay to develop a CO2 storage site and in October 2021 the HyNet North West Cluster has been selected by the UK Government as one of the two priority projects (Track 1 projects) out of five competing in the CCUS Cluster Sequencing Process.

Moreover, Eni UK has recently signed further agreements with Cory, Uniper and the Cavendish Project to evaluate further solutions in terms of storage for the decarbonisation of the UK's industrial clusters.

Eni UK currently operates Liverpool Bay facilities in the East Irish Sea and the depleted Hewett gas field, located 19 miles off the Norfolk coast, which is currently in its decommissioning phase.

Decarbonisation tech instantly converts CO2 to solid carbon

The carbon dioxide utilisation technology from RMIT researchers is designed to be smoothly integrated into existing industrial processes. By Gosia Kaszubska.

Decarbonisation is an immense technical challenge for heavy industries like cement and steel, which are not only energy-intensive but also directly emit CO2 as part of the production process.

The new technology offers a pathway for instantly converting carbon dioxide as it is produced and locking it permanently in a solid state, keeping CO2 out of the atmosphere.

The research is published in the journal Energy & Environmental Science.

Co-lead researcher Associate Professor Torben Daeneke said the work built on an earlier experimental approach that used liquid metals as a catalyst.

"Our new method still harnesses the power of liquid metals but the design has been modified for smoother integration into standard industrial processes," Daeneke said.

"As well as being simpler to scale up, the new tech is radically more efficient and can break down CO2 to carbon in an instant.

"We hope this could be a significant new tool in the push towards decarbonisation, to help industries and governments deliver on their climate commitments and bring us radically closer to net zero."

A provisional patent application has been filed for the technology and researchers have recently signed a $AUD2.6 million agreement with Australian environmental technology company ABR, who are commercialising technologies to decarbonise the cement and steel manufacturing industries.

Co-lead researcher Dr Ken Chiang said the team was keen to hear from other companies to understand the challenges in difficult-to-decarbonise industries and identify other potential applications of the technology.

"To accelerate the sustainable industrial revolution and the zero carbon economy, we need smart technical solutions and effective research-industry collaborations," Chiang said.

The steel and cement industries are each responsible for about 7% of total global CO2 emissions (International Energy Agency), with both sectors expected to continue growing over coming decades as demand is fuelled by population growth and urbanisation.

Technologies for carbon capture and storage (CCS) have largely focused on compressing the gas into a liquid and injecting it underground, but this comes with significant engineering challenges and environmental concerns. CCS has also drawn criticism for being too expensive and energy-intensive for widespread use.

Daeneke, an Australian Research Council DECRA Fellow, said the new approach offered a sustainable alternative, with the aim of both preventing CO2 emissions and delivering value-added reutilisation of carbon.

"Turning CO2 into a solid avoids potential issues of leakage and locks it away securely and indefinitely," he said.

"And because our process does not use very high temperatures, it would be feasible to power the reaction with renewable energy."

How the tech works

The RMIT team, with lead author and PhD researcher Karma Zuraiqi, employed thermal chemistry methods widely used by industry in their development of the new CCS tech.

The "bubble column" method starts with liquid metal being heated to about 100-120°C.

Carbon dioxide is injected into the liquid metal, with the gas bubbles rising up just like bubbles in a champagne glass.

As the bubbles move through the liquid metal, the gas molecule splits up to form flakes of solid carbon, with the reaction taking just a split second.

"It's the extraordinary speed of the chemical reaction we have achieved that makes our technology commercially viable, where so many alternative approaches have struggled," Chiang said.

The next stage in the research is scaling up the proof-of-concept to a modularized prototype the size of a shipping container, in collaboration with industry partner ABR.

ABR Project Director David Ngo said the RMIT process turns a waste product into a core ingredient in the next generation of cement blends.

"Climate change will not be solved by one single solution, however, the collaboration between ABR and RMIT will yield an efficient and effective technology for our net-zero goals," Ngo said.

The team is also investigating potential applications for the converted carbon, including in construction materials.

"Ideally the carbon we make could be turned into a value-added product, contributing to the circular economy and enabling the CCS technology to pay for itself over time," Daeneke said.

The research involved a multi-disciplinary collaboration across engineering and science, with RMIT co-authors Jonathan Clarke-Hannaford, Billy James Murdoch, Associate Professor Kalpit Shah and Professor Michelle Spencer.

'Direct Conversion of CO2 to Solid Carbon by Liquid Metals', with collaborators from University of Melbourne and Deakin University, is published in Energy & Environmental Science (DOI: 10.1039/d1ee03283f).

More information

www.rmit.edu.au

IEAGHG reports on DACCS and Negative Emissions Technologies

The studies aims to collate and improve the current knowledge base on costs and performance of DACCS systems and assess the costs and value of NETs.

IEAGHG has released two reports, "A Global Assessment of DACCS costs, scale and potential" and "Assessing the Techno-Economic Performance, Opportunities and Challenges of Mature and Nearly-mature Negative Emissions Technologies."

Direct air carbon capture and storage (DACCS) has some advantages over other negative emissions technologies (NETs). NETs interacting with biomass, such as afforestation, soil carbon storage and bioenergy with carbon capture and storage (BECCS), require significant water and arable land. Other chemical NETs, such as enhanced weathering, risk changing the chemistry of oceans and rivers.

DACCS avoids many of these limitations as it has a comparatively small land footprint, but does require a sustainable energy source, geological CO2 storage to operate and is relatively immature technology with as-yet unproven deployment potential. Furthermore, the varying levels of modularity of DACCS systems imply potential for easy scaling up and rapid deployment.

Current information on DACCS costs, performance, and impact of plant siting have several data gaps and significant uncertainties. Despite the climate relevance of DACCS technologies, current capture capacities are only at ktCO2/year levels.

The study develops and carries out a high-level techno-economic analysis (TEA), assesses key global siting factors, derives recommendations for the IAM community on inclusion and representation of DACCS, and discusses the potentially required policy support mechanisms.

Key messages:

• Although DACCS is more expensive than many carbon mitigation and removal options, careful plant siting and rapid learnings can achieve significantly more competitive DACCS costs.

• First-of-a-kind (FOAK) DACCS projects are likely to range from ~\$400-\$700/net-tCO2, when global average solar photovoltaics (PV) costs are used, or ~\$350-\$550/net-tCO2, when lowest-cost renewables are used.

• Significant cost reduction can be achieved for nth-of-a-kind (NOAK) DACCS plants, reaching ~\$194-\$230/net-tCO2 for 1 MtCO2/year scale, driven by reduced electricity prices, cost of capital and upfront capital investment.

• The lifecycle emissions associated with DACCS range from 7-17% of the CO2 captured for FOAK plants and 3-7% for NOAK plants (if low carbon energy is used).

• Since no large-scale plant is built to date, inherent uncertainties on most parameters are high.

• To date DACCS representation in integrated assessment models (IAMs) has been relatively simplistic. Technical parameters compiled and developed throughout this study can be used for representation of DACCS technologies in future IAM studies.

• Most current DACCS policy support consists of generic R,D&D funding, and financial support aimed at wider negative emissions technologies (NETs) or carbon capture and storage (CCS) technologies.

The aim of this study is to provide a transparent framework to evaluate the potential (in terms of sequestered and displaced carbon), and economics (in terms of cost of carbon avoided and removed) of a non-exhaustive selection of NETs pathways. Ecosystem and socio-economic impacts associated with their deployment is also quantified.

NETs assessment

The study sets out to help the CCS community in trying to gain a better understanding of the costs and value of NETs. It also helps the modelling community in being able to better model the role of NETs; and policy/decision makers in having more information on costs, value and scalability of NETs.

Key messages

• 11 key performance indicators (KPIs) have been defined and assessed for a select number of NET pathways, including direct air capture (DAC), biochar and bioenergy with CCS (BECCS) for power, fuel, hydrogen, steel and cement production.

• The highest CO2 removals are achieved in NET pathways that maximize the capture of CO2, have low energy conversion efficiencies, or have access to low-carbon energy.

• Except for corn-based ethanol, all BECCS to bioenergy pathways achieve net negative emissions in the range of 0.08 - 0.35 tCO2/GJ.

• For pathways involving the production of bioenergy, the amount of CO2 emissions that can be avoided depends on the carbon intensity and on the products/fuel's substitution factor.

• Configurations that maximize the CO2 capture perform better in terms of certain

• Recommendations:

- Demonstration of NETs at scale to improve and validate the existing data.

- NETs should be included in new and existing emission trading schemes.

More information

Download the reports:

www.ieaghg.org

Capture and utilisation news

Chevron invests in Carbon Clean

www.carbonclean.com

Chevron has made a further investment in Carbon Clean and aims to develop a pilot plant in California.

The size and cost of installing carbon capture technology has been a barrier to adoption. Carbon Clean's technology is designed to reduce the costs and physical footprint required for carbon capture compared with many existing approaches. Carbon Clean's technology and fully modular construction also aims to reduce site disruption and facilitate faster permitting.

"Chevron has a long history of supporting innovation," said Chris Powers, vice president of Carbon Capture, Utilization, and Storage (CCUS) with Chevron New Energies (CNE). "We strive to apply our internal capabilities and longstanding partnership approach toward developing and commercializing breakthrough technologies, including those that enable lower carbon solutions in the marketplace."

As part of the new investment, Chevron and Carbon Clean are seeking to develop a carbon capture pilot for Carbon Clean's CycloneCC technology on a gas turbine in San Joaquin Valley, California. Chevron is targeting 25 million tonnes of CO2 per year in equity storage by the end of this decade, with a focus on developing regional hubs that leverage its existing and emerging partnerships with customers, governments, and industry.

Chevron Technology Ventures made an initial investment in Carbon Clean in 2020. In 2021, Chevron launched CNE to accelerate lower carbon business opportunities in CCUS, hydrogen, and offsets and emerging energies, as well as support Chevron's ongoing growth in biofuels.

"Chevron's investment demonstrates interest in our technology, business strategy and rapidly expanding order book. We are seeking to deliver a revolution in carbon capture driven by our modular technology and are thrilled that Chevron shares our vision for the sector," said Aniruddha Sharma, Co-founder and CEO of Carbon Clean.

"We are working to remove the biggest barriers to the adoption of widespread industrial carbon capture. It is vital that we decarbonise hard-to-abate sectors while developing new low-carbon technologies. This latest investment and our work with partners, such as Chevron, will provide us with the opportunity to deliver exponential growth in carbon capture and meet ever rising demand."

Breakthrough in converting CO2 into fuel using solar energy

www.lunduniversity.lu.se

A research team led by Lund University in Sweden has shown how solar power can convert carbon dioxide into fuel, by using advanced materials and ultra-fast laser spectroscopy.

The sunlight that hits Earth during one hour corresponds roughly to humanity's total energy consumption for an entire year. Our global carbon dioxide emissions are also increasing. Using the sun's energy to capture greenhouse gases and converting it into fuel or another useful chemical, is a research focus for many today. However, there is still no satisfactory solution, but an international research team has now revealed a possible way forward.

"The study uses a combination of materials that absorb sunlight and use its energy to convert carbon dioxide. With the help of ultrafast laser spectroscopy, we have mapped exactly what happens in that process", says Tõnu Pullerits, chemistry researcher at Lund University.

The researchers have studied a porous organic material called COF - covalent organic framework. The material is known for absorbing sunlight very efficiently. By adding a so-called catalytic complex to COF, they succeeded, without any additional energy, in converting carbon dioxide to carbon monoxide.

"The conversion to carbon monoxide requires two electrons. When we discovered that photons with blue light create long-lived electrons with high energy levels, we could simply charge COF with electrons and complete a reaction", says Kaibo Zheng, chemistry researcher at Lund University.

How can these results be useful? Tõnu Pullerits and Kaibo Zheng hope that in the future the discovery can be used to develop larger units that can be used on a global level to, with the help of the sun, absorb carbon dioxide from the atmosphere and convert it into fuel or chemicals. That could be one of many solutions to overcome the climate crisis we are facing.

Shell's CANSOLV CO2 capture technology contracted for Humber Zero

www.shell.com/CT

www.humberzero.co.uk

Shell Catalysts & Technologies has been appointed to provide the technology that will capture millions of tonnes of carbon dioxide from the VPI Immingham combined heat and power station as part of Humber Zero.

Humber Zero is a government-supported multi-billion-pound project to decarbonise vital industry in the Immingham industrial area in northern Lincolnshire, on the south bank of the River Humber. The total project will incorporate both post-combustion carbon capture and the production of hydrogen for energy. The entire project aims to prevent up to eight million tonnes of CO2 from being released into the atmosphere as a greenhouse gas and will future-proof industry in the region.

Shell will be providing Shell's CANSOLV CO2 post-combustion carbon capture technology to be retrofitted to the VPI Immingham power station stacks which emit carbon-rich flue gas. Shell's Alliance partner for CANSOLV CO2 technology, Technip Energies, will support the design of the capture unit and the pilot plant. The technology will capture 95 per cent or more of the CO2 in the gas, allowing it to be compressed, transported and safely stored in geological structures under the seabed.

VPI Project Director for Humber Zero, Jonathan Briggs, said, "Industrial decarbonisation at scale using carbon capture and storage will be essential if the UK is to achieve its ambition of a Net Zero economy by 2050. Humber Zero's goal of decarbonising the Immingham industrial site will capture up to eight million tonnes of carbon from critical industry and make a significant contribution to toward reaching that goal.

As the UK's largest cluster by industrial emissions, decarbonisation of the Humber Region by 2040 is critical for the UK's net zero ambitions.

Wyoming CarbonSAFE Project team drills second exploratory test well

Led by the University of Wyoming School of Energy Resources (SER) and in collaboration with Basin Electric Power Cooperative, a team of researchers and partners on the Wyoming CarbonSAFE Project recently began drilling a second deep test well for site characterization.

Spudding of the test well near Basin Electric's Dry Fork Station near Gillette began Dec. 23 and, despite the frigid temperatures and blustery wind, the well is nearing completion.

"This second well will lead to valuable information to fully characterize a second carbon storage site in Wyoming -- taking another step toward building a carbon capture, utilization and storage (CCUS) industry in the state," says SER Executive Director Holly Krutka. "I am proud of the team in SER's Center for Economic Geology Research and our project partners for their dedication in the adverse weather and over the holidays to advance this project."

The U.S. Department of Energy-funded Carbon Storage Assurance Facility Enterprise (CarbonSAFE) initiative is to determine the suitability of the underground geological formations for commercial-scale carbon dioxide storage.

Phase 2 of the project investigated the storage complex feasibility with the drilling of a test well at the site and a 3D geophysical survey. The well was completed at a total depth of 9,873 feet, and 625 feet of core samples from nine different geological formations were collected for analysis, which has now been concluded.

"Results to date have shown that the geology located below the Dry Fork Station is suitable for commercial-scale geologic storage," says Scott Quillinan, SER's senior director of research.

Quillinan, who serves as a co-principal investigator on the grant with SER's Fred McLaughlin and Kipp Coddington, notes that the efforts of the comprehensive team and project partners have played an integral part of the project's success thus far.

"There has been a tremendous amount of work that has brought us to this point," Quillinan says. "There are a lot of pieces that had to fall into place that have been built off the complex analysis of data by SER scientists and our project team. As we continue to advance the project, we are grateful for the expertise and support found here in Wyoming."

The current project activities of Phase 3 are focused on finalizing the site characterization, well permitting and carbon dioxide capture assessment.

Adjacent to a first well that was completed in 2019, the new well allows researchers to gain valuable data and fully characterize the geologic layers of the subsurface site, including the target storage reservoirs and the cap rock seals.

According to McLaughlin, the interim director of SER's Center for Economic Geology Research (CEGR), the second well will allow the team to design a testing program to measure the response of injection -- using water -- within the formations. Additionally, the team will address some of the research questions that previous field activities presented.

"We are so fortunate to be able to drill a second well at the study site," McLaughlin says. "For the long term, we propose that this is the best way to optimize the injection of carbon dioxide in the three deep geologic formations that our technical team has characterized at the site. All of this will help us address remaining challenges for future commercial activities."

To provide a full analysis of the site, othermajor ongoing activities include wide-scale baseline monitoring of soil gas, seismic activity and water samples. Charles Nye, a CEGR associate research scientist, has led the efforts.

"The detailed baseline analysis will allow us to differentiate between natural and anthropogenic CO2, monitor the migration of the CO2 plume and pressure front, and verify containment effectiveness," Nye says.

A unique attribute of both wells is that they have been drilled and will be completed to meet Class 6 well construction standards and will likely become Wyoming's first Class 6 CO2 injection wells for geologic storage.

Wyoming's Department of Environmental Quality recently completed the permitting guidelines for Class 6 wells in the state, including both drilling a well and operating one. Additionally, this project will provide an open-book analysis of the Class 6 permitting process for all Wyoming stakeholders. The technical and regulatory team will publish the findings and results of drafting the Class 6 permits.

"These wells are the first two wells in Wyoming that will be completed to the rigorous standards of carbon storage wells, which necessitate the use of noncorrosive construction materials and an expanded subsurface testing program designed to meet permitting requirements," McLaughlin says. "When the wells are constructed, the team will work to complete Class 6 applications in an effort to make the field site the first fully permitted and constructed carbon storage site in Wyoming."

"We are grateful for all of the support we have received to drive this innovative project -- from the Department of Energy, to the state of Wyoming and our project partners," Krutka says.

"Together, we are demonstrating that Wyoming has safe, secure CO2 storage options, and we appreciate the chance to engage with the public to discuss the opportunities for Wyoming and beyond afforded by the deployment of this exciting technology."

More information

www.uwyo.edu

Transport and storage news

Researchers identify factors for safe and effective carbon capture and storage

www.utexas.edu

Researchers at the University of Texas at Austin have developed computer models to optimize CO2 storage in porous rocks in underground reservoirs.

Sahar Bakhshian, a researcher at the University of Texas at Austin's Bureau of Economic Geology, recently used supercomputers at the Texas Advanced Computing Center (TACC) to fundamentally understand how CO2 storage works at the level of micrometer-wide pores in the rock, and to determine the characteristics and factors that can help optimize how much CO2 can be stored.

Writing in the International Journal of Greenhouse Gas Control in December 2021, she explored the trapping efficiency of CO2 through dissolving the gas into the resident brine in saline aquifers.

"We tried different scenarios—using different injection rates and fluid-rock properties—to determine how the properties affect what percentage of injected CO2 can ideally be trapped by the dissolution mechanism," she explained.

She found that two factors greatly impacted the amount of CO2 that could be stored in the spaces within the rocks: wettability (or how well CO2 molecules stick to the surface of the rock); and injection rate (the speed at which supercritical CO2 is pushed into the reservoir).

Another effective process that ensures the security of CO2 storage is capillary trapping, which happens when CO2 pinches off and becomes immobilized in the pore space by capillary forces. In a study published in Advances in Water Resources in April 2019, Bakhshian presented the results of pore-scale, two-phase flow simulations that used digital versions of real rocks from a CO2 storage test-site in Cranfield, Mississippi to explore how CO2 migrated through the rock's pore structure during the injection stage and how it can be trapped as immobilized blobs in the pore space during post-injection.

Bakhshian's work is done under the auspices of the Gulf Coast Carbon Center (GCCC), which has been working on understanding the potential, risks, and best methods for geologic carbon storage since 1998.Play

Supercomputers are one of the key tools that geoscientists have at their disposal to study processes relevant to carbon capture and storage, according to Bakhshian. "Computational fluid dynamics techniques are essential for this field, to better screen suitable target reservoirs for CO2 storage, and predict the behavior of CO2 plumes in these reservoirs," she said.

Understanding the dynamics of storage capacity at the level of the pore through high performance computing simulations provides one lens into how carbon capture and storage could be achieved on a large scale.

"Our research is basically trying to characterize geologic settings suitable for storage and exploring the way we inject CO2 to make sure it's safe, effective and poses no threat to people or groundwater resources," said Bakhshian.

Another aspect of Bakhshian's research involves using machine learning techniques to develop computationally fast models that can estimate the storage capacity of reservoirs and assist with the environmental monitoring of CO2.

Writing in Environmental Science and Technology in October 2021, Bakhshian proposed a deep learning framework to detect anomalies in soil gas concentration sensor data. The model was trained on data acquired from sensors being used for environmental characterization at a prospective CO2 storage site in Queensland, Australia.

Bakhshian's method, which incorporates processes based on natural soil respiration into a deep learning framework, was able to detect anomalies in the sensor data that, in future applications, could represent either sensor errors or leakages.

"Having a trustworthy real-time anomaly detection framework that is trained using the streaming sensor data and guided by a process-based methodology could help facilitate environmental monitoring in future projects," Bakhshian said.

According to the Global CCS Institute, the U.S. is one of the nations with the greatest potential for geologic CO2 storage. Though some environmentalists argue that CCS is simply a way for energy companies to continue to extract fossil fuels, others, including the International Panel on Climate Change, include CCS as one of the ways the global community can achieve net-zero emissions by mid-century.

"It's safe and effective," said Bakhshian. "And computing will help us find economical ways to achieve this goal."

Santos books 100 million tonnes of CO2 storage resource

www.santos.com

Santos has booked CO2 storage capacity in the Cooper Basin in South Australia as part of it's annual reserves statement.

The storage represents a subset of the total prospective storage resource in the Cooper Basin and follows the final investment decision on the 1.7 million tonne per annum Moomba carbon capture and storage project in November 2021.

Santos believes this is the first booking in the world in accordance with the CO2 Storage Resource Management System (SRMS) sponsored by the Society of Petroleum Engineers.

Santos Managing Director and Chief Executive Officer Kevin Gallagher said today's announcement of storage capacity in the Cooper Basin is a significant step in Santos' decarbonisation pathway and carbon storage hub strategy.

"CCS is a critical technology to achieve the world's emission reduction goals and we only have to look at current carbon prices to see how valuable 100 million tonnes of storage is," Mr Gallagher said.

"Santos sees CO2 storage capacity as a strategic competitive advantage in evolving cleaner energy, clean fuels and carbon markets. This globally significant carbon storage capacity booking is another tangible example of Santos leading the way in establishing the foundations to support the energy transition."

The announcement forms part of the release of Santos' Annual Reserves Statement.


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