Carbon Capture Journal

CCUS in Canada

International CCS Knowledge Center - the business case for CCS

Canada could play leading role in carbon conversion industry

LafargeHolcim cement CO2 emissions re-use

Sept / Oct 2019 Issue 71

CMC Research Institutes' Field Research Station

Chevron's Gorgon project starts storing CO2

Electrocatalytic reactor converts CO2 into liquid fuel

Global storage regulations reviewed in new CCP report

'Crucial Role' of Oil and Gas Industry in meeting UK Net Zero targets

Hydrogen production with CCS in Australia's Gippsland region

The Australian Carbon Innovation and Federation University event, 'Hydrogen - a pathway to environmental and regional prosperity - where to for Gippsland?' was held Thursday 8 August 2019

The pathways to hydrogen production and the opportunities this emerging industry presents Victoria's Gippsland region was highlighted at an event at Federation University, Churchill, on Thursday 8 August, reports the Global CCS Institute.

The event, titled Hydrogen Forum: A pathway to environmental & regional prosperity - Where to for Gippsland?, brought together researchers, industry and community heard from a range of speakers on the pathways to hydrogen production, including from fossil fuels with CCS, its applications and export market potential.

In his welcome, Mayor of the Latrobe City Council, Cn Graeme Middlemiss, encouraged the delegates to view brown coal as a resource; one that can be utilised for new industries such as hydrogen production and recognised as vital in securing the future of the Latrobe Valley and its communities. He noted this would not only be beneficial to the Gippsland region, but to Australia, and welcomed the open discussion around, and progression of, the hydrogen story in the Latrobe Valley.

Australia's Chief Scientist and Chair of the National Australian Hydrogen Strategy Working Group, Dr Alan Finkel, presented the keynote address. During his presentation, Dr Finkel explained that with limited options to decarbonise our energy system, scale and diversity need to be considered, and demonstrated the unique capabilities hydrogen offers.

He added that hydrogen production from coal or natural gas will be an important part of Australia's energy transition, calling it the is the "third primary energy source for a low emissions economy", and noting that has to be done with carbon capture and storage. Dr Finkel also addressed cost, saying that for hydrogen in the Latrobe Valley, hydrogen production from brown coal is "likely to be cost competitive".

Global CCS Institute CEO Brad Page spoke of the new energy economy that is required to reach global climate change targets, and the opportunity that hydrogen - as a zero emission, flexible fuel - offers as part of the decarbonisation road map. He demonstrated the various applications of hydrogen, it's low relative cost when produced with natural gas or coal with CCS and the twelve hydrogen production with CCS facilities currently operating or in planning around the world.

In addressing the potential that hydrogen production presents the Latrobe Valley, Mr Page spoke of the region's abundant natural resources, extensive sunk cost infrastructure, highly skilled workforce, familiarity of the resources industry and well-characterised, offshore geological storage nearby. With a carbon constrained future confronting the local and regional economy of the Latrobe Valley,

Mr Page told the audience that climate change does not mean no fossil fuels; addressing CO2 is the issue. It is in this context that CCS can facilitate a new, clean energy economy of hydrogen production for the region, delivering jobs, a strong economy and further efficient new industries.

Gabrielle Henry of the Victorian Government's Department of Environment, Land, Water and Planning spoke about the Victorian Hydrogen Investment Program, sharing the progress and plans for renewable energy generated hydrogen. Ms Henry's presentation demonstrated once again the need for all options to be pursued for Victoria to achieve it's net-zero emissions target by mid century.

Other speakers earlier in the day included Parliamentary Secretary to the Treasurer, Steve Dimopoulos MP, the CSIRO's Dr Patrick Hartley, Richard Bolt from Swinburne University of Technology and Mr Koji Omata and Mr Seiji Hongo of J-Power Latrobe Valley who presented coal to hydrogen technology and what it means for the Latrobe Valley.

The afternoon session centred on the social and end user perspective of the hydrogen opportunity with University of Queensland's Professor Peta Ashworth presented research findings on the social license requirement of hydrogen production, followed by Professor Michael Brear of University of Melbourne who spoke about hydrogen from a safety perspective and Toyota Australia's Troy D'-Souza on the progress to date, and future, of hydrogen fuel cell vehicles.

The day concluded with an informative Panel discussion enabling those present, including the community, to engage with representatives from industry, academia and local Gippsland leaders on the topic of whether hydrogen production for the region presents a success story or a pipe dream.

It was clear from each presentation, and the Panel discussion, that Hydrogen production presents an incredible opportunity for the Gippsland region. Hydrogen production offers the region the chance to secure a sustainable future through utilising its abundant natural resources, suitable geology, existing local workforce and high levels of community acceptance of extractive industries.

The Forum was hosted by Australian Carbon Innovation and Federation University, full presentations will be available from the ACI website.

More information

View presentations:

www.acinnovation.com.au

www.globalccsinstitute.com

Carbon Capture Journal

Sept / Oct 2019 Issue 71

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

Editor
Keith Forward
editor@carboncapturejournal.com

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

Subscriptions
subs@carboncapturejournal.com

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

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

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

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

Front cover:

CMC Research Institutes' Field Research Station for the development of carbon monitoring technologies – Canada could play a leading role in the carbon conversion industry (pg. 6)

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

Leaders - CCUS in Canada

Projects and policy

Capture and utilisation

Transport and storage

Making a business case for large-scale CCS

In a world dedicated to having both a safe, clean environment - represented in the COP21 Paris Agreement; and having economic progress – evident with the desire and drive for growth and prosperity, a consolidative and deployable approach that holds both these qualities with integrity is needed.
By Beth Hardy, VP Strategy & Stakeholder Relations, International CCS Knowledge Centre

"There is no silver bullet to a 2-degree-or-less future. We need to stop putting carbon dioxide (CO2) into the atmosphere, and for that we need to fire off at least three bullets at once: energy efficiency, renewables, and carbon capture and storage (CCS)," as citied in the DNV-GL article by Kaare Helle and Anne Louise Koefoed.

Shifting away from the world's dependence on fossil fuels for secure and reliable energy has been a slow process. In fact 81% of the world's energy supply is still sourced from fossil fuels (Total Energy Supply by Type, IEA). This has been the situation for over 30 years. As long as it is in the mix, CCS is needed to close the emissions gap. Experts from governments and industry continue to stress that carbon capture is nothing new – in fact it is well understood and operating, so the barrier to mobilization is not the technical know-how, but rather due to a lack of policy or policy uncertainty.

In a climate of ambitious emission reduction targets, CCS has been proven to be a reliable and adaptive technology which will realize significant cost reductions - in a study spearheaded by the International CCS Knowledge Centre, next generation CCS plants could see capture capital cost reductions of 67% per tonne of CO2, bringing the cost of capture down to USD$45/tonne.

Business Models for CCS

With technological certainty and reductions in risk and cost, policy drivers can be supported by strong business cases for CCS. For example, in Saskatchewan Canada retrofitting Unit 3 at the SaskPower Boundary Dam Power Station (BD3) had the benefit of federal and provincial government funding as a first mover; saw the retrofit add three decades of operation to an aging power plant, rather than decommissioning it; and, the sale of byproducts including CO2 to offset the cost of capture.

At BD3, which has now captured almost three million tonnes, CO2 is either stored in a deep geological sandstone formation or sold for enhanced oil recovery (EOR) where it is ultimately stored permanently in the depleted oil reservoir. As a first out-of-the-gate, BD3 is a pioneer project and a point of pride for Saskatchewan and Canada offering critical lessons for the world in areas of CCS, engineering, and emission reductions.

There are various types of business case models considering both the capture and the storage/utilization sides that an entity may choose when developing CCS. This article explains models in two parts of the process:

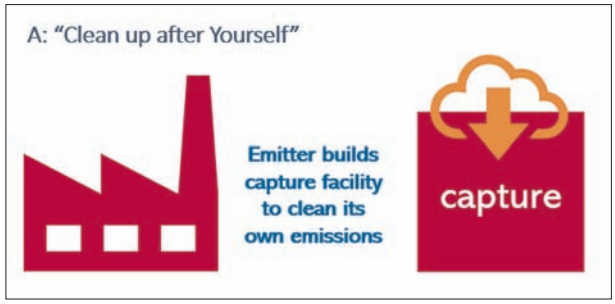
- Emissions Being Cleaned Up – CO2 Capture (Models A,B,C), and
- CO2 Permanently Stored (Models 1,2,3).

Emissions Being Cleaned Up – CO2 Capture

All industrial facilities release CO2 as part of their emissions. Emissions from fossil fuels, cement, iron and steel, or other large sources can all be cleaned up using post-combustion capture technology already in place today.

Model -A- Clean Up after Yourself

Model A represents a company who captures its own emissions. SaskPower used this model at BD3. In that case, Canadian coal regulations were looming, and at the time analyses showed that compared to natural gas prices, CCS would allow the coal plant to extend its life economically, while also having deeper cuts to greenhouse gas emissions. Due to its first-of-kind nature, the project was government subsidized, and was paired with Model 1 below to generate income from the sale of CO2 to an oil field for EOR (with the backup of having its own storage site as well). Other project developers may consider business Model A to simply clean up their emissions; to avoid carbon taxes; or if the CO2 content of the emissions is near pure and easier to capture, therefore reducing costs.



Model -B- The Janitor

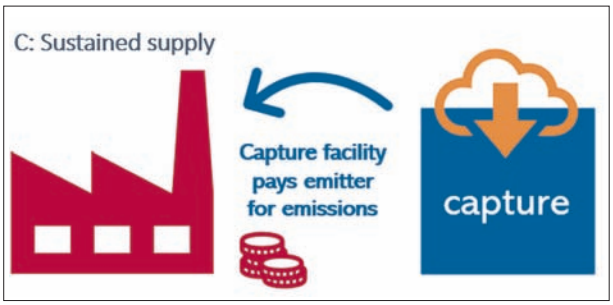
In Model B, the emitter would pay an outside party (CO2-capturer) to clean up their emissions. However, the amount that would be paid to the CO2-capturer would likely not suffice to cover the cost of clean-up. So eco-

nomically, with a price on carbon, that price would have to be lower than the cost to 'hire the janitor' in order for the emitter to act.

Model B is most useful, therefore, when paired with a secondary income from a CO2 off-taker such as Model 1 or 2 below.

Model -C- Sustained Supply

Model C represents a constant input of CO2 from the emitter. This can occur in two scenarios: First, when a CO2-capturer purchases CO2 from an emitter to sell on the market to an off-taker. The CO2-capturer may want a supply guarantee to avoid a penalty with its off-taker. The second scenario would occur if the capture design required a minimum or constant CO2 input level. A problem factor comes when the emitter is a power plant and there isn't enough power demand to generate the required level of emissions.

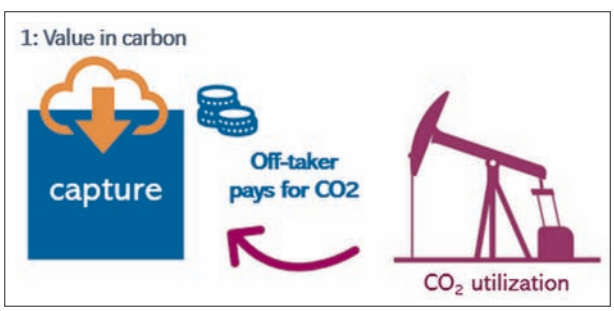


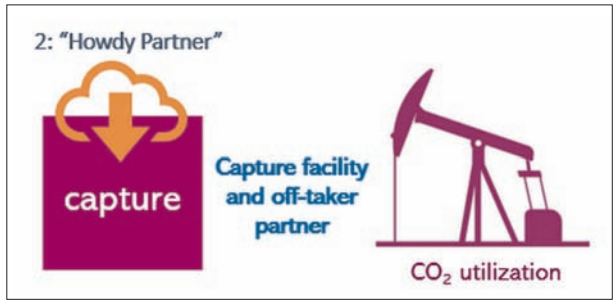
CO2 Permanently Stored

The permanent storage of large amount of CO2 is crucial to meeting objectives of the Paris Agreement. Alongside sequestration, CO2 utilization via EOR also falls into the category of permanent storage because in both instances large amounts of CO2 stay deep underground.

Model – 1- Value in Carbon

As briefly mentioned above, business Model 1 represents a party purchasing the CO2 from the capture facility. This could be any form of utilization, but in the case of the BD3, an oil company purchases CO2 from SaskPower. In this instance there is value in the CO2.





Model -2- Howdy Partner

A successful model for the Petra Nova CCS Project has a CO2 off-taker (like in Model 1) and paired it with a secured interest in the CO2 provided to them. In Model 2 having a partnership places a direct investment in the outcome and output of the CCS project.

There are logical and essential business models in utilizing CO2 in ways other than EOR such as value-add products like adding CO2 to concrete or other notable processes. However, as Imperial College London's Dr. Niall Mac Dowell highlights in his article "The role of CO2 capture and utilization in mitigating climate change", utilization other than EOR "should be encouraged when and only when CO2 is useful as a cheap feedstock, or when it can robustly and reliably shown that the CO2-derived product can reasonably displace the incumbent product, that is, deliver the same service at the same price, and also not result in an increase in the emission of CO2 associated with delivering that service." Dr. Mac Dowell also has an informative graph that shows these processes can only reduce minimal amounts of CO2.

Given the findings of that article, the need to reach mitigation targets, and the simple fact that the large-scale storage doesn't have the front-and-centre marketability of other utilization opportunities, the end-use models are critical business considerations for large-scale permanent CO2 storage. EOR is one method of recouping costs, however, not all locations can find profit in this way – which leads us to Model 3.

Model -3- The Garbage Man

In Model 3 the off-taker gets paid to be the ultimate end point in storing away the CO2. This concept is gaining interest for countries looking to limit emissions. For instance, a new hub at the Port of Rotterdam plans to create a CO2 transport hub to serve the Netherlands' industrial facilities with the potential to expand to serve industrial plants in other countries looking to dispose of their CO2 such as Belgium, Germany or the UK.

The pipeline network would transport the CO2 for injection in depleted oil and gas fields in the North Sea. It is a prime example of how non-EOR CO2 hubs can exist for storage. However, there is criticism that this can only exist if the price of carbon increases or there is significant subsidizing of development.

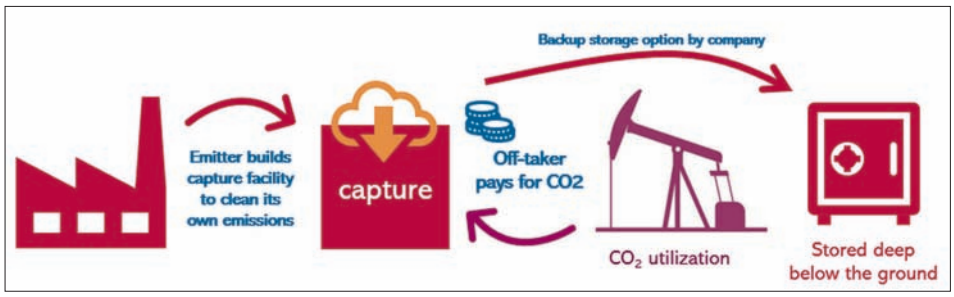
Combing Models Builds Better Business Cases

So how can these models be combined? Let's go back to Boundary Dam 3 CCS Facility. When the project was developed it was decided to take a full-scale approach to permanent storage of CO2. This means not only did it integrate a CCS facility into an existing coal plant (giving 30 years of clean life to the asset) but it also took the CO2 and used it for EOR with the backup option to permanently store it.

The Aquistore project, whose assets are owned by SaskPower, acts as a backup to permanently store CO2 if the off-taker doesn't need or want the CO2 produced. Therefore, captured CO2 isn't emitted into the atmosphere, if the oil company doesn't buy it. With over 30 monitoring technologies installed subsurface and above ground, the Petroleum Technology Research Centre's (PTRC) research program at Aquistore is the largest active field lab in the world for measurement, monitoring and verification proving safe deep geological storage of CO2.

In Alberta, Canada the Quest CCS facility, which is operated by Shell has over four million tonnes of CO2 permanently stored, uses this same sequestration option without the benefit of EOR. Even without EOR, the project makes a profit on its operations because of the provincial carbon price. The project has an operating cost in the mid-$20 per tonne and with a provincial carbon price of $30 per tonne it means the carbon price pays for the costs to operate.

The Alberta Carbon Trunk Line (ACTL) is another example combining models to build a better business case. It brings together multiple partners using proximity and the notion of a hub, the ACTL will aim to maximize the opportunities for capture, utilization in the oil fields, and permanent sequestration. ACTL will consist of a 240km pipeline that can transport up to 14.6Mt of CO2 per year at full capacity. The CO2 in intended to be transported from capture plants at different industrial facilities and then either injected into depleted oil reservoirs for permanent storage or sequestered directly into a permanent deep geological storage site.



Coupling Models & Policy

Climate change is a formidable challenge that requires a formidable, collaborative approach along all avenues for emission reductions. CCS needs to be an active part of the toolkit now and into the future. To reach our collective commitment in the Paris Agreement, the value of CCS goes up, not down.

Business models coupled with market shifts can actively ensure a pickup in CCS deployment – and definitive and clear policies, through a creation of a variety of CCS incentives or subsidies will help drive market shifts.

A convergence of industries, government along with policy mechanisms, to support strong investment in CCS is imperative. Ultimately, and ideally, the world can achieve more large-scale CCS facilities, which means more emission reductions, and a cleaner industrial future.

More information

Beth Hardy
ccsknowledge.com

Boilermakers advocate for CCUS technology in Canada

The Boilermakers Union championed CCUS technology at two key energy and climate events in Saskatchewan and British Columbia in May. www.boilermakers.org

The Boilermakers union partnered with Saskatchewan Building Trades to host a town hall on CCUS in Estevan, Saskatchewan, and participated in a panel discussion with the International CCS Knowledge Centre during the global CEM10/MI-4 conference in Vancouver.

"Climate change isn't just a problem regionally or locally," said Boilermakers International Director for Climate Change Policy Solutions, Cory Channon, who spearheaded the Boilermakers' involvement in the events. "This is a global problem, and the Boilermakers are a part of the global solution."

The CCUS Town Hall in Estevan brought in leaders from the Global CCS Institute and International CCS Knowledge Centre on May 23 to share the latest information on CCUS, provide updates on costs and technology and advocate for local opportunities for additional CCUS projects.

Estevan has much at stake concerning the future of CCUS: Coal mining is among the largest employers in the town, which is also home to the Shand and Boundary Dam coal-fired power stations. Further, the Boundary Dam station is SaskPower's largest coal-fired station and was the first of its kind to have one of its units retrofit for CCUS technology.

"This is very important to us in our community," said Estevan Mayor Roy Ludwig, who works at the Westmoreland Coal Company's Estevan mines and is a member of the UMW. "I've had the privilege to work in a coal mine, and I'm sure all my brothers and sisters will attest that these are great paying jobs and we'd like to keep them going in the community. We want to continue to expand the clean coal technology we're so proud of, and we're going to continue to push for it."

Town hall attendees included trade union members from the Boilermakers, IBEW and United Mine Workers, among other trades; provincial media; provincial-level Member of

the Legislative Assembly Lori Carr; and three prominent federal-level leaders, conservative Members of Parliament Robert Kitchen (Saskatchewan), John Barlow (Alberta) and Ed Fast (British Columbia). "This is a global challenge that requires a global response," said MP Ed Fast. "I'm so pleased to see the Boilermakers and other trades here."

Discussions centered around the technology as well as the potential for another CCUS project—either retrofitting another Boundary Dam unit due for retirement or building a CCUS unit at nearby Shand Power Station. Nationwide, Canada has called for a federal coal phase-out and the shuttering of all coal-fired plants by 2030—unless they are retrofitted with CCUS.

"It all comes down to politics and economics," Ludwig said. Those arguing against CCUS often focus on the technology's price.

Robert Mitchell, Senior Client Engagement Lead with the Global CCS Institute noted that as with any new, first-generation technology, costs for CCUS have decreased and will further decrease as the technology scales up, while at the same time, technology improvements continue to develop. He said there are now 43 CCUS projects in operation, under construction or in development around the world, and that many more are needed—along with all other climate-change solutions—to meet the Paris Agreement targets on climate change.

"What you've done here [in bringing CCUS to the Boundary Dam station] is spur the next generation [of CCUS technology], which will spur the next generation," he said. "We need that; and, in order to meet the IPCC targets and reduce emissions to net-zero by mid-century in an effort to prevent dangerous climate changes, we need all solutions to be deployed as soon as possible, including renewables, hydro, nuclear and carbon capture and storage."

"If you object to CCUS technology, then you object to the United Nations' Intergovernmental Panel on Climate Change report. And that means you are disagreeing with some of the brightest scientists on the planet, who are saying that carbon capture is the pathway to correct the carbon dioxide emissions we are currently throwing into the air globally," Channon reminded the crowd after sharing the Boilermaker-commissioned film "CCS: Bridge to a Cleaner Energy Future."

MP Robert Kitchen lauded the Boilermakers' advocacy of CCUS. "It's great to see the Boilermakers putting up this video. That's the kind of thing we need people to do."

Boilermakers Director of Government Affairs Cecile Conroy serves on a panel to talk about the impact of CCUS technology on jobs and the economy. The panel discussion served a packed, standing-room only event space

Dion Malakoff, executive director of Saskatchewan Building Trades and a member of Local 555 (Winnipeg, Manitoba), added, "We need people to understand how this technology works. We need to debunk the myths."

"CCS: Bridge to a Cleaner Energy Future" was also featured during a special screening at the CEM10/M1-4 conference in Vancouver. The International CCS Knowledge Centre hosted the film in its conference event space.

CEM10/M1-4 is the Clean Energy Ministerial, a high-level global forum that promotes policies and programs to advance clean energy technology, coupled with Mission Innovation, a global initiative of 23 countries and the European Commission working together to accelerate clean energy innovation and address climate change. The conference brings together the most prominent leaders in government, private sector and international organizations to promote progress toward a clean energy future.

In addition to the film screening, the Boilermakers served on a panel discussion on CCUS co-hosted and moderated by both the Knowledge Centre's President and CEO Mike Monea and ClearPath's CEO, Rich Powell. This was also held in the Knowledge Centre's event space. Director of Government Affairs Cecile Conroy represented the Boilermakers on the panel, joining Michal Kurtyka, Poland's Minister of Energy and Environment and COP24 President; Steve Winberg, the U.S. Department of Energy's Associate Secretary for Fossil Energy; Tim Thomas, Mitsubishi's Vice President of Heavy Industries; Hang Wang, Deputy Director-General of the Agenda 21 Administrative Centre, Ministry of Science and Technology, China; Mechthild Wörsdörfer, Director of Sustainability, Technology and Outlooks for the International Energy Agency, France; and, Richard Jackson, President of Occidental Low Carbon Ventures and SVP of Operations.

Amid discussions about CCUS technology, costs, different applications for CCUS (such as in manufacturing) and timelines for continued development and scale-up, Conroy was specifically asked to address the impact of CCUS on jobs and the economy.

"The Boilermakers have spent decades modernizing the power sector with effective pollution controls, and we see CCUS as the natural progression of that for the future of our craft," she said. "CCUS is a win-win for jobs and the environment. This is a global issue, and CCUS is a solution, not just to preserve jobs and our communities, but to truly ensure our planet survives."

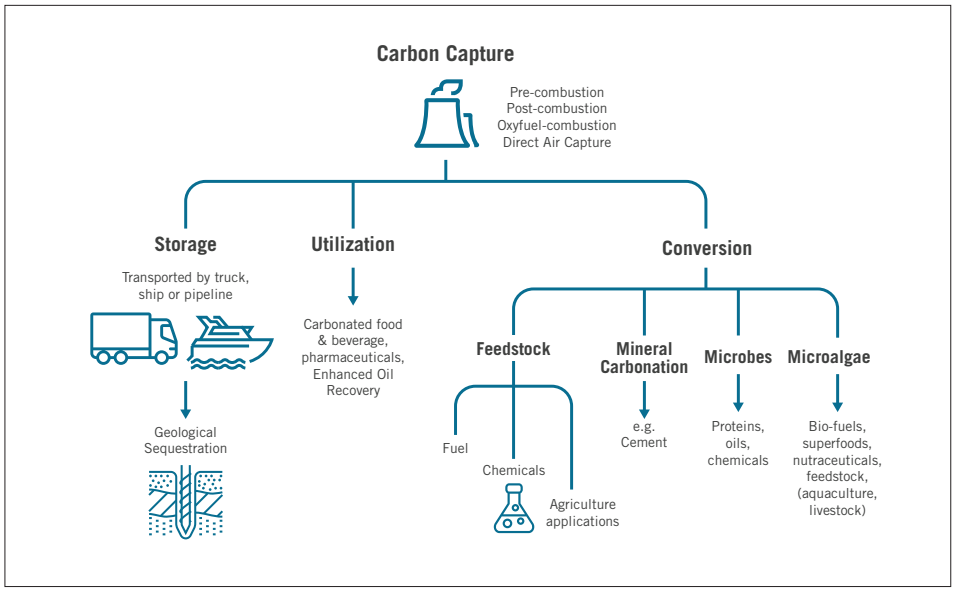
"CCS technology is proven, it's continually improving and now it can be done much cheaper too," said Monea. "As global citizens concerned about sustainability and climate, we need action more than just conversations about CCS. And when the Boilermakers come in, it's not just talk. These guys—the Boilermakers—are ready to do it."

Canada could play leading role in carbon conversion industry

A new report by by CMC Research Institutes documents Canadian strengths in carbon capture, conversion, utilization and storage technology development.

A new report championing the strengths of the Canadian carbon capture, utilization and storage sector says the country has the expertise, infrastructure and drive to play a leading role in the growing global low carbon economy.

The report, by CMC Research Institutes (CMCRI) and Canadian Business for Social Responsibility (CBSR), details the challenges and opportunities behind four tools that are key in the growing global effort to reduce greenhouse gas emissions: carbon capture, conversion, utilization and storage (CCUS). It concludes that Canada has the necessary elements to position it as a leading source of all these technologies but that converting carbon into commercial products could be especially lucrative.



Overview of CO2 capture, utilization, conversion, and storage pathways. (CBSR, 2019)

"The global market for carbon products could be an estimated $800 billion. We found that Canada is well-positioned to take advantage of those markets," says Sandra Odendahl, President and CEO of CMCRI. "It will take a focused effort to build a robust carbon conversion sector in Canada, but our report demonstrates that we've already got the ball rolling."

The report documents a number of strengths Canada has in the CCUS sector which include:

Several technology innovation and testing hubs located across the country, including CMCRI's research station for testing CCS measurement and monitoring technologies, and its carbon capture and conversion technology test centre;

Large-scale pilot and commercial CCS projects operating in western Canada including Shell's Quest facility in Alberta and the Boundary Dam Capture and Storage project in Saskatchewan. Coming online this fall is the Alberta Carbon Trunk Line which will supply captured CO2 for enhanced oil recovery in central Alberta;

The existence of regulations for carbon capture and storage operations in Alberta which provide a model for other jurisdictions; and

Federal and provincial government support for the development and scale up of clean technologies.

Canadian entrepreneurs are active in the conversion technology space and have been developing innovative processes for creating products from captured carbon. Currently, companies and researchers have commercialized or are working on technologies that store carbon in concrete, that use carbon to create minerals that can be used in products such as soap or fertilizer, and that grow algae for use as biofuels or in plastics.

"Innovators are creating products which allow consumers to reduce emissions by purchasing low carbon products and building materials," says Leor Rotchild, Executive Director of CBSR. "Another benefit of these products is that they are often superior to traditional products in the same category."

Both Odendahl and Rotchild hope that highlighting details of the Canadian landscape will increase interest and accelerate development in the country's CCUS sector. To achieve that end, report was written to appeal to a multitude of audiences.

"Too often technology reports are difficult to read unless you're an expert. We wanted something that had broad audience appeal," says Odendahl. "We believe carbon capture, utilization, conversion and storage technologies can make an important contribution to the Canadian economy and also to climate change. But we won't get there until people know about and support them."

More information

Download the report:

www.cmcghg.com

www.cbsr.ca


MAN
Your efficiency rises
MAN Energy Solutions
Future in the making
Oil & Gas solutions expertise
Innovative decarbonizing systems
Satisfying the world's demand for more energy and lower carbon emissions requires imaginative solutions that are both sustainable and profitable. Make use of our expertise in resource-efficient, low environmental impact technologies and services for the upstream, midstream and downstream sectors.
www.man-es.com

Canada news

LafargeHolcim launches carbon capture project in Canada

www.lafargeholcim.com

The objective is to build the world's first full-cycle solution to capture and reuse CO2 from a cement plant while also reducing greenhouse gas emissions. The project is a partnership between Lafarge Canada, Inventys and Total.

Over the next four years, Project CO2MENT will demonstrate and evaluate Inventys' CO2 Capture System and a selection of LafargeHolcim's carbon utilization technologies at its Richmond, British Columbia, Canada cement plant. The project has three phases and is expected to be fully operational by the end of 2020. Subject to the pilot's success, the vision is to scale up the project and explore how the facility can be replicated across other LafargeHolcim plants.

During the first phase the partners will work on purifying the cement flue gas in preparation for CO2 capture. The second phase will focus on the separation of CO2 from flue gas using a customized for cement version of Inventys' carbon capture technology at pilot scale.

As part of the final phase, the captured CO2 will be prepared for reuse and support the economical assessment and demonstration of CO2 conversion technologies onsite, such as CO2 injected concrete and fly ash.

Apart from increasing its focus on new innovative breakthrough solutions such as the CO2MENT project, LafargeHolcim is also further investing into measures to reduce the clinker-to-cement ratio and consume less energy per tonne of cement by using lower carbon fuels and improving the efficiency of the company's processes.

At its Richmond plant, the company recently launched a new and improved lower carbon fuel (LCF) system to reduce greenhouse gas emissions associated with the production of cement. It will also help minimize landfill waste; specifically, non-recyclable plastics that are creating a backlog for municipalities across Canada.

The CAD 28 million system is expected to replace up to 50 per cent of fossil fuel use with lower carbon fuels and could result in a 20 per cent reduction of combustion emissions. It also allows Lafarge Canada to divert approximately 100,000 tonnes per year of waste from local landfills, the equivalent of about 8,300 loaded garbage trucks.

René Thibault, Region Head North America: "We hope to discover ways to capture emissions from our production processes and reuse them in our products, advancing a circular economy even further than today."

Locking carbon dioxide in mine waste

science.ubc.ca

Two Canadian mines will pilot University of British Columbia-led research that combats greenhouse gas emissions by trapping carbon dioxide in mine tailings, the waste left over from ore mining.

The technology could drastically reduce the greenhouse gas emissions of mining operations and result in the world's first greenhouse gas neutral mine.

The project—a collaboration between UBC, the University of Alberta, Trent University and Institut national de la recherche scientifique (INRS) and three leading mining companies—heads to the field this summer with a $2-million boost from Natural Resources Canada's (NRCan) Clean Growth Program. The funding was announced in Yellowknife, N.W.T., as part of the program's investments into clean technology research and development in the Canadian mining sector.

The field trials build on more than a decade of research and will focus on new technologies that maximize the reaction between carbon dioxide (CO2) and magnesium silicate-rich mine tailings, the waste from mining nickel, diamond, platinum and others materials.

In a natural process called carbon mineralization, CO2 reacts with magnesium silicate and hydroxide minerals in tailings. The reaction traps the greenhouse gas into a solid, cement-like mineral, where it can remain in a benign state for thousands of years or more.

"We estimate that reacting just 10 per cent of a mine's waste stream could be more than enough to offset the annual carbon emissions produced by a mining operation," said Greg Dipple, project lead and professor at the Bradshaw Research Initiative for Minerals and Mining (BRIMM) at UBC. "This generous funding from the government and support from our industry partners will allow us to move these technologies to a larger scale at active mine sites.

Field trials will take place at the De Beers Group's Gahcho Kué Diamond Mine in N.W.T. this summer and at a prospective nickel mine in B.C. in 2020. They will be supported by an additional $1.2 million in funding from De Beers Group, FPX Nickel Corp, Giga Metals Corp and Geoscience B.C. and is supported by the governments of B.C., Yukon and N.W.T.

Efforts in N.W.T. will focus on capturing carbon dioxide produced by the mine's powerplant, while testing in B.C. will focus on capturing carbon directly from the atmosphere.

"We've achieved rapid carbonation within days to weeks in the lab," said Dipple. "The challenge is to reproduce this success at large volumes in the field."

In order to achieve results at scale at the active mine sites, the researchers will test more effective ways to identify the most reactive tailings and store them in a way that improves CO2 delivery and reaction.

Co-benefits of the process include stabilizing tailings piles and reducing the amount of dust generated on mine sites.

The current scale of mining of commodities hosted in magnesium silicate rocks would be sufficient to trap between 100 to 200 million tons of CO2 per year if all their waste streams were fully reacted.

"Our work will help to unlock the potential of these minerals as an effective resource for managing greenhouse gas emissions and will contribute to making Canada's resource sector more environmentally and economically sustainable," said team member Sasha Wilson, associate professor and Canada Research Chair in Biogeochemistry of Sustainable Mineral Resources at the University of Alberta.

In the future, the team hopes to expand the technologies to include other types of rocks.

Projects and policy news

Total joins National Carbon Capture Center

www.nationalcarboncapturecenter.com

The U.S. Department of Energy's (DOE) National Carbon Capture Center - which is managed and operated by Southern Company - has welcomed French major energy player Total as a new member.

Total is the second major oil and gas producer to sponsor the center - following ExxonMobil in 2018 - and its membership reflects the center's growing focus on advancing carbon capture, use and storage (CCUS) solutions for natural gas-based power generation. Active in more than 130 countries, Total produces and markets fuels, natural gas and low-carbon electricity.

"Total aspires to become a major player in CCUS technologies, which are vital to achieving carbon neutrality in the second half of the century," said Samuel Lethier, Total carbon capture research and development project manager.

"We are delighted to be part of the National Carbon Capture Center as it provides the tools, expertise and infrastructure to test and evaluate next-generation carbon capture technologies."

The National Carbon Capture Center serves as a neutral research facility to advance technologies that reduce greenhouse gas emissions from fossil-based power plants. Third-party developers bring their technologies to the facility for real-world testing - a key step in bridging the gap between the lab and commercial-scale demonstrations.

Through the evaluation of over 60 technologies, the National Carbon Capture Center has already reduced the projected cost of carbon capture from fossil generation by one-third. The facility is currently adding infrastructure to expand testing of carbon capture technologies for natural gas power plants.

"The duality of flue gas sources available at the center brings a span of compositions, which provide a strong baseline to understand the effectiveness and robustness of technologies to capture carbon dioxide (CO2) from power plants, as well as other CO2-intensive industries such as cement and steel," said Lethier.

Brad Page, CEO of the Global CCS Institute welcomed a delegation from China led by the Ministry of Ecology and Environment

"We are honored to welcome Total into our group of project sponsors, organizations that are committed to finding technology solutions for a low-carbon energy future," said John Northington, National Carbon Capture Center director. "Advancing cost-effective carbon capture technologies is critical in providing clean, safe, reliable, affordable energy. With Total's participation, we look forward to deepening the effectiveness and value of our research."

In addition to Total, partners of the National Carbon Capture Center include DOE and its National Energy Technology Laboratory, American Electric Power, ClearPath, the Electric Power Research Institute, ExxonMobil, the National Rural Electric Cooperative Association, Tennessee Valley Authority, Peabody and Wyoming Infrastructure Authority.

Since its creation by DOE , the National Carbon Capture Center has worked with more than 30 organizations from seven countries to evaluate and scale up emerging carbon capture technologies. In 2019, the facility marked its 10th year of technology development.

Chinese government delegation visits Australia to learn about CCS

www.globalccsinstitute.com

A Chinese government delegation visited Australia from 29 July to 1 August 2019 on a CCS Study Tour. The delegation was led by the Ministry of Ecology and Environment, and included representatives from central government and provincial governments.

The delegation began their CCS study tour in Melbourne where they met with experts from the Global CCS Institute to learn more about the global progress of the technology and discuss ongoing collaborations on CCS. Whilst in Melbourne, the delegation also met with the Victorian Government's CarbonNet Project and had constructive discussions with representatives from the Australian Department of Industry, Innovation and Science, Department of Environment and Energy, and Department of Foreign Affairs. Climate change polices, carbon capture and storage, climate finance and other topics were also discussed.

Spending time in regional Victoria, the group also visited the CSIRO/IHI carbon capture plant at Loy Yang Power Station.

Moving to New South Wales, the delegation met with Coal Innovation NSW where discussions focused on state level CCS projects and programs, had meetings with the Clean Energy Finance Corporation on climate finance and visited CSIRO and University of Sydney to discuss carbon capture research.

UCLA carbon capture team preparing for industrial demonstration

www.co2concrete.com

A UCLA team in the finals of a multi-million dollar, international prize for turning carbon emissions into commercial products, is preparing for a major showcase of its technology.

The team aims to decrease the emission of CO2 from a coal-burning power plant by turning the waste gas into concrete-based building products.

Carbon Upcycling UCLA is one of ten teams in the final round of the NRG COSIA Carbon XPRIZE. The competition is scheduled to conclude in 2020, when two prizes of $7.5 million each will be awarded to a team in each of two energy tracks, coal and natural gas, that demonstrates the most viable technology for turning carbon dioxide emissions into valued products. The UCLA team is one of five in the competition's coal track.

In February 2020, Carbon Upcycling UCLA will move into the Wyoming Integrated Test Center to demonstrate its system at an industrial scale. The test center is part of Dry Fork Station, a coal-based power plant outside the town of Gillette, Wyo.

The demonstration of UCLA's technologies is supported by a $1.9 million grant from the U.S. Department of Energy. The team is working with Susteon, a sustainable technologies development company in North Carolina, to help transition their system up to an industrial level.

Carbon Upcycling UCLA plans to turn carbon dioxide from flue gas—that is, the exhaust gases from a coal-burning power plant—into pre-fabricated concrete blocks called "CO2Concrete," a name that the team has trademarked. The team will operate the system for over 30 days, with the goal of producing up to 10 tons of the product each day. The blocks will then be used in demonstration construction projects.

The team has already demonstrated a prototype system and produced the concrete components and are currently finalizing the design of the equipment for the field test.

"Our vision is that CO2Concrete will be at the center of a much more sustainable and environmentally responsible construction ecosystem," said team lead Gaurav Sant, a professor of civil and environmental engineering, and materials science and engineering at UCLA Samueli.

"We think we have a revolutionary process and product. Not just because of our carbon utilization technology, which alone is really exciting, but our end product appeals to both energy and building construction companies to enable them to meaningfully reduce carbon dioxide emissions."

The carbon-to-concrete technology throws a one-two punch at carbon dioxide emissions, a major greenhouse gas and an underlying cause of climate change.

First, it captures carbon dioxide gas before it exits the power plant, reducing emissions to the atmosphere.

Second, it cuts down on the use of traditional cement, the binding agent in concrete. The production of cement results in more than 8% of annual man-made carbon dioxide emissions, according to the Netherlands Environmental Assessment Agency. The resulting product will have a carbon footprint at least 50% lower than current equivalent building materials, Sant said.

Norway Youth Parties demand full-scale CO2 storage

e24.no

The nine Youth Parties have agreed a common position that the government realize a CO2 capture and storage project as soon as possible.

The head of the Confederation of Norwegian Enterprise (NHO) and the head of the Federation of Norwegian Workers (LO) joined the team to push the government to progress in its efforts to put in place CCS.

"We have gathered a few times before, including with the request that everyone vote. But

this is the first time all nine youth organizations have a common climate requirement," says Labor Youth Party leader Ina Libak.

The NHO boss made clear demands, "When the country's young people gather like this, and the LO and NHO give them full support, then it's time for politicians to take the signal. We demand progress in the process of establishing a system for capturing, transporting and storing CO2," says Ole Erik Almlid, head of the Confederation of Norwegian Business and Industry (NHO).

"After a somewhat slow start, the government came up with money in a revised budget this spring so that the pilot projects in Brevik and waste incineration Klemetsrud can be realized and NOK 345 million for a test well for storage in the North Sea."

"It's good, but it's just the pilots. This is going to be expensive, but it will be more expensive not to do it. They must deliver to get to transport and not just storage in the North Sea," says Almlid.

The estimate for establishing facilities to capture CO2 at the two plants in Oslo and Brevik, as well as storage in the North Sea, is NOK 15 billion. "We expect an investment decision next year and at the latest before the elections in 2021," says the NHO chief.

Young Right and R&D push their own government, 1st Deputy Chairman Daniel Skjevik-Aasberg in the Youth Conservative party is very clear, "We expect the government to follow up with more money and realize the plans for full-scale CO2 storage - as they have promised. We have had enough of crash landings with ambitious CCS projects, now it is time to land it properly," says Skjevik-Aasberg.

The youth in the Progressive party will also join the climate team.

"I have faith in CO2 capture and storage as both an important climate measure, but also as a measure to secure tomorrow's jobs. If we get a commercial solution in place, it will mean a lot for both climate and Norwegian jobs," says chairman Bjørn-Kristian Svendsrud in the Progressive Party's Youth.

He says it is a good start that the government has raised money for an exploration well on the continental shelf.

"I think it is absolutely crucial to get CCS in place. It is not just about cutting the emissions, we also have to clean it up. We simply have to pay for old sins. It must appear in the state budget this fall," says Christian Youth Party KrFU head Martine Tønnessen.

Leader Ada Johanna Arnstad of the Center Youth says Norway needs political climate change, "Small, low-impact measures, such as a slight increase in fuel tax, are getting a lot of attention in the climate debate, while the big promises are too rarely confronted by the parent parties. They should take the signal when all the youth parties come together about this measure," she says.

AUF leader Ina Libak says it is urgent, "Norway may become a world leader in carbon capture and storage due to its expertise in the oil and gas sector, but then we must speed up. At the moment, this is not enough, we at AUF think we must use public investment to get started," says Libak.

"We must shut down the oil industry and cut all Norwegian emissions, but at the same time we must contribute to technology to extract CO2 from the atmosphere so that we can limit global warming down to 1.5 degrees," says Sondre Hansmark of Young Left.

"CCS must be in place, but it must not be a reason for the fossil industry to continue business as usual. Extraction of fossil energy such as oil and gas must be discontinued by 2030," says Andreas Sjalg Unneland in Socialist Youth.

"It is incredibly important to get CCS in place. The state must take responsibility and provide funding," says Tobias Drevland Lund in Red Youth.

LO leader Hans-Christian Gabrielsen says CCS can be a great industry for Norway, "It can be built on the shoulders of today's oil industry. One thing is new jobs and new industries in a climate-friendly future. But we must also ensure that existing jobs are secured and restructured."

"We are talking here about 30-40,000 new jobs, and that we can secure 80-90,000 existing jobs, with the strength of the ripple effects; up to 200,000. This will be a very important restructuring industry," says the LO manager.

NHO boss Almlid says CCS is needed to reach the Climate goals, "The UN Climate Panel's 1.5-degree report documents that we need CCS if we are to manage to reduce global emissions by fifty percent by 2030, and come down to zero in 2050. CCS is potentially Norway's most important contribution to the global and European climate agenda: We can offer what Europe lacks - a storage for CO2, and technology for CO2 capture."

Norway's CCS plans look like this. Originally, three relevant projects in Norway were considered, but in 2018 the project was dropped at Yara's facility in Herøya. Two pilot projects that can end up at full scale now remain: the waste facility at Klemetsrud in Oslo and Norcem's cement plant in Brevik.

The companies Equinor, Shell and Total are working on transport and storage of CO2 in a Norwegian full-scale project. The three companies themselves pay large portions of the costs for the pre-planning, but got NOK 345 million in the revised budget to drill an exploration well in the North Sea, where CO2 can be stored where oil and gas were previously stored.

"We believe it is natural for the state to take primary responsibility for the costs of building the infrastructure that allows the CO2 to be transported and stored. There is a long tradition in Norway for that: The state takes the cost of the water and electricity infrastructure and it is natural for this to happen in this area as well, says the head of LO.

The Minister of Petroleum and Energy believes in a new Norwegian industrial adventure. Minister of Petroleum and Energy Kjell-Børge Freiberg (Frp) likes the young initiative and says they plan to deliver next fall.

"I understand the impatience, and we are impatient as well. But the lessons of the CCS work so far is that you cannot just decide for it to succeed, it must be created. We do this with the industry, We do this with the industry, by laying stone on stone. Projects of this magnitude must be quality assured," he says.

"But we want to succeed. I both hope and believe that we can create a new Norwegian industrial adventure."

He was asked if the cost is estimated at NOK15 billion, what percentage are you willing to pay?

"We are negotiating this with the industry. This distribution will be part of the decision-making basis, which we hope we can deliver to the Storting in the autumn of 2020. We are also in dialogue with the EU, which has shown a strong increase in interest and who initiated a CCS meeting in Oslo in September."

CSIRO In-Situ Laboratory Project

The CSIRO In-Situ Laboratory successfully monitors a 38t CO2 controlled-release experiment in a fault zone in Western Australia.

The CSIRO In-Situ Laboratory Project (In-situ Lab) entails a configuration of wells at approximately 400 m depth for monitoring the controlled release of CO2 in a fault zone at the South West Hub CCS Flagship project 140 km south of Perth in Western Australia.

The project aims to evaluate the ability to monitor and detect unwanted leakage of CO2 from a storage complex.

The In-Situ Lab consists of three instrumented wells up to 400 m deep:

1) Harvey-2 – primarily for CO2 injection,

2) a fiberglass geophysical monitoring well with behind-casing instrumentation

3) a shallow groundwater well for fluid sampling.

A controlled- release test involving the injection of 38 tonnes of CO2 between 336-342 m depth was conducted successfully in February 2019.

Monitoring during the CO2 controlled-release test included:

a) continuous downhole pressure and temperature recording in the injection well

b) recording of pressure and temperature at the wellhead and at various points in the injection system

c) regular distributed temperature measurements

d) multiple vertical seismic profiling surveys using the behind-casing distributed acoustic sensor fiber-optic cable and geophones

Aerial photograph of the CSIRO In-Situ Laboratory filed site in Western Australia

e) electric resistivity imaging

f) groundwater sampling

g) comprehensive soil flux and atmospheric monitoring surveys

h) collection of gas samples from the surface injection facilities

i) recording of passive seismic data close to the injection well and in the wider area around the well lease

j) downhole video camera surveys

k) pulsed neutron and induction logging

The intermediate depth of injection sets this project apart from shallow-release tests (<25 m) and actual CO2 storage experiments (>800 m) and thereby provides new insights into the monitorability of potential CO2 leakage before it reaches shallow groundwater or the atmosphere. It is also one of the first injection experiments into a fault zone.

The In-Situ Lab project was supported by the Australian Government through the Commonwealth Carbon Capture and Storage Research Development and Demonstration Fund CCS49360. The field experiment was performed in collaboration with the Western Australian Department of Mines, Industry Regulation and Safety (DMIRS), Curtin University, Geoscience Australia, and the University of Strathclyde.

More information

www.csiro.au

UK Government must act urgently to maintain credibility on climate action

The UK has legislated for net-zero emissions by 2050 – now the UK Government must show it is serious about its legal obligations to tackle and prepare for climate change says the Committee on Climate Change. www.theccc.org.uk

UK action to curb greenhouse gas emissions is lagging far behind what is needed, even to meet previous, less stringent, emissions targets. Over the past year, the Government has delivered just 1 of 25 critical policies needed to get emissions reductions back on track, its new report shows.

Meanwhile, action to prepare our homes, businesses and natural environment for a warming world is less ambitious than it was ten years ago. Of 33 key sectors assessed by the Committee in a second, related report, none show good progress when it comes to managing climate change risk.

"The UK is the first major economy to set a net-zero emissions target and intends to host the world's leaders at next year's landmark climate conference (COP26), said Lord Deben, CCC Chairman.

"These are historic steps forward and position the UK at the forefront of the global low-carbon transition. But international ambition does not deliver domestic action. It's time for the Government to show it takes its responsibilities seriously. Reducing emissions to net zero by 2050, requires real action by Government now."

Baroness Brown of Cambridge, Chair of the CCC's Adaptation Committee, said, "The UK is not ready for the impacts of climate change, even at the minimum expected level of global warming. The Government is not yet addressing adequately all of the climate risks it has itself identified as critical – including from surface water flooding and the impacts of high temperatures on health."

"As the UK prepares to host next year's global climate summit, the Government has a window to demonstrate its commitment to addressing these responsibilities. Citizens, homes, workplaces and critical infrastructure must be prepared for a future with unavoidable climate impacts. The effects of climate change are already being felt in the UK."

In order to meet the UK's legally-binding emissions targets, the Committee's 2019 Progress Report to Parliament recommends:

• Net-zero policy is embedded across all levels and departments of Government, with strong leadership at the centre. The new Prime Minister will need to lead the UK's zero-carbon transition from day one, working closely with First Ministers in Wales and Scotland and in Northern Ireland, once appointed.

• Government policies to reduce UK emissions to net zero are business-friendly. Policy should provide clear and stable direction and a simple, investable set of rules and incentives which leave room for businesses to innovate and find the most effective means of switching to low-carbon technologies.

• The public must be fully engaged in the UK's net-zero transition. Over half of the emissions cuts required to reach net zero require people to do things differently. Policy and low-carbon products should be designed around individuals' needs.

• The UK strongly leads international action to tackle climate change. The UK should use its new net-zero target, and potential position as host of COP26, to encourage increased effort to reduce emissions worldwide, including pushing for the adoption of similar world-leading targets by other developed countries in the EU and beyond.

The Committee's report shows that Government plans to deal with climate change impacts are insufficient in critical areas such as the natural environment, health, and business. Key opportunities need to be seized over the next 12 months. The Government should:

• Reward farmers who are working to improve the natural environment. The Agriculture Bill will lead to a new payment system for farmers after the UK leaves the EU. It must support soil and water conservation, habitat protection and natural flood management. The draft Environment Bill also needs to set a framework for environmental targets that take climate change into account.

• Take steps to protect people from the dangerous effects of overheating in homes, schools, care homes and hospitals, including through the current review of Building Regulations.

• Require businesses to disclose the financial risks they face from climate change impacts, including those overseas, and ensure businesses plan properly for risks as well as opportunities for new goods and services. This could include a one-stop shop 'advice service' for small businesses.

• Take positive steps to reduce water consumption. Setting an ambitious water consumption target to reduce the average person's consumption from 140 litres to 100 litres per day is on the Government's agenda. Achieving it will require new measures to help people use water more efficiently.

• Implement the Environment Agency's proposed Flood Strategy, including the need for flexible approaches to manage flooding in different parts of the country, natural flood management measures like tree planting, and increased property-level flood protection – around 9,000 properties need to be fitted with protection per year, up from 500 currently.

There are many co-benefits of taking action to adapt to the impacts of climate change whilst reducing the UK's emissions to net zero. These include improvements to physical and mental health through increased green infrastructure, resilient homes with excellent indoor environmental quality, less noise thanks to quieter vehicles; more cycling and walking; and healthier diets.

Pathways to a low-carbon China

MIT study projects a key role for carbon capture and storage for China to fulfill it's climate change objectives.

Fulfilling the ultimate goal of the 2015 Paris Agreement on climate change — keeping global warming well below 2 degrees Celsius, if not 1.5 C — will be impossible without dramatic action from the world's largest emitter of greenhouse gases, China.

Toward that end, China began in 2017 developing an emissions trading scheme (ETS), a national carbon dioxide market designed to enable the country to meet its initial Paris pledge with the greatest efficiency and at the lowest possible cost.

China's pledge, or nationally determined contribution (NDC), is to reduce its CO2 intensity of gross domestic product (emissions produced per unit of economic activity) by 60 to 65 percent in 2030 relative to 2005, and to peak CO2 emissions around 2030.

When it's rolled out, China's carbon market will initially cover the electric power sector (which currently produces more than 3 billion tons of CO2) and likely set CO2 emissions intensity targets (e.g., grams of CO2 per kilowatt hour) to ensure that its short-term NDC is fulfilled. But to help the world achieve the long-term 2 C and 1.5 C Paris goals, China will need to continually decrease these targets over the course of the century.

A new study of China's long-term power generation mix under the nation's ETS projects that until 2065, renewable energy sources will likely expand to meet these targets; after that, carbon capture and storage (CCS) could be deployed to meet the more stringent targets that follow. Led by researchers at the MIT Joint Program on the Science and Policy of Global Change, the study appears in the journal Energy Economics.

"This research provides insight into the level of carbon prices and mix of generation technologies needed for China to meet different CO2 intensity targets for the electric power sector," says Jennifer Morris, lead author of the study and a research scientist at the MIT Joint Program.

Highlights

- An emissions trading scheme in China affects its generation mix.
- CCS can help China meet low carbon intensity targets for electricity.
- Our modeling shows a potential two-stage transition for China's power sector.
- Renewables expand to meet initial targets; CCS is used for deeper decarbonization.
- Coal CCS in China can be cost-competitive at 35–40$/tCO2 and dominate at 100 + $/tCO2.

"We find that coal CCS has the potential to play an important role in the second half of the century, as part of a portfolio that also includes renewables and possibly nuclear power."

To evaluate the impacts of multiple potential ETS pathways — different starting carbon prices and rates of increase — on the deployment of CCS technology, the researchers enhanced the MIT Economic Projection and Policy Analysis (EPPA) model to include the joint program's latest assessments of the costs of low-carbon power generation technologies in China.

Among the technologies included in the model are natural gas, nuclear, wind, solar, coal with CCS, and natural gas with CCS. Assuming that power generation prices are the same across the country for any given technology, the researchers identify different ETS pathways in which CCS could play a key role in lowering the emissions intensity of China's power sector, particularly for targets consistent with achieving the long-term 2 C and 1.5 C Paris goals by 2100.

The study projects a two-stage transition — first to renewables, and then to coal CCS. The transition from renewables to CCS is driven by two factors. First, at higher levels of penetration, renewables incur increasing costs related to accommodating the intermittency challenges posed by wind and solar. This paves the way for coal CCS. Second, as experience with building and operating CCS technology is gained, CCS costs decrease, allowing the technology to be rapidly deployed at scale after 2065 and replace renewables as the primary power generation technology.

The study shows that carbon prices of $35-40 per ton of CO2 make CCS technologies coupled with coal-based generation cost-competitive against other modes of generation, and that carbon prices higher than $100 per ton of CO2 allow for a significant expansion of CCS.

"Our study is at the aggregate level of the country," says Sergey Paltsev, deputy director of the joint program.

"We recognize that the cost of electricity varies greatly from province to province in China, and hope to include interactions between provinces in our future modeling to provide deeper understanding of regional differences. At the same time, our current results provide useful insights to decision-makers in designing more substantial emissions mitigation pathways."

More information

globalchange.mit.edu

Global storage regulations reviewed in new CCP report

Increased CCS policy confidence and a growth in regulatory regimes for CO2 storage worldwide are among the key findings of a new report published by CCP (CO2 Capture Project).

The 'Survey of CO2 Storage Regulations' report looks at selected recent developments in regulations for CO2 storage projects globally - with particular emphasis on key developments, outstanding issues and gaps that might help or hinder commercial success of CCS.

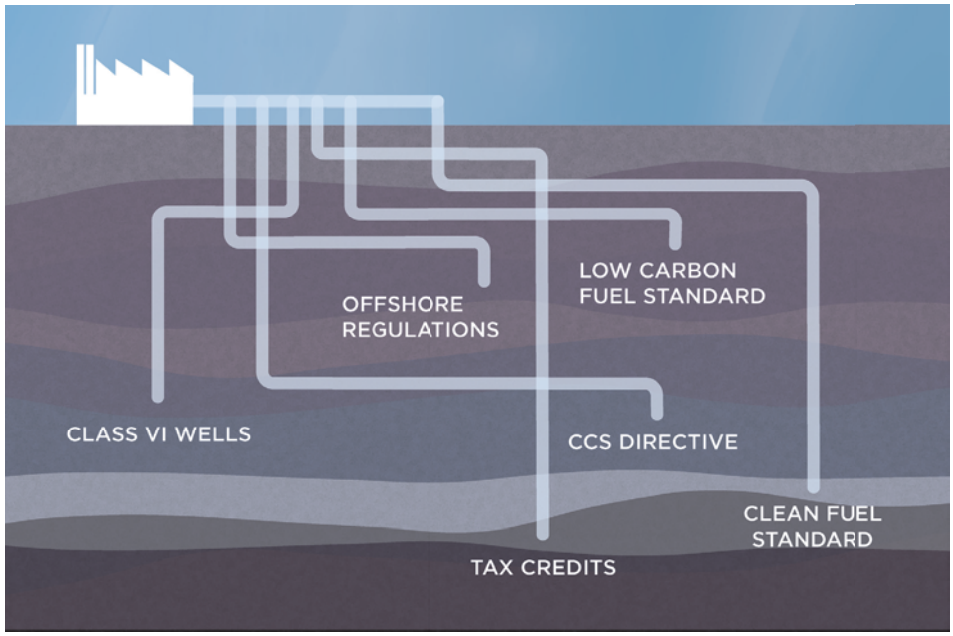
It finds that regulations for CO2 storage are not consistent, with various disparities in the treatment of long-term liability and post-injection monitoring requirements. Despite this, there are some areas - such as the need for proof of financial ability to cover potential liabilities and public engagement - which are, on the whole, being approached in a similar way.

Overall growth in CCS policy confidence is reflected in the development of new regulatory frameworks - such as for tax incentives provided by the Internal Revenue Service's 45Q provisions in the United States. Also, in the growing ambition of certain countries regarding CCS – for example the UK, which has created the CCS Council and CCUS Cost Challenge Taskforce with the aim of making CCS economically feasible.

The report looked at regulations from the USA, Canada, the EU, the UK, Netherlands, Norway, Indonesia, Japan and Australia. These included regulations for permitting and for qualifying CO2 storage projects for incentives. The focus was on CO2 storage projects relevant to oil & gas as well as other industries.

A detailed comparison was undertaken of five different regulatory frameworks that best address the key regulatory issues:

- EPA UIC Class VI Well Permits
- California LCFS
- Alberta CCS Regulatory Framework Assessment recommendations
- EU CCS Directive



- Australian Offshore Petroleum Amendment

Conclusions

Overall, regulators are aiming to promote transparency and generally seem to be taking into account comments from key stakeholders when developing regulations. Although many of these regulations have yet to be rigorously tested due to a relatively low level of CCS project deployment, reviews of regulations have been carried out using hypothetical projects (Victoria, Australia) or recommendations from technical panels (Alberta CCS).

Regulations that have been developed are not consistent across the globe, with key disparities relating in particular to long-term liability and post-injection monitoring requirement. Despite this, there are some areas such as the need for proof of financial ability to cover potential liabilities and public engagement which on the whole are being approached in a similar way.

In general, there has been a growth in CCS policy confidence. This can be seen by the development of new regulatory frameworks, in particular incentives such as 45Q. This is also reflected in the growing ambition of certain countries such as the UK, who have created the CCS Council and CCUS Cost Challenge Taskforce to aim to make CCUS economically feasible.

The GCCSI legal and regulatory indicator ranks only five countries as having legal and regulatory models which are sophisticated enough to address novel aspects of the CCS process, showing there is still a considerable amount of development required in many countries, such as Japan and Indonesia, as highlighted in the report.

The report can be downloaded for free, find it in the 'policies' section on the publications page.

More information

www.co2captureproject.org

Silixa's in-well fibre optic sensing – good for subsea and carbon capture

Silixa reports that its improved fibre optic sensing technology for wells is proving useful in subsea wells and CO2 storage wells. By Karl Jeffery. **www.silixa.com**

UK fibre optic sensing company Silixa reports that its new technology "Carina" is proving very useful in subsea wells, which may have long tie-backs to the nearest platform.

The fibre optic cables are installed permanently in wells and connected to an interrogator system at the surface. The fibre optic cable is installed at the time of completion of the well.

The interrogator sends a light pulse through the fibre, part of which gets reflected back. From the patterns in the reflection, it is possible to detect tiny changes in strain on the cable, which are caused by the effects of acoustics, vibration or pressure acting on the fibre.

The fibre optic cables are commonly used for Vertical Seismic Profiling (VSP) surveys, recording seismic signals as they propagate through the subsurface to the well.

Being permanently installed in a well, they enable repeat surveys to be made inexpensively, because you only need a seismic source, the recording equipment is already in place.

The result is a picture of how the reservoir is changing over time, such as how a reservoir is draining into a well, or how a CO2 injected plume is spreading into the reservoir.

You can also monitor caprock integrity, because the acoustic signature of any cracks in the caprock will be recorded and can be located.

Seismic recording can be much better quality when it is recorded in a well, rather than recording it on the surface, because the seismic energy has a much shorter travel distance. The signal only has to travel from the surface, down to the reflector then to the well, rather than from the surface, down to a reflector and back to the surface.

The conventional way to do seismic surveys in wells is by using geophone wireline equipment which involves lowering an array of geophones into the well temporarily on a winch.

Wireline surveys on subsea wells can cost "tens of millions of pounds", says Andy Clarke, DAS Applications Principal with Silixa. For this reason, they are rarely done.

Another alternative to VSP surveys is to have sensors installed on the seabed, using either ocean bottom cables (OBC) or nodes (OBN).

This technology can generate "amazing images" but a cost of hundreds of millions of dollars, Mr Clarke says.

One difficulty (until now) with fibre optic cables in subsea wells is that the wells are often located tens of kilometres away from the nearest platform, connected through a "subsea tieback", and there was a limitation to the length of fibre optic cable which could be used.

But Silixa has got around this problem by developing its own specially engineered fibre optic cable which enhances the backscattered light enabling much longer lengths of fibre to be interrogated. It calls this cable "Constellation". It is a key component of the "Carina" product.

Constellation provides 100 times better signal to noise ratio compared to standard fibre optic cables. It does this by being specially engineered to reflect more light back to the interrogator.

The Carina system can detect a strain of less than 1 x 10 to the power of -12. (That's a number with 11 noughts after a decimal place, then a one).

It can work with up to 20km of umbilical (cable between the well head and the surface interrogator equipment) and with wells up to 6km deep – so a total length of 26km.

Silixa says that many subsea wells have lower recovery factors than they should do, due to the difficulty of collecting data from them. This is something that subsea fibre optics should be able to help fix.

CO2 monitoring

The same technology has also been used in a number of CO2 sequestration wells, to monitor how the CO2 plume is spreading through the subsurface. It has been used in projects in Australia, the US, Canada, Italy, Spain and Korea.

One project is the Otway experimental CO2 storage site in Australia, storing 65,000 tonnes of CO2 in 6 wells. Here the plan is to use fibre optic sensing to image the whole reservoir.

Other projects include the Battelle CO2 storage project in Michigan and the Citronelle CO2 storage project in Alabama.

The technical set-up is similar, with a permanent fibre optic installation in the well.

As well as monitoring the CO2 reservoir in the same way as you monitor an oil reservoir, you might want to listen for fractures or identify microseismic events that could indicate a compromise to the integrity of the storage medium.

The same system can also monitor the wells for leaks by listening to the sound created by the leak.

Less intrusive sources

The company's Carina system is so sensitive that it allows the use of much less intrusive seismic sources. This is important following environmental concerns about standard seismic sources.

It is experimenting with using continuous low-power seismic sources to gently shake the ground rather than using explosives or large vibroseis trucks..

There have also been experiments using naturally occurring noise, such as sea waves or traffic noise, as a seismic source. This could completely remove the need for any seismic sources.

'Crucial Role' of Oil and Gas Industry in meeting UK Net Zero targets

Oil and Gas UK has published a blueprint setting out five key themes requiring industry, government and regulator action to ensure the sector can continue to provide secure energy supply, support net-zero and remain a vital contributor to the UK economy.

The report identifies several pathways that oil and gas companies can follow to contribute towards the drive towards net zero carbon emissions in the UK.

This ranges from helping to maintain indigenous oil and gas production at a lower emissions intensity (thereby helping to provide energy security by displacing international imports) to incremental investments in alternative energy sources.

Pathway 3 involves supporting and deploying emissions mitigating technologies including CCUS.

Alongside actions to reduce the emissions intensity of oil and gas production, the report says the industry is well placed to support the reduction of emissions produced from the use of oil and gas — which constitute a much greater proportion of emissions in the UK.

"The UK oil and gas industry has the technical and commercial capabilities, skills and resources to support the development and implementation of CCUS and hydrogen capacity at scale."

"CCUS will be crucial to achieving net-zero emissions. The Committee on Climate Change (CCC) report envisages that CCUS will be critical in achieving the net-zero objective, and forecasts that the UK will need to capture and store up to 175 million tonnes of CO2 per annum by 2050 (nearly half of current total UK CO2 emissions)."

"Taking an integrated approach to the development of CCUS infrastructure at scale, beyond the proposed initial clusters, will be essential. At the time of writing, the Department for Business, Energy and Industrial Strategy (BEIS) is consulting on the most appropriate business models for the development of CCUS and of industry."

UK is in a unique position to lead in the development of CCUS, says the report, owing to its geographic location, geological storage potential and experienced supply chain. Furthermore, oil and gas company assets, expertise and investment will be central in implementing this technology.

"While initial costs required to implement CCUS in power generation, heavy industry and other sectors are high, a government-supported programme of investment rolled out across the UK will advance its development. This approach has been crucial in other low-carbon energy sources, such as wind power."

"With an estimated 10,000 CCUS projects required to be online around the world by 2070 to limit global warming to 2°C, the global CCUS industry is forecast to be worth in the order of £100 billion per year by 2050. This compares with 18 operational projects, five under construction and 20 in the early stages of development at present."

"The level of required investment presents diversification opportunities for both operators and supply chain companies. Whilst CCUS projects are still typically sub-commercial, as technologies develop, carbon prices increase and business models evolve, CCUS may become investible on its own merits, supporting a range of increasingly diversified business portfolios."

The report also identifies hydrogen as forming a central element of the next phase of decarbonisation in the UK, while acknowledging that the production of hydrogen through methane reformation needs to be combined with CCUS to be a net-zero source of energy.

What Oil & Gas companies can do

Oil and gas companies have already supported the implementation of CCUS at 18 sites around the world, capturing many million tonnes of CO2. OGUK member companies are active in all the current UK cluster projects on an individual basis and through the Oil and Gas Climate Initiative (OGCI).

Oil and gas companies can work with governments and regulators to develop a commercial, regulatory and technical framework which will allow the required assets to be made available for transport and storage of carbon, and to provide a reliable storage service to projects that capture CO2.

A positive investment framework and long-term commitment are required including:

- infrastructure liability, measurement, reporting and verification
- amendments to EU/UK legislation
- recognition that decarbonised gas is key to meeting UK industrial and domestic heat requirements
- further supportive legislation to develop a UK hydrogen industry.

More information

oilandgasuk.co.uk

Removing CO2 from power plant exhaust - combining capture and disposal

MIT researchers are developing a battery that could both capture carbon dioxide in power plant exhaust and convert it to a solid ready for safe disposal.
By Nancy W. Stauffer, MIT Energy Initiative

Reducing CO2 emissions from power plants is widely considered an essential component of any climate change mitigation plan. Many research efforts focus on developing and deploying carbon capture and sequestration (CCS) systems to keep CO2 emissions from power plants out of the atmosphere. But separating the captured CO2 and converting it back into a gas that can be stored can consume up to 25% of a plant's power-generating capacity. In addition, the CO2 gas is generally injected into underground geological formations for long-term storage—a disposal method whose safety and reliability remain unproven.

A better approach would be to convert the captured CO2 into useful products such as value-added fuels or chemicals. To that end, attention has focused on electrochemical processes—in this case, a process in which chemical reactions release electrical energy, as in the discharge of a battery.

The ideal medium in which to conduct electrochemical conversion of CO2 would appear to be water. Water can provide the protons (positively charged particles) needed to make fuels such as methane. But running such "aqueous" (water-based) systems requires large energy inputs, and only a small fraction of the products formed are typically those of interest.

Betar Gallant, an assistant professor of mechanical engineering, and her group have therefore been focusing on non-aqueous (water-free) electrochemical reactions—in particular, those that occur inside lithium-CO2 batteries.

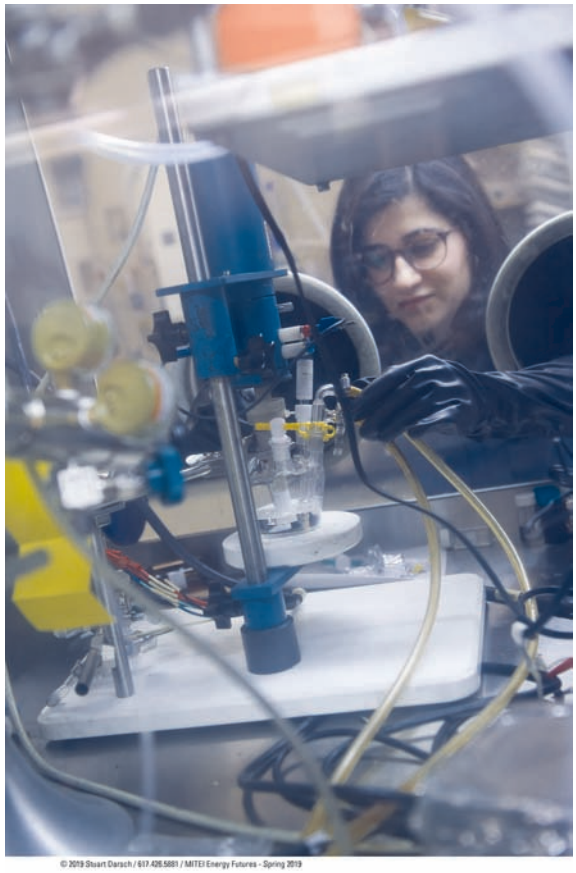
Research into lithium-CO2 batteries is in its very early stages, according to Gallant, but interest in them is growing because CO2 is used up in the chemical reactions that occur on one of the electrodes as the battery is being discharged. However, CO2 isn't very reactive. Researchers have tried to speed things up by using different electrolytes and electrode materials. Despite such efforts, the need to use expensive metal catalysts to elicit electrochemical activity has persisted.

Given the lack of progress, Gallant wanted to try something different. "We were interested in trying to bring a new chemistry to bear on the problem," she says. And enlisting the help of the sorbent molecules that so effectively capture CO2 in CCS seemed like a promising way to go.

Rethinking amine

The sorbent molecule used in CCS is an amine, a derivative of ammonia. In CCS, exhaust is bubbled through an amine-containing solution, and the amine chemically binds the CO2, removing it from the exhaust gases. The CO2—now in liquid form—is then separated from the amine and converted back to a gas for disposal.

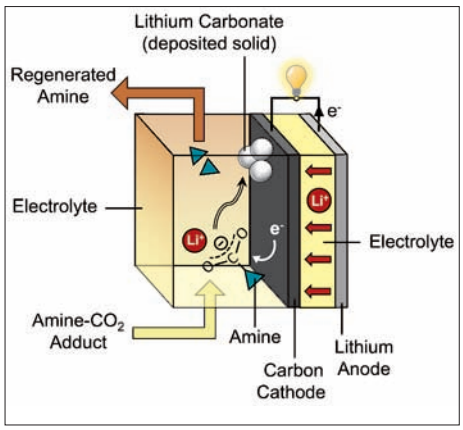
In CCS, those last steps require high temperatures, which are attained using some of the electrical output of the power plant. Gallant wondered whether her team could instead use electrochemical reactions to separate the CO2 from the amine—and then continue the reaction to make a solid, CO2-containing product. If so, the disposal process would be simpler than it is for gaseous CO2.



Graduate student Aliza Khurram prepares for experiments by pumping carbon dioxide through an electrochemical cell consisting of lithium and carbon electrodes plus a specially designed electrolyte. Credit: Stuart Darsch

The CO2 would be more densely packed, so it would take up less space; and it couldn't escape, so it would be safer. Better still, additional electrical energy could be extracted from the device as it discharges and forms the solid material. "The vision was to put a battery-like device into the power plant waste stream to sequester the captured CO2 in a stable solid, while harvesting the energy released in the process," says Gallant.

Research on CCS technology has generated a good understanding of the carbon-capture process that takes place inside a CCS system. When CO2 is added to an amine solution, molecules of the two species spontaneously combine to form an "adduct," a new chemical species in which the original molecules remain largely intact. In this case, the adduct forms when a carbon atom in a CO2 molecule chemically bonds with a nitrogen atom in an amine



Process during discharge of the novel lithium-CO2 battery. The researchers' proposed battery consists of a lithium anode plus a carbon cathode that is surrounded by a special electrolyte that incorporates lithium ions (Li+) and amine

molecule. As they combine, the CO2 molecule is reconfigured: It changes from its original, highly stable, linear form to a "bent" shape with a negative charge—a highly reactive form that's ready for further reaction.

In her scheme, Gallant proposed using electrochemistry to break apart the CO2-amine adduct—right at the carbon-nitrogen bond. Cleaving the adduct at that bond would separate the two pieces: the amine in its original, unreacted state, ready to capture more CO2, and the bent, chemically reactive form of CO2, which might then react with the electrons and positively charged lithium ions that flow during battery discharge (see the diagram below). The outcome of that reaction could be the formation of lithium carbonate (Li2CO3), which would deposit on the carbon electrode.

At the same time, the reactions on the carbon electrode should promote the flow of electrons during battery discharge— even without a metal catalyst. "The discharge of the battery would occur spontaneously," Gallant says. "And we'd break the adduct in a way that allows us to renew our CO2 absorber while taking CO2 to a stable, solid form."

More information

Read the full article in the Spring 2019 issue of Energy Futures, the magazine of the MIT Energy Initiative.

energy.mit.edu/energy-futures

Exploring Clean Energy pathways - the role of CO2 storage

A new IEA report analyses the implications for the global energy system of CO2 storage facilities not being developed at the scale and pace needed to follow the optimised pathway of the International Energy Agency Clean Technology Scenario (CTS).

In the International Energy Agency Clean Technology Scenario (CTS), a cumulative 107 gigatonnes of carbon dioxide (Gt CO2) are permanently stored in the period to 2060, requiring a significant scale-up of CO2 storage from today's levels.

By limiting CO2 storage availability to 10 Gt CO2 over the scenario period, the report analysis provides insights into the additional measures and technologies that would be required in the power, industrial, transport and buildings sectors in order to achieve the same emissions reductions by 2060 as the CTS.

The Limited CO2 Storage scenario variant (LCS) finds that restricting the role of CO2 storage would result in higher costs and significantly higher electricity demand, with 3 325 gigawatts of additional new generation capacity required relative to the CTS (a 17% increase). The main reason is that limiting the availability of CO2 storage would require much more widespread use of electrolytic hydrogen in industry and the production of synthetic hydrocarbon fuels.

More generally, the LCS would increase reliance on technologies that are at an earlier stage of development. Beyond the scenario period of 2060, constraints on CO2 storage availability would also limit the availability of many carbon dioxide removal options, and may therefore not be consistent with the achievement of long-term climate goals.

Policy recommendations

- Support the development and deployment of carbon capture, utilisation and storage (CCUS) as part of a least-cost portfolio of technologies needed to achieve climate and energy goals.
- Accelerate pre-competitive exploration and assessment of CO2 storage facilities in key regions to ensure future availability of storage.
- Establish policy and regulatory frameworks for CO2 storage that provide certainty and transparency for investors and the broader community.
- Facilitate planning and investment for multi-user CO2 transport and storage infrastructure capable of servicing a range of industrial and power facilities.
- Support research, development and demonstration to improve the performance and costcompetitiveness of technologies that may be important where CO2 storage availability is limited, including CO2 use, electrolytic hydrogen and synthetic hydro-carbon fuels produced from hydrogen.

More information

www.iea.org

Capture and utilisation news

ExxonMobil partners with Mosaic Materials on MOFs

mosaicmaterials.com

The companies have entered into an agreement to explore the advancement of Metal Organic Frameworks (MOFs) for removing CO2.

Mosaic Materials has progressed research on a unique process that uses MOFs to separate carbon dioxide from air or flue gas. The agreement with ExxonMobil will enable further discussion between the two companies to evaluate opportunities for industrial uses of the technology at scale.

"New technologies in carbon capture will be critical enablers for us to meet growing energy demands, while reducing emissions," said Vijay Swarup, vice president of research and development for ExxonMobil Research and Engineering Company.

"Our agreement with Mosaic expands our carbon capture technology research portfolio, which is evaluating multiple pathways -- including evaluation of carbonate fuel cells and direct air capture – to reduce costs and enable large-scale deployment. Adding Mosaic's approach will allow us to build on their work to evaluate the potential for this technology to have a meaningful impact in reducing carbon dioxide emissions."

"Through this agreement with ExxonMobil, we look to accelerate the pace of our development and demonstrate the business and environmental benefits that our technology can offer," said Thomas McDonald, chief executive officer of Mosaic Materials. "Our proprietary technology allows us to separate carbon dioxide from nearly any gas mixture using moderate temperature and pressure changes, substantially increasing energy efficiency and decreasing costs."

Mosaic Materials' agreement with ExxonMobil is part of Mosaic's commitment to accelerate the impact of its innovative, low-cost technology, and is Mosaic's latest direct engagement with companies across a range of industries to demonstrate both the cost reductions and the environmental benefits of employing Mosaic's solutions.

ExxonMobil also recently announced a 10-year, up to $100 million agreement to research and develop advanced lower-emissions technologies with the U.S. Department of Energy's National Renewable Energy Laboratory and National Energy Technology Laboratory.

Sheffield project turns CO2 into fertiliser

www.sheffield.ac.uk/sustainable-food

Carbon dioxide captured from the atmosphere could be used to restore degraded soils, save water and boost crop yields. A laboratory study showed pellets boost crop yields by 38 per cent and improve soil water retention by up to 62 per cent.

Scientists at the University of Sheffield's Institute for Sustainable Food in collaboration with industry partner CCm Technologies Ltd have developed pellets made from a mixture of captured CO2 and waste straw or anaerobic digestate from slurry, which can be used like a normal fertiliser to improve the health and water retention of soils.

The production of each tonne of these pellets generates up to 6.5 tonnes less CO2 than a typical conventional fossil fuel-based fertiliser – and could therefore dramatically reduce the carbon footprint of foods like bread.

"These new pellets could turn damaging CO2 into something positive – helping communities to cope with increasingly extreme droughts by allowing farmers to grow more food while using less water," said Dr Janice Lake, Institute for Sustainable Food at the University of Sheffield.

A new study published in the Journal of CO2 Utilization found the pellets improved soil water retention by up to 62 per cent with immediate and prolonged effect, potentially helping crops to survive drought conditions for longer. They also resulted in a 38 per cent increase in crop yields – demonstrating the pellets' potential to grow more food using fewer resources.

There was a 20 per cent increase in microbial growth in soil treated with the pellets, which is crucial for soil fertility and soil functions like decomposition and nutrient cycling. The pellets also increased the pH of the soil, making it less acidic, which could help restore degraded or even contaminated soils – and potentially increase their ability to act as a carbon sink.

Dr Janice Lake from the Institute for Sustainable Food, an Independent Research Fellow at the University of Sheffield's Department of Animal and Plant Sciences, is the lead author of the study. She said: "Faced with a climate emergency and a growing population, we urgently need innovative solutions to feed the world.

"As well as reducing greenhouse gas emissions, we need to capture carbon dioxide from the atmosphere to limit temperature rises. These new pellets could turn damaging CO2into something positive – helping communities to cope with increasingly extreme droughts by allowing farmers to grow more food while using less water.

"These initial results are really exciting, and we hope to be able to prove this new product's potential with field tests in the near future."

Dr Lake collaborated with Pawel Kisielewski, Dr Fabricio Marques and Professor Peter Hammond from CCm Technologies. Professor Hammond is also a visiting Professor in Chemical and Biological Engineering at the University of Sheffield.

The Institute for Sustainable Food at the University of Sheffield brings together multidisciplinary expertise and world-class research facilities to help achieve food security and protect the natural resources we all depend on.

LanzaTech expands with further $72m investment

www.lanzatech.com

Novo Holdings is making a $72 million investment in the company in a Series E financing, and Senior Director Anders Bendsen Spohr will join LanzaTech's Board of Directors.

The investment will expand LanzaTech's carbon recycling platform and enable LanzaTech to accelerate the commercialization of Carbon Smart™ products allowing consumers to choose where the carbon in their products comes from, recycled carbon or fossil carbon.

Novo Holdings said it is increasing its focus on investing in market-leading bio-industrial companies with the ability to have a long-term sustainable impact on society through innovative technologies.

LanzaTech's platform takes pollution and recycles it, eliminating single-use carbon. Examples of the uses of the technology include taking steel mill emissions in China and unsorted, unrecyclable household waste in Japan and converting these wastes to ethanol, sustainable aviation fuel or polyethylene for consumer goods.

When a product has reached the end of its useful life, it can go unsorted and uncleaned to a LanzaTech facility and be recycled repeatedly without losing any of the properties of the original material. This locks carbon into a cycle and supports a transition to a circular economy.

Anders Bendsen Spohr, Senior Director at Novo Holdings, said, "LanzaTech is addressing our collective need for sustainable fuels and materials, enabling industrial players to be part of building a truly circular economy."

Chemical industry experts meet to discuss CO2 emissions reduction

www.basf.com

www.weforum.org

A BASF workshop brought together industry experts to discuss innovative CO2-reduction technologies as well as new collaborative approaches.

Representatives from 20 international chemical companies, including scientific experts and Chief Technology Officers, attended a collaborative innovation workshop at BASF in Ludwigshafen at the joint invitation of BASF CEO Martin Brudermüller and the World Economic Forum.

With the declared aim of accelerating progress on climate protection, the participants discussed innovative CO2-reduction technologies as well as new collaborative approaches.

"We all want to further significantly reduce CO2 emissions at our plants," said host Dr. Martin Brudermüller, Chairman of the Board of Executive Directors and Chief Technology Officer of BASF SE, in his opening remarks.

"To do this, we have to develop and implement groundbreaking technologies. This process can be very time-consuming and we no longer have that much time. The Forum and BASF are hosting the industry to think about how they cooperate and explore ways to accelerate technology development."

Climate protection is firmly embedded in BASF's corporate strategy. A central goal of this strategy is to achieve CO2-neutral growth until 2030. To accomplish this, BASF is continuously optimizing existing processes and gradually replacing fossil fuels with renewable energy sources.

In addition, BASF wants to develop radically new low-emission production processes to reduce CO2 emissions in a large scale. The company is bundling all this work in an ambitious Carbon Management program, aiming to harmonize climate protection and production growth.

Making high value chemicals from CO2

sites.udel.edu/ccst

University of Delaware researchers have developed a new way to synthesize valuable chemicals from CO2.

Feng Jiao, an associate professor of chemical and biomolecular engineering at the University of Delaware, is a leader in the field of carbon capture and utilization. Now, he and his colleagues have made a new discovery that could further advance carbon capture and utilization and extend its promise to new industries.

In the journal Nature Chemistry, Jiao and collaborators from the California Institute of Technology, Nanjing University (China), and Soochow University (China) describe how they formed carbon-nitrogen bonds in an electrochemical carbon monoxide reduction reaction, which led to the production of high-value chemicals called amides. These substances are useful in a variety of industries, including pharmaceuticals.

The team is the first to do this. "Now, starting with carbon dioxide as a carbon source, we can expand to a variety of products," said Jiao, the associate director for UD's Center for Catalytic Science and Technology (CCST).

The science behind these findings is electrochemistry, which utilizes electricity to produce chemical change. In previous research efforts, Jiao developed a special silver catalyst, which converts carbon dioxide to carbon monoxide. Next, he wanted to further upgrade carbon monoxide into multi-carbon products useful in the production of fuels, pharmaceuticals and more.

"In the field of electrochemical carbon dioxide conversion, we were stuck with only four major products we can make using this technology: ethylene, ethanol, propanol, and, as we reported just a couple months ago in Nature Catalysis, acetate," said Jiao.

Nitrogen is the secret ingredient to unlock the potential of the system. The team used an electrochemical flow reactor that is typically fed with carbon dioxide or carbon monoxide, but this time they put in both carbon monoxide and ammonia, a compound that contains nitrogen. The nitrogen source interacts with the copper catalyst at the electrode-electrolyte interface, leading to the formation of carbon-nitrogen (CN) bonds.

This process allowed the team to synthesize chemicals that had never before been made in this way, including amides, which can be used in pharmaceutical synthesis. Many pharmaceutical compounds contain nitrogen, and "this actually provides a unique way to build large molecules which contains nitrogen from simple carbon and nitrogen species," said Jiao.

At a meeting of the American Chemical Society, Jiao shared some of his preliminary findings with William A. Goddard III, principal investigator at the Joint Center for Artificial Photosynthesis at Caltech. Goddard, a world-leading expert who uses Quantum Mechanics to determine reaction mechanism and rates of such electrocatalytic processes, was very excited about this unexpected discovery and immediately set his team.

Tao Cheng in the Goddard lab found that the new carbon-nitrogen bond coupling was an off-shoot of the mechanism that had been determined for the production of ethylene and ethanol, suggesting that Jiao might be able couple bonds other than CN.

"Through a close collaboration with Prof. Goddard, we learned quite a lot in terms of how this carbon-nitrogen bond formed on the surface of the catalyst," said Jiao. "This gave us important insights on how we can design even better catalysts to facilitate some of these kinds of chemical reactions."

The implications of this work could be far-ranging.

"This has the significant impact down the road, I think, to partially address carbon dioxide emission issues," said Jiao. "Now we can actually utilize it as the carbon feedstock to produce high-value chemicals."

Reactor converts CO2 into liquid fuel

The catalytic reactor developed at Rice University uses carbon dioxide as its feedstock and, in its latest prototype, produces highly purified and high concentrations of formic acid.

A common greenhouse gas could be repurposed in an efficient and environmentally friendly way with an electrolyzer that uses renewable electricity to produce pure liquid fuels.

Formic acid produced by traditional carbon dioxide devices needs costly and energy-intensive purification steps, Wang said. The direct production of pure formic acid solutions will help to promote commercial carbon dioxide conversion technologies. The method is detailed in Nature Energy.

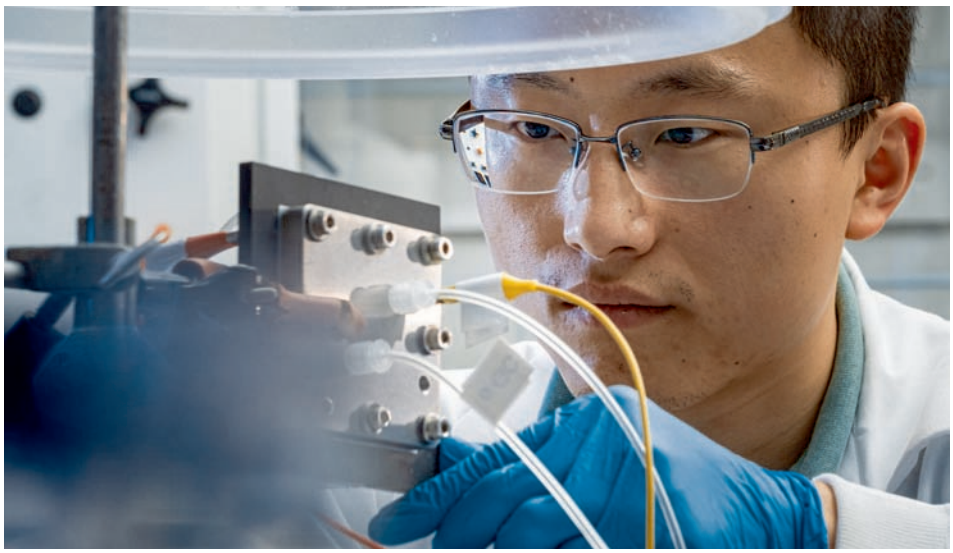
In tests, the new electrocatalyst reached an energy conversion efficiency of about 42%. That means nearly half of the electrical energy can be stored in formic acid as liquid fuel. "Formic acid is an energy carrier," Wang said. "It's a fuel-cell fuel that can generate electricity and emit carbon dioxide — which you can grab and recycle again."

"It's also fundamental in the chemical engineering industry as a feedstock for other chemicals, and a storage material for hydrogen that can hold nearly 1,000 times the energy of the same volume of hydrogen gas, which is difficult to compress," he said. "That's currently a big challenge for hydrogen fuel-cell cars."

Two advances made the new device possible, said lead author and Rice postdoctoral researcher Chuan Xia. The first was his development of a robust, two-dimensional bismuth catalyst and the second a solid-state electrolyte that eliminates the need for salt as part of the reaction.

"Bismuth is a very heavy atom, compared to transition metals like copper, iron or cobalt," Wang said. "Its mobility is much lower, particularly under reaction conditions. So that stabilizes the catalyst." He noted the reactor is structured to keep water from contacting the catalyst, which also helps preserve it.

Xia can make the nanomaterials in bulk. "Currently, people produce catalysts on the milligram or gram scales," he said. "We developed a way to produce them at the kilogram scale. That will make our process easier to scale up for industry."



Rice University engineer Haotian Wang adjusts the electrocatalysis reactor built in his lab to recycle carbon dioxide to produce liquid fuel. The reactor is designed to be an efficient and profitable way to reuse the greenhouse gas and keep it out of the atmosphere. (Credit: Jeff Fitlow/Rice University)

The polymer-based solid electrolyte is coated with sulfonic acid ligands to conduct positive charge or amino functional groups to conduct negative ions. "Usually people reduce carbon dioxide in a traditional liquid electrolyte like salty water," Wang said. "You want the electricity to be conducted, but pure water electrolyte is too resistant. You need to add salts like sodium chloride or potassium bicarbonate so that ions can move freely in water.

"But when you generate formic acid that way, it mixes with the salts," he said. "For a majority of applications you have to remove the salts from the end product, which takes a lot of energy and cost. So we employed solid electrolytes that conduct protons and can be made of insoluble polymers or inorganic compounds, eliminating the need for salts."

The rate at which water flows through the product chamber determines the concentration of the solution. Slow throughput with the current setup produces a solution that is nearly 30% formic acid by weight, while faster flows allow the concentration to be customized. The researchers expect to achieve higher concentrations from next-generation reactors that accept gas flow to bring out pure formic acid vapors.

The Rice lab worked with Brookhaven National Laboratory to view the process in progress. "X-ray absorption spectroscopy, a powerful technique available at the Inner Shell Spectroscopy (ISS) beamline at Brookhaven Lab's National Synchrotron Light Source II, enables us to probe the electronic structure of electrocatalysts in operando — that is, during the actual chemical process," said co-author Eli Stavitski, lead beamline scientist at ISS. "In this work, we followed bismuth's oxidation states at different potentials and were able to identify the catalyst's active state during carbon dioxide reduction."

With its current reactor, the lab generated formic acid continuously for 100 hours with negligible degradation of the reactor's components, including the nanoscale catalysts. Wang suggested the reactor could be easily retooled to produce such higher-value products as acetic acid, ethanol or propanol fuels.

More information

engineering.rice.edu

New technique for membrane filters

UCLA researchers have developed a new technique called thin-film liftoff, or T-FLO, for creating membrane filters with application in carbon capture.

The approach could offer a way for manufacturers to produce more effective and energy-efficient membranes using high-performance plastics, metal-organic frameworks and carbon materials. To date, limitations in how filters are fabricated have prevented those materials from being viable in industrial production.

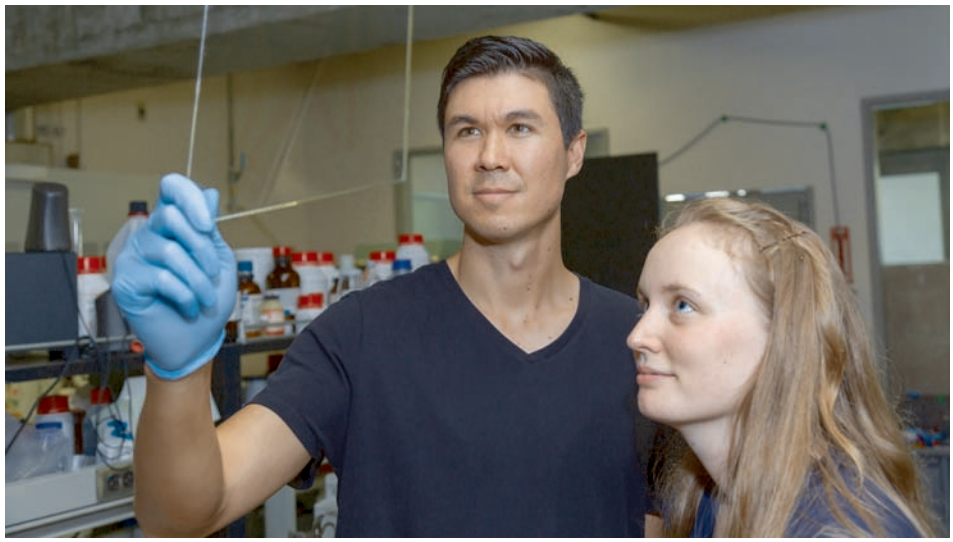
"There are a lot of materials out there that in the lab can do nice separations, but they're not scalable," said Richard Kaner, UCLA's Dr. Myung Ki Hong Professor of Materials Innovation and the study's senior author. "With this technique, we can take these materials, make thin films that are scalable, and make them useful."

In addition to their potential for improving types of filtration that are performed using current technology, membranes produced using T-FLO could make possible an array of new forms of filtration, said Kaner, who also is a distinguished professor of chemistry and biochemistry, and of materials science and engineering, and a member of the California NanoSystems Institute at UCLA. For example, the technique might one day make it feasible to pull carbon dioxide out of industrial emissions — which would enable the carbon to be converted to fuel or other applications while also reducing pollution.

Filters like the ones used for desalination are called asymmetric membranes because of their two layers: a thin but dense "active" layer that rejects particles larger than a specific size, and a porous "support" layer that gives the membrane structure and allows it to resist the high pressures used in reverse osmosis and other filtering processes. The first asymmetric membrane for desalination was devised by UCLA engineers in the 1960s.

Today's asymmetric membranes are made by casting the active layer onto the support layer, or casting both concurrently. But to manufacture an active layer using more advanced materials, engineers have to use solvents or high heat — both of which damage the support layer or prevent the active layer from adhering.

In the T-FLO technique, the active layer is cast as a liquid on a sheet of glass or metal and cured to make the active layer solid. Next, a support layer made of epoxy reinforced with fabric is added and the membrane is heated to solidify the epoxy.



UCLA postdoctoral scholar Brian McVerry and doctoral student Mackenzie Anderson examine an ultra-thin membrane film on a glass plate used in the T-FLO process. (Photo credit: Marc Roseboro/CNSI)

The use of epoxy in the support layer is the innovation that distinguishes the T-FLO technique — it enables the active layer to be created first so that it can be treated with chemicals or high heat without damaging the support layer.

The membrane then is submerged in water to wash out the chemicals that induce pores in the epoxy and to loosen the membrane from the glass or metal sheet. Finally, the membrane is peeled off of the plate with a blade — the "liftoff" that gives the method its name.

"Researchers around the world have demonstrated many new exciting materials that can separate salts, gases and organic materials more effectively than is done industrially," said Brian McVerry, a UCLA postdoctoral scholar who invented the T-FLO process and is the study's co-first author. "However, these materials are often made in relatively thick films that perform the separations too slowly or in small samples that are difficult to scale industrially.

"We have demonstrated a platform that we believe will enable researchers to use their new materials in a large, thin, asymmetric membrane configuration, testable in real-world applications."

The researchers tested a membrane produced using T-FLO for removing salt from water, and it showed promise for solving one of the common problems in desalination, which is that microbes and other organic material can clog the membranes. Although adding chlorine to the water can kill the microbes, the chemical also causes most membranes to break down. In the study, the T-FLO membrane both rejected the salt and resisted the chlorine.

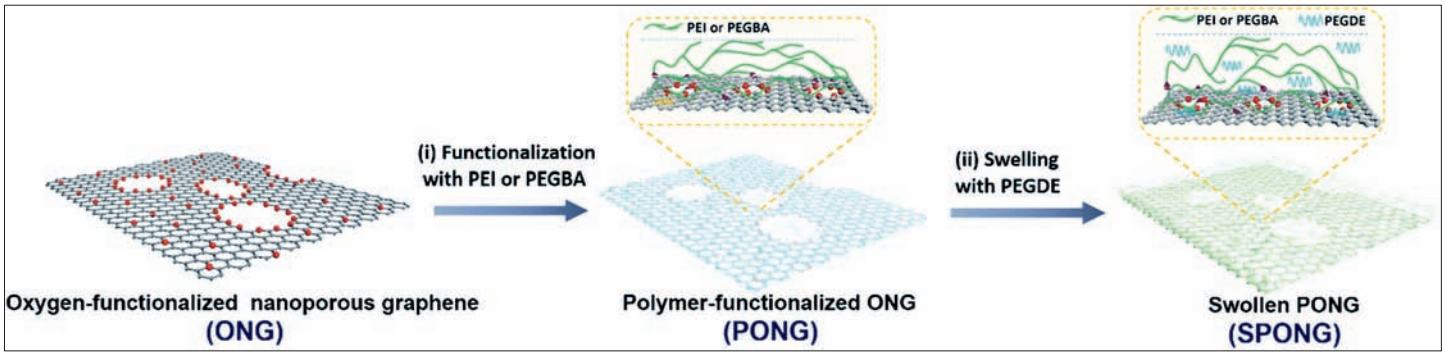
In other experiments, the new membrane was also able to remove organic materials from solvent waste and to separate greenhouse gases.

More information

cnsi.ucla.edu

Next-gen membranes for carbon capture

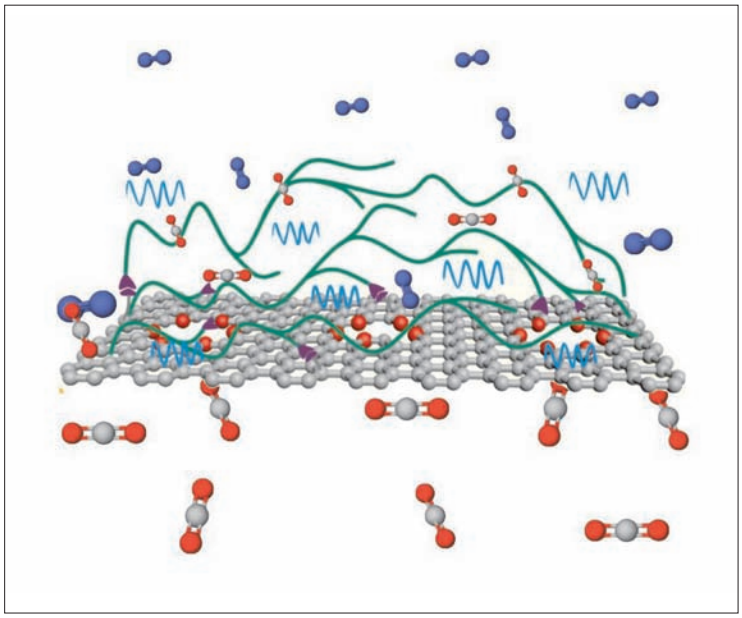
EPFL chemical engineers have developed a new class of high-performance membranes for carbon capture that greatly exceed current targets.



Schematic illustration of the preparation and the structure of the SPONG membrane

Carbon capture can be done using so-called "high-performance membranes", which are polymer filters that can specifically pick out CO2 from a mix of gases, such as those coming out of a factory's flue. These membranes are environmentally-friendly, they don't generate waste, they can intensify chemical processes, and can be used in a decentralized fashion. In fact, they are now considered as one of the most energy-efficient routes for reducing CO2 emissions.

Scientists led by Kumar Varoon Agrawal at EPFL Valais Wallis have now developed a new class of high-performance membranes that exceeds post-combustion capture targets by a significant margin.



CO2-selective polymeric chains anchored on graphene effectively pull CO2 from a flue gas mixture. Credit: KV Agrawal (EPFL)

The membranes are based on single-layer-graphene with a selective layer thinner than 20 nm and are highly tunable in terms of chemistry, meaning that that can pave the way for next-generation high-performance membranes for several critical separations.

Current membranes are required to exceed 1000 gas permeation units (GPUs), and have a "CO2/N2 separation factor" above 20 – a measure of their carbon-capturing specificity. The membranes that the EPFL scientists developed show six-fold higher CO2 permeance at 6,180 GPUs with a separation factor of 22.5.

The GPUs shot up to 11,790 when the scientists combined optimized graphene porosity, pore size, and functional groups (the chemical groups that actually react with CO2), while other membranes they made showed separation factors up to 57.2.

"Functionalizing CO2-selective polymeric chains on nanoporous graphene allows us to fabricate nanometer-thick yet CO2-selective membranes," says Agrawal.

"This two-dimensional nature of the membrane drastically increases the CO2 permeance, making membranes even more attractive for carbon capture. The concept is highly generic, and a number of high-performance gas separations are possible in this way."

More information

actu.epfl.ch

Chevron's Gorgon project starts storing CO2

Chevron Australia and the Gorgon Joint Venture participants have started the carbon dioxide injection system at the Gorgon natural gas facility on Barrow Island, off the northwest coast of Western Australia. **australia.chevron.com**

Chevron Australia personnel at the Chevron-operated Gorgon carbon dioxide injection facility on Barrow Island

Once fully operational, the carbon dioxide injection facility will reduce Gorgon's greenhouse gas emissions by about 40 percent, or more than 100 million tonnes over the life of the injection project.

Chevron Australia managing director Al Williams said, "We are pleased to reach the first milestone of safely starting the operation of the Gorgon carbon dioxide injection system, one of the world's largest greenhouse gas mitigation projects ever undertaken by industry."

"This achievement is the result of strong collaboration across industry and governments and supports our objective of providing affordable, reliable and ever-cleaner energy essential to our modern lives."

The Chevron-operated Gorgon Project is a joint venture between the Australian subsidiaries of Chevron (47.3 percent), ExxonMobil (25 percent), Shell (25 percent), Osaka Gas (1.25 percent), Tokyo Gas (1 percent) and JERA (0.417 percent).

The Australian Government has contributed $60 million towards the capital cost of the Carbon Dioxide Injection Project as part of the Low Emissions Technology Demonstration Fund.

Williams added, "We are monitoring system performance and plan to safely ramp up injection volumes over the coming months as we bring online processing facilities."

If we are serious about reducing emissions, then we better be serious about large-scale CCS.

You want substantial emission reductions.

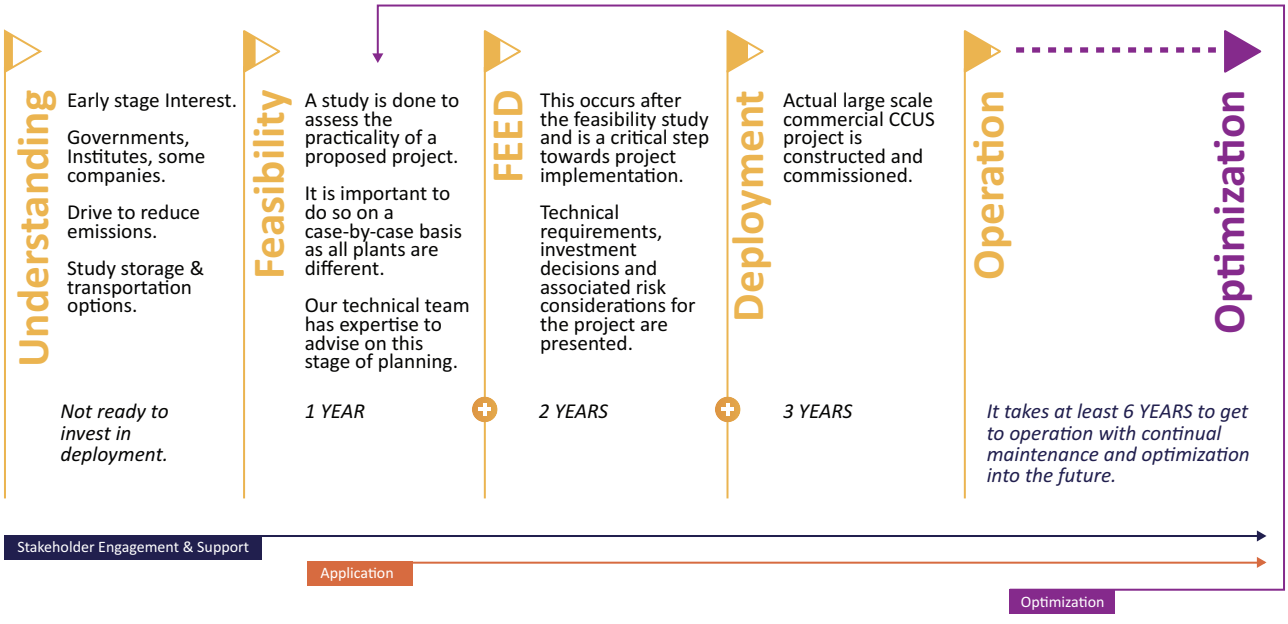
You need credible know-how.

Lessons learned can reduce risk and cost for CCS projects through-out their development.

This is our area of expertise. *And its substantial.*

Where are you on the path to CCS?

Aggressive Timeline to Deploy a CCS Project



Action will delineate and define our futures.
CCS is action, *designed for the world.*

INTERNATIONAL CCS KNOWLEDGE CENTRE

ccsknowledge.com
@CCSknowledge