Carbon Capture Journal

CCUS in Canada

Canada CCUS policy roundup - a suite of policies to induce investment in CCUS technologies and projects

Entropy Inc. - leading the world in post-combustion carbon capture

Sept / Oct 2022

Issue 89

Canadian CCS projects gaining momentum

- The pore rights challenge for CCS projects in the US
- Using the railway network to capture CO2 for under $50 / tonne
- Value through decarbonization: hydrogen's role in achieving net-zero
- Using bacteria to convert sunlight, water and CO2 into high value chemicals

Net Zero Industry Tracker helps map path to industrial decarbonization

The World Economic Forum has released the first edition of a report on the state of the net-zero transition in key industrial sectors.

The Net-Zero Industry Tracker 2022 highlights the need to fully understand the scope and scale of the challenge for these sectors and identifies a significant gap versus the pace of decarbonization necessary to achieve net-zero goals to limit global warming to 1.5°C by 2050. The urgency for industrial decarbonization is reinforced by high energy prices and energy supply chain disruptions.

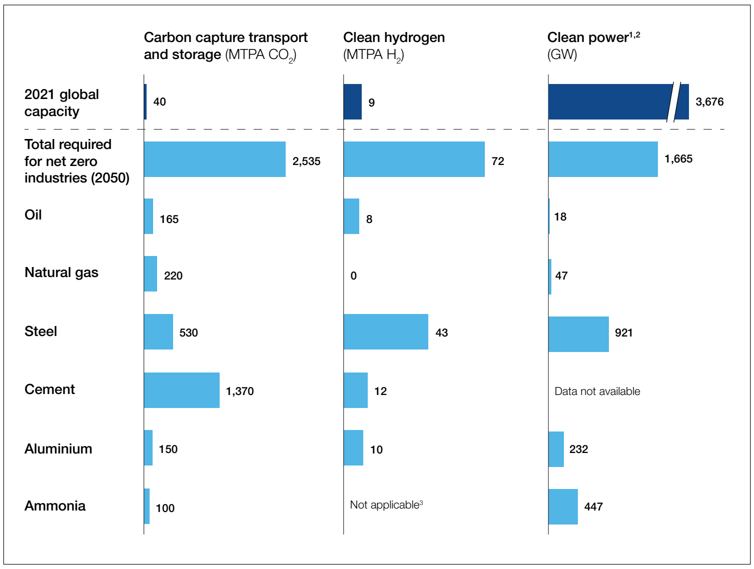
This initiative, launched by the World Economic Forum in collaboration with Accenture, establishes a common, fact-based understanding of the industrial sector's net-zero transformation enabling cross-industry and multistakeholder collaboration. The report introduces a holistic framework for a 360-degree perspective and standard metrics needed to measure progress, as well as key recommendations for industrial firms, policymakers, consumers and other stakeholders.

Progress-tracking and transparency are essential to help industries determine the trajectory of their decarbonization, maintain steady progress, and inform necessary course corrections along the way.

"While there are efforts under way and climate commitments being made, we currently lack a robust and comprehensive mechanism to understand the pace and direction of the progress of transformation of heavy industries, which account for 30% of global greenhouse gas emissions," said Roberto Bocca, head of Energy, Materials and Infrastructure, World Economic Forum. "Several industrial sectors and individual companies have set up targets with the aim of reaching net zero emissions. We believe that bringing transparency to closing net-zero gaps and reporting on this progress is critical to achieve these ambitious goals."

The report provides qualitative and quantitative measures to track the evolution of key enabling dimensions such as maturity of technology, access to enabling infrastructure, supporting policy frameworks, demand for low-emission products and availability of capital for investments in low-emission assets.

It assesses the state of these enablers, which need to advance simultaneously, and highlights sector-specific accelerators and priorities in five heavy industries – steel, cement, aluminium, ammonia, and oil and gas, which together generate 80% of industrial emissions, according to Accenture analysis.



Enabling infrastructure capacity requirements for net-zero industries by 2050

Notes: 1 Includes nuclear, hydropower and other renewables; 2 Based on today's clean power load factor of 35%; 3 Hydrogen is not applicable as the production of hydrogen is part of the ammonia production process

Given the cross-sector nature of barriers and priorities for industrial net-zero transformation, innovative forms of partnership within and across sectors, and with other stakeholders, will be fundamental to addressing the challenge. Other measures include consensus on defining "low-emission" industrial products and processes, robust and stable green demand signals, and risk-sharing mechanisms to attract necessary capital in technology and infrastructure development.

The report points out that over $2 trillion will be required to make low-emission industries a reality and that the first full-scale commercial projects still hold significant risks for companies to invest in.

Espen Mehlum, head of Energy, Materials and Infrastructure Programs for Benchmarking, World Economic Forum, said, "Investments in low-emission assets are riskier for companies due to their dependencies on new technologies and infrastructure. Collaboration will be at the heart of making the enablers of policy, fuel demand, technology, capital and infrastructure all pull in the same direction to accelerate progress towards climate goals."

The report underlines that concerted efforts also should include policy-makers, financial institutions and consumers.

Muqsit Ashraf, a senior managing director and global Energy industry lead, Accenture, said, "Accelerating the transformation of industries, and in particular hard-to-abate industries such as cement and steel, is critical to realize net-zero ambitions. In addition, in today's high energy and material prices environment, reducing the energy intensity of industries will also become a source of competitive advantage. Along with innovation, regulation and investments, the Net-Zero Industry Tracker will become an essential tool by bringing transparency to the decarbonization and energy efficiency journey."

More information

Download the full report at:

www.weforum.org

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Front cover: The Boundary Dam 3 CCS facility has now captured more than 4.5 million tonnes of CO2 since it began operation in 2014 and has proven capable of its design capacity of capturing 90% of CO2 from flue gas (pg. 2)

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Canadian CCS projects gaining momentum

In early spring of this year, the Canadian government gave CCUS development a significant boost, putting an anticipated tax credit in writing in the 2022 federal budget.

The investment tax credit, along with escalating carbon pricing and a comprehensive federal climate plan, sent strong signals to industry that now is the time to invest in carbon capture technology, infrastructure, transportation and storage.

As federal policy and incentives have fallen into place in Canada, they've been met by an industry that has already begun laying the groundwork for CCS technology development across heavy industries. In western Canada in particular, where oil and gas, agriculture, and manufacturing provide the economic foundation for the region, meeting ambitious climate targets around emissions reduction has become a driving force.

Canada has been a world leader in the first generation of CCS projects, as home to five of the 27 commercial-scale facilities in the world today. This pioneering expertise is providing a strong platform for the development of the next wave of projects now on the horizon. SaskPower's Boundary Dam Unit 3 (BD3) CCS facility outside Estevan, Saskatchewan, in particular, provides almost a decade's worth of experience as the world's first fully integrated, full-chain CCS facility on a coal-fired power plant.

The BD3 CCS facility has now captured more than 4.5 million tonnes of CO2 since it began operation in 2014 and has proven capable of its design capacity of capturing 90 per cent of the CO2 in the flue gas it is sent from the power plant.

This impressive performance for a first-of-a-kind facility - and the valuable lessons that are serving to reduce risk levels and save new projects time and money - were recognized by the Carbon Sequestration Leadership Forum, which recognized the BD3 CCS facility with a Global Achievement Award at the CSLF's Technical Group Mid-Year Meeting held in Bergen, Norway in late-June.

All of this has put Canada in a strong position for current and future project development.

Lehigh Hanson's cement plant in Edmonton, Alberta, Canada

Lehigh Edmonton CCS study proves cement industry feasibility

Building directly upon the knowledge derived from the BD3 CCS project, the Canadian-based International CCS Knowledge Centre (the Knowledge Centre) worked with Lehigh Hanson Materials Limited (Lehigh) to study the feasibility of a CCS retrofit on an urban cement production facility in Edmonton, Alberta. Studying the potential for installation of a full-scale, post-combustion, amine-based CO2 capture system, the project represents a first in North America for CCS application in the cement industry and was made possible through an investment of CDN$1.4 million from Emissions Reductions Alberta (ERA) and funding from Lehigh.

The Lehigh feasibility report, released earlier this year, studied costs, optimal design, potential incentives, job creation and public perception. The overall conclusion of the study showed that a retrofit using technology at a readiness level of TR9 would cause minimal disruption to the site and to ongoing operations at the plant. The CCS facility could feasibly capture up to 95 per cent of CO2 emitted by the cement plant and an auxiliary boiler required for the capture process. This captured CO2 could be safely and permanently stored in a compatible deep geological saline aquifer.

Throughout the study, the Knowledge Centre drew on learnings from BD3 and also from a feasibility study for second-generation CCS project on SaskPower's Shand Power Station, which investigated a CCS retrofit on a 300-megawatt single-unit coal-fired power plant with double the capacity of BD3.

The Shand study showed the potential for significant cost savings through realizing greater efficiency and economies of scale on a second-generation project — results also seen in the Lehigh feasibility study.

Based on results from BD3, and similar technology potentially deployed at Lehigh's Edmonton cement plant, the amine-based carbon capture process was also found to coincidentally diminish concentrations of certain released pollutants – including significant reductions of sulphur dioxide and particulate emissions.

This feasibility study made a particularly close examination of potential energy needs and ideas around innovative repurposing of excess energy and wastewater. The economics of installing an efficient combined heat and power generation system that could power a steam-generated CO2 compressor and provide further reductions of indirect greenhouse gas emissions, will be examined in a subsequent phase of the study.

Because of the continuous operation typical of heavy industry such as cement manufacturing, the Lehigh study incorporated a selection of design changes to mitigate amine degradation and ensure that the capture facility could be maintained and upgraded without significantly impacting plant operations. These mitigations included an added filtration system that removes particulates and limits degradation of amines over time.

As well, redundancy and isolation were proposed for key components of the capture facility, to reduce shutdowns, improve reliability and minimize maintenance costs. The study also proposed an innovative combination of wet and dry cooling processes that reduced usage of fresh water and eliminated wastewater.

The Knowledge Centre estimated that the life-cycle cost of capture for the Lehigh plant will fall within the range of US$100-200 per tonne of CO2 captured. This aligns with estimates in a comprehensive report released by McKinsey and Company in 2020 that studied the costs of a variety of methods for decarbonizing cement manufacture.

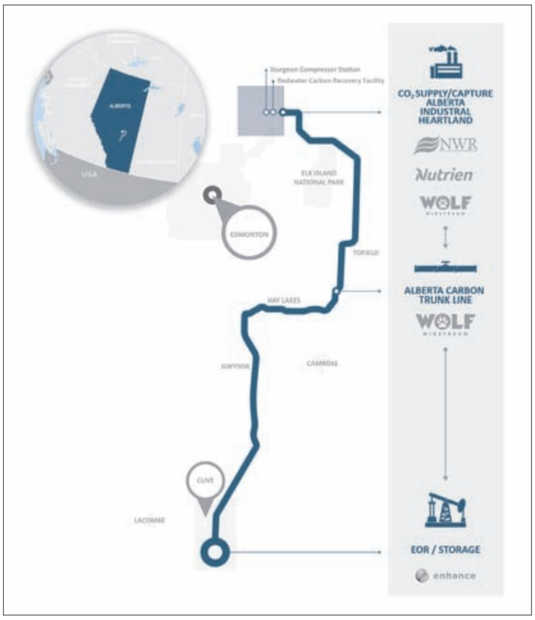
With the global demand for cement expected to grow by 12 to 23 per cent by 2050, this study provides an early forecast for the potential to decarbonize cement manufacturing with existing technology. It also creates a path forward for further study and testing.

The Knowledge Centre and Lehigh will soon begin work on a Front-End Engineering and Design (FEED) study to establish detailed engineering design and integration to Class Three estimate, to result in a business case for moving forward.

Funding round boosts 11 new projects

All of this groundwork and early deployment of technology has created a baseline of knowledge and expertise that will be leveraged in the development of new projects around the world, as well as a suite of other large-scale CCS projects in Alberta. In July, the provincial government in Alberta announced backing for 11 diverse, large-scale CCS projects through ERA.

The Carbon Capture Kickstart funding competition provided more than CDN$40 million for pre-construction engineering and design for innovative projects in a wide range of industrial sectors, including power generation, fertilizer, cement, forest products and oil and gas. Many of these projects represent the first stage of significantly larger overall project plans that could lead to an estimated CDN$20 billion in planned capital expenditures. Together, the projects are anticipated to eliminate approximately ten per cent of Alberta's total GHG emissions annually.



Alberta Carbon Trunk Line, the world's largest CO2 pipeline, began operation in 2020 with a capacity of 14.6 million tonnes per year of CO2, to connect multiple large-scale CCS projects and sequestration facilities through a transport hub

Carbon Capture Kickstart signals ongoing interest and investment in CCS projects in Canada, a sign that confidence in homegrown technology and access to significant carbon transport and storage infrastructure will transform the country's approach to emissions reduction in the decades to come

These 11 projects will share in national expertise built through successful projects including the BD3 CCS Facility, Shell Canada's Quest CCS facility outside Edmonton, Alberta, which has sequestered more than six million tonnes of CO2 so far, and the Alberta Carbon Trunk Line – the world's largest CO2 pipeline that began operation in 2020 with a capacity of 14.6 million tonnes per year of CO2, to connect multiple large-scale CCS projects and sequestration facilities through a transport hub.

The 11 projects chosen for ERA's Carbon Capture Kickstart program will advance CCUS-related technologies in step with emerging provincial and federal policies. In addition, ERA is providing funding for the Knowledge Centre to provide up to 200 hours of consultation and technical advice to each project, helping to increase performance while reducing the risk and cost of new projects, and ensuring that important new knowledge gained is documented and shared as broadly as possible.

ERA awarded project development funding to projects that are expected to be operational by 2030. They include CCS projects across a range of industries, all based in Alberta, with a combined estimated emissions reduction equivalent of taking five million cars off the road annually. They are all chosen in part as projects of sufficient technical and commercial scale to be deployment-ready, selected through a unique proposal structure designed to fill knowledge gaps and promote cross-collaboration to build networks of CCS projects that will have a lasting impact on current and future industry.

Among the planned projects, Calgary-based Entropy, Inc. is developing CCS technology for Athabasca Oil's Leismer SAGD oil sands facility. The project will deploy the company's trademarked Modular Carbon Capture and Reverse Entropy Storage processes to demonstrate capture on Athabasca's once through steam generator (OTSG) boilers. This is estimated to capture 164,000 tonnes of CO2 per year and will refine the design for future applications at the Leismer facility and to other OTSG applications around the world.

Nutrien, the world's largest producer of potash, and the third-largest producer of nitrogen fertilizer, will develop technology feasibility, preliminary engineering, and business case for carbon emissions reduction at the company's

Redwater, Alberta ammonia plant. The plant is already capturing CO2 from on-site hydrogen production (transported through the Alberta Carbon Trunk Line), and the goal for this study and project development is to achieve net-zero emissions for ammonia nitrogen fertilizer production out of Redwater.

ERA will provide CDN$2.5 million to the city of Medicine Hat, Alberta for a FEED study to develop the Project Clear Horizon regional CCUS facility, planned to capture and permanently sequester up to three million tonnes of CO2 annually. The study will include scope, planning, costs, and expected environmental and economic outcomes for development of capture technology on natural gas-fired power plants, plus pipeline transport, and a sequestration hub in this city in the southeastern corner of the province.

The project development team at Vault 44.01 received CDN$2.5 million from ERA for a Bioenergy Carbon Capture and Sequestration study at West Fraser Timber's Hinton, Alberta pulp mill. The study would outline a project to capture and store up to 1.3 Mt of biogenic CO2 emissions per year. Part of the study will also detail the economic value of the mill's negative emissions, which could be used to offset CO2 in hard-to-abate industries such as aviation and shipping.

Two of the province's largest electric utility companies, Enmax and Capital Power, received development funding for projects. Enmax will fund a FEED study for a carbon capture unit on its Shepard Energy Centre commercial scale combined-cycle natural gas generating plant in Calgary, which, when completed, will be the largest facility of its type in Canada.

Edmonton-based Capital Power has already completed a FEED study for retrofitting CCS technology on its Genesee natural gas-fired combined-cycle generating plant near Wabamun, Alberta. With a goal of net-zero emission electricity generation, this project could remove approximately three million tonnes of CO2 annually and be in operation as early as 2027.

Oil sands operators Canadian Natural and Suncor will use ERA funding to advance carbon capture technology in this hard-to-abate industry. Suncor will fund a FEED study to apply Svante's post-combustion absorption technology to the flue gas stream at the company's Fluid Catalytic Cracking Unit at their Edmonton refinery. Funding for Canadian Natural will support a study that would analyze emissions reduction among major oil sands producers, an alliance with a plan to reduce greenhouse gas emissions by approximately 22 million tonnes per year.

The Boundary Dam 3 CCS facility has now captured more than 4.5 million tonnes of CO2 since it began operation in 2014 and has proven capable of its design capacity of capturing 90 per cent of the CO2 in the flue gas it is sent from the power plant

This preliminary funding will contribute to planning for a CCS network to encompass approximately 20 oil sands producers, including development of a carbon pipeline and a storage hub in the Cold Lake region of Alberta.

Also at Cold Lake, Calgary-based Strathcona Resources received CDN$5 million for a feasibility and FEED study for post-combustion flue gas carbon capture on three SAGD oil sands operations. The company is interested in developing modular CCS technology that can be optimally applied to facilities with boiler and power supply configurations, which combined currently emit approximately 2.2 million tonnes of CO2 per year.

Remaining funded projects include CDN$5 million to Heartland Generation to study the feasibility of converting the company's Battle River Generating Station from natural gas to hydrogen with carbon capture, producing zero-emission electricity. Funding to Lafarge Canada will explore the feasibility of retrofitting the company's Exshaw, Alberta cement plant with CCS technology, including the possibility of linking this plant located in the province's Bow Valley with other industrial capture facilities through a transport and sequestration hub.

Federal policy aligns with support for CCS

These funded studies will advance CCS technology and deployment across industries, and will help to prove the value of Canada's existing innovations, and take advantage of the country's extensive energy industry expertise and the porous geological formations in the Western Canadian Sedimentary Basin that provide enormous CO2 storage capacity.

The work is all part of a focus on developing business cases for clean technology that work with Canada's existing industry, building capacity in innovation, job creation, and investment, and align with federal policy and incentives.

With the successful deployment of CCS at BD3, through smaller-scale capture facilities, comprehensive study of technology for other hard-to-abate industries, and funding, incentives and support from various levels of government, carbon capture and storage technology is poised for significant advancement in Canada through the next decade and beyond.

More information

ccsknowledge.com

Canada CCUS Policy Roundup

The Canadian government has been driving hard toward a net-zero agenda and has clearly stated that the country's path to decarbonization will involve large-scale uptake of CCUS. To reach this objective, federal and provincial governments in Canada have implemented a suite of policies to induce investment in CCUS technologies and projects. By Marla Orenstein and Brendan Cooke, Canada West Foundation.

Policies include regulations and emissions caps designed to encourage the use of CCUS, opportunities for CCUS projects to generate offset credits, tax incentives specifically designed to induce CCUS investments, direct government funding of large-scale CCUS projects, and the development of CCUS hubs and ecosystems.

In this article, we review existing and planned policies, to inform Carbon Capture Journal readers about the scale and scope of what is required to successfully establish a large-scale model of CCUS use in the Canadian context.

Project	Location	Emission Source	CCUS method	Year initiated	Annual carbon capture capacity (Mt)
Existing					
Boundary Dam	Estevan, SK	Coal-fired power plant	EOR and saline aquifer	2014	1
Weyburn-Midale Oilfields	Weyburn/Midale, SK	Coal gasification	EOR	2000 to 2005	2.8
Shell Quest	Scotford, AB	Oilsands upgrader	Saline aquifer	2015	1
Alberta Carbon Trunk Line	Central Alberta	Industrial emissions	EOR	2020	14.6

Table 1: Existing CCS projects in Canada
Note: some of these CCS projects consist of multiple smaller projects

Scale and scope of CCUS in Canada

Canada is a world leader in the commercial development of CCUS. There are currently four active projects contributing approximately 20Mt of capture capacity annually (Table 1). Additional projects are expected to contribute substantial additional sequestering; the province of Alberta alone currently has roughly 56Mt of capacity in various pre-commercialization stages.

The concentration of projects in these two western Canadian provinces is not coincidental and points to one of Canada's major strengths in the development of CCUS – geography. Of Canada's estimated 404Mt of potential storage capacity, 396Mt is in Western Canadian subterranean basins which sit beneath Alberta and Saskatchewan. The region's saline aquifers, depleted oil and gas reservoirs, and co-location with large industrial emitters make it an ideal location for carbon capture projects.

However, geography is not Canada's only strength in CCUS development. With over two decades of experience in carbon capture, industry and regulators have developed best-in-class monitoring and measurement practices and a regulatory environment that is prepared for further expansion of CCUS investment.

Canada's CCUS policy environment

The push for industrial decarbonization comes from shareholders, boards, investors and customers, among others. But government policy also plays a key role through setting decarbonization targets and creating frameworks that determine the speed at which we travel to those targets and the mechanisms used to get there.

Canada's uptake of CCUS similarly rests on a set of policies that provide a foundation for the development and deployment of CCUS in the country. These policies are described below.

Policies that price or constrain carbon emissions

The economics of CCS generally only make sense when a constraint or cost is placed on emitting carbon. Canada has a number of policies at both the federal and provincial levels that restrict GHG emissions and steer emitters to CCUS as a means of compliance.

• The federal **Output-Based Pricing System Regulations (OBPS)** establish a carbon tax for large industrial emitters. Industrial emissions are currently priced at $50/tonne and will increase by $15/tonne annually until 2030, when $170/tonne is reached.

• The **Technology Innovation and Emissions Reduction Regulation (TIER)** applies to most oil and gas producers in Alberta. It combines an industrial carbon pricing system with a system of offsets that allow CCS projects to generate sellable or tradeable credits.

• Canada's **Clean Fuel Regulations**—which take effect in 2023—require the life cycle emissions of gasoline and diesel fuels to be reduced by around 15 per cent. While the reduction can happen anywhere on the "well to wheels" pathway, it is anticipated that CCUS will be a major compliance mechanism.

• **Methane regulations**. In 2018, federal and provincial regulations were introduced that required the upstream oil and gas sector to reduce methane emissions by 40-45 per cent by the year 2025, and a reduction of 75 per cent by 2030 has also been pledged.

• An **Oil and Gas Sector Emissions Cap** is currently under consideration by the federal government. The cap would use either a more stringent sector-specific emissions pricing system or a cap-and-trade system.

• The proposed federal **Clean Electricity Standard** will require natural gas power facilities and any other GHG-emitting electricity sources to reach net-zero by 2035.

• Canada's federal **Impact Assessment Act (IAA)** evaluates projects in part based on the degree to which they help or hinder the government's ability to meet its climate change targets.

Policies that provide direct financial support to CCUS projects

CCS is expensive in all its stages: research and development, commercialization, construction and operations. The following policies provide direct financial support.

• **Proposed federal tax credit.** The federal government is introducing a refundable investment tax credit for eligible CCUS projects. Some elements are similar to the 45Q tax credit in the United States, although there are also substantial differences. Carbon dioxide can be captured from industrial emissions or through direct air capture (DAC); however, it must be permanently sequestered either in concrete or geologically. DAC projects will receive a 60 per cent credit, other eligible projects a 50 per cent credit and transport and storage projects a 37.5 per cent credit. EOR projects are ineligible. The credit is based on the number of tonnes sequestered.

• **R&D funding**. Government funding for CCUS research and development has been made available at both the federal and provincial levels. In the 2021 budget, the federal government allocated $319 million to support CCUS research, development, and demonstration projects. Project Carbon Capture Kickstart, funded by the Government of Alberta via the agency Emissions Reduction Alberta, also recently announced over $40 million for 11 CCUS projects for the pre-construction design and engineering phases.

• **Funding support for CCUS construction and operation.** Provincial and federal governments have also directly supported individual CCUS projects. Key examples include the Shell Quest CCUS facility in Alberta and Saskatchewan's Boundary Dam CCUS facility, which both received considerable provincial and federal contributions.

The funding for Quest came with the stipulation that knowledge and lessons learned from building the project be made public in order to help reduce costs for future projects. Substantial additional funding continues to be made available, such as through Saskatchewan's Oil Infrastructure Investment Program and Alberta's Industrial Energy Efficiency CCUS Grant Program.

Policies that indirectly financially support CCUS viability

Government policies also create the conditions for CCUS projects to produce economic returns, enabling the sequestration of carbon to generate revenue rather than just act as a cost.

• **Offset markets.** Several of the emissions reduction regulations regimes described above (including TIER and the Clean Fuel Regulations) also enable CCUS to generate offset credits that can be traded or sold in order to balance regulatory emissions obligations. While Alberta's TIER system is currently the only one that has established protocols for CCUS credit generation (saline aquifer storage and EOR), federal protocols are also under development.

Policies that support building and permitting CCUS infrastructure

Finally, there are a number of related policies that smooth the way for the adoption of CCUS across a number of industrial settings.

• **Alberta's Carbon Hub** strategy uses a competitive process to issue carbon sequestration rights to companies to develop and operate carbon sequestration hubs. The strategy creates efficiencies in CCUS development by aggregating captured carbon dioxide from a variety of industrial emitters and sequestering it in a common location. So far six projects have been selected from the initial call for proposals in 2022.

• The **hydrogen strategies** released by the federal government, British Columbia, Alberta and Ontario all include CCUS as a key part of blue hydrogen production.

Conclusion

Canada has taken an aggressive role with respect to promoting CCUS—a role that rests not only on technology innovations, but on a policy ecosystem that makes carbon capture make economic sense. While every country takes a different approach to CCUS policy, what can be learned from Canada's approach is the key role early government support plays in sector development.

Grants provided for development of Canada's four current facilities, and past and current research funding programs helped grow world-class expertise. These factors, plus strong regulatory and policy regimes, have allowed Canada to punch above its weight in the field.

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More information

The Canada West Foundation is an independent, non-partisan public policy think that provides practical solutions to tough public policy challenges facing the West and Canada as a whole. For more see **www.cwf.ca**

Leading the world in post-combustion carbon capture

Entropy Inc. (Entropy) is a Calgary-based cleantech company that has developed a first-in-kind modular carbon capture technology that can be retrofitted on existing industrial emitters or built on greenfield projects and the world's first commercial CCS facility for natural gas combustion.

Entropy's first post-combustion CCS project at Glacier is paving the way for the creation of an innovative pathway to low-cost CCS technologies that will play a pivotal role in global greenhouse gas emissions reduction. This is a key step in providing scalable, reliable, emissions-free energy for the world.

Entropy is a built-for-purpose full-service CCS company that leverages decades of expertise with geologic and operational experience of pre-combustion carbon capture and sequestration, gas processing facility design, solvent research and testing. The outcome is the development of novel processes and technology, which has led to the commercial scale development of the CCS facility at the Glacier natural gas plant, 100 km northwest of Grande Prairie, Alberta.

The team is comprised of experts from Advantage Energy Ltd., Allardyce Bower Consulting Inc., the Clean Energy Technologies Research Institute (CETRI) at the University of Regina and others who have been recruited to support the initiative of bringing commercial scale technology to emitters to achieve their decarbonization goals. In addition, Entropy has secured financing of $300 million from Brookfield to scale up additional post-combustion CCS facilities with a global scope.

The International Energy Agency's (IEA) 'Net Zero by 2050: A Roadmap for the Global Energy Sector' publication (2021) references CCS as an essential process to achieving net zero by 2050. Currently active CCS projects worldwide are capturing 40 megatonnes (Mt) per annum. The scale of CCS is estimated to require an increase to 1670 megatonnes per annum (Mtpa) by 2030 and to 7600 Mtpa by 2050 in order to achieve global emissions targets.

CCS can be achieved in both pre-combustion and post-combustion applications. In pre-combustion, CO2 is removed from the process before combustion is complete, the emissions are significant but limited in types of activities. Post-combustion applications, where CO2 is captured from the exhaust gases, are typically lower in concentration but represent the majority (roughly three quarters) of global emissions.

Entropy's Phase 1 CCS project at the Glacier gas processing facility abates and captures a total of 47,000 tonnes per annum

Of the world's current 40 Mtpa active CCS projects, only 1 Mtpa is achieved through post-combustion carbon capture, which is at the Boundary Dam coal-fired power plant in Saskatchewan, Canada. Post-combustion carbon capture will need to be scaled by orders of magnitude to achieve global emission objectives.

Post-combustion carbon capture has historically been an energy intensive process. To reduce the cost of carbon capture and apply it to a widely used technology, engineering design innovation is required to advance historic practices and increase efficiency to reach economic hurdles at current expected CO2 price levels. Entropy has achieved energy-efficient savings through several innovations including waste-heat capture, facility design and proprietary solvent design from research at the University of Regina.

The World's First Commercial Scale Post-Combustion CCS of Emissions from a Natural Gas Fuel Source

Entropy's Phase 1 CCS project at Glacier has been constructed, installed and is currently operating. This facility is the first commercial development of Entropy's advanced CCS technologies. The facility received financial support from the province of Alberta's Industrial Energy Efficiency (IEE) CCUS grant, reached final investment decision (FID) in February of 2021, broke ground in November of 2021 and captured first-carbon in August of 2022; 18-months from FID to first-capture.

Entropy's Phase 1 at the Glacier gas processing facility abates and captures a total of 47,000 tonnes per annum (tpa). The facility consists of heat recovery exchangers, an exhaust gas blower, an absorber tower, solvent, water pumps, a solvent regeneration skid, compression and dehydration (to remove the water from the CO2 stream).

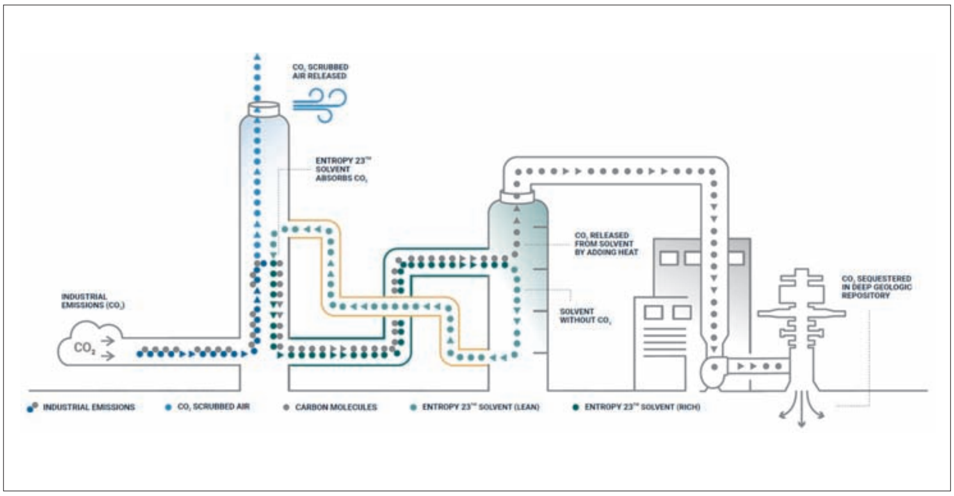
Making use of waste heat from the facility significantly reduces the energy required for the CCS process and results in a higher abatement volume of CO2. The post-combustion stream will commingle with the existing facility pre-combustion CO2 stream before being injected into an existing disposal well.

All parts of the system are designed with modularity in mind to allow for reduced capital cost as well as viable maintenance, scalability, and installation. The CCS equipment is designed and scaled for emissions from CAT3616 compressors 16-cylinder reciprocating engines fueled by natural gas, with an output of 5,000 horsepower. This is a typical and very widely deployed engine utilized in natural gas transportation across North America and will be suitable for significant scale up across the industry.

Proven permanent sequestration has been established in a deep reservoir with sufficient permeability and porosity to accept significant CO2 volumes without affecting the surrounding geology. CO2 is injected at a depth of ~2600 metres into the reservoir, which is overlain by an impermeable caprock, preventing leakage into more shallow reservoirs and aquifers.

The Glacier project will add CCS to the entire facility in three phases: Phase 1, Phase 1b and Phase 2. The full deployment of CCS will target the removal of approximately 200,000 tpa of CO2 emissions. Phase 1b recently received FID and is planned to be installed by early 2023, the first deployment of integrated CCS technology. Entropy and an original equipment manufacturer partner have designed a fully integrated CCS prototype, iCCS™.

This integrated technology will reduce the amount of retrofitting required for the modular installation of the CCS equipment. The prefabricated unit is on-track to deliver an additional 25% capital cost savings versus Entropy's current low-cost retrofit modular design.



Entropy's tailored design has a small footprint and allows for scalability, with economic CCS at industrial facilities with emissions as low as 8,000 tpa

iCCS™ not only achieves increased emissions reduction capacity, but demonstrates the ability to collaborate with an industrial partner while they increase processing capacity in a forward thinking emissions reduction manner – the increased compression will result in the Glacier gas plant capacity increasing to 425MMcf/d, which is enough natural gas to heat the homes of approximately 4 million people.

Process Innovation

Entropy's first-in-kind Modular Carbon Capture™ (MCC™) is an innovative engineering design that can be retrofitted within an existing industrial facility. The tailored design has a small footprint and allows for scalability, with economic CCS at industrial facilities with emissions as low as 8,000 tpa. The industrial facility's operating conditions are unchanged by the CCS installation. Due to the modular nature of Entropy's technology, projects may advance from FID to on-stream within two years.

Entropy's unique research and development partnership with the University of Regina's CETRI provides exclusive access to facilities and experts that are required to advance state of the art solvents that, based on testing, significantly exceed industry standards for post-combustion carbon capture. Entropy will be deploying its proprietary solvent, Entropy23™ (patent pending). Highlights of Entropy23™, relative to monoethylamine (MEA, an industry standard solvent) include improvements in heat duty, absorption, desorption, cyclic capacity and lean loading resulting in lower energy and solvent requirements.

In addition, significantly lower ammonia (NH3) emissions result in high stability and low solvent degradation. The attributes of Entropy23™ contribute to reduced costs and improved economics relative to other carbon capture methodologies. Research on high performance solvents by the team at CETRI is ongoing and may be customized for distinct CO2 flue gas concentrations and applied to a variety of emitters across a broad scope of industries.

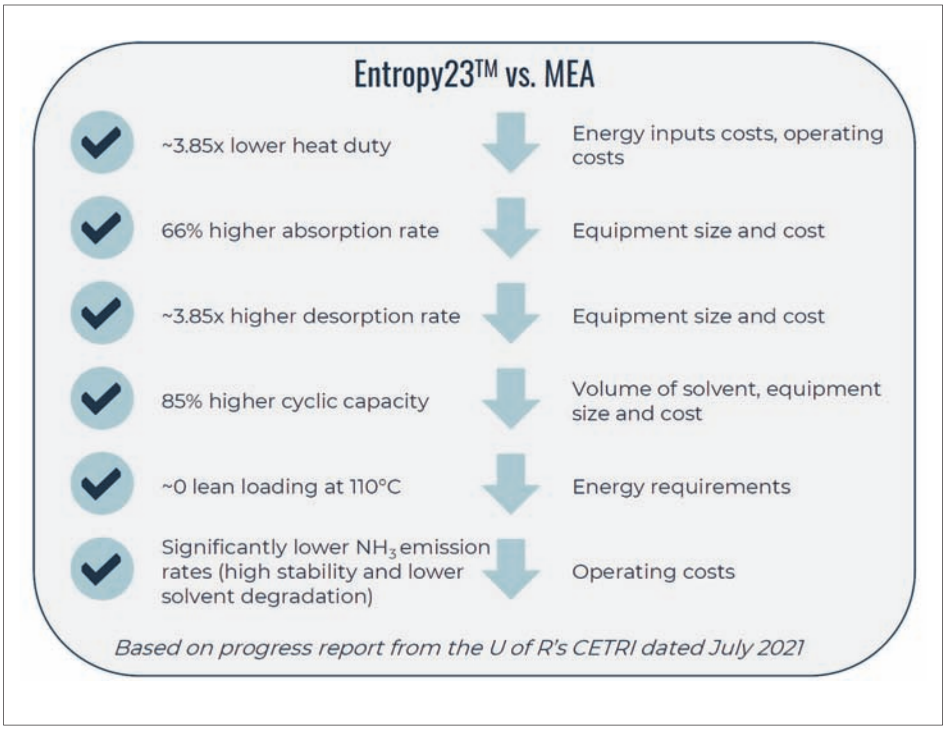
Studies have been performed to formulate and screen different solvents using a semi-batch setup. In the last phase of development, thirty different formulations were screened and compared with the conventional 5M MEA system. The formulations were selected for screening based on extensive knowledge of reaction dynamics, chemical structure and the CO2 capture performance relationship of the amines. Such a relationship enabled systematic selection and solvent formulation containing structures that would effectively capture CO2 while minimizing degradation, emissions, and all other solvent issues.

To mimic the continuous cycle process, both Entropy23™ and MEA were tested by the research team at CETRI to replicate the same process conditions. Results revealed a remarkable increase in overall gas phase mass transfer coefficient for Entropy23™ by 68%, while the liquid side coefficient was approximately 3.85 times higher when compared to conventional MEA. This implies much smaller column sizes which translates to a significant reduction in capital costs.

The results showed that Entropy23™ had the highest performance in all aspects relative to all other known solvents, including baseline MEA.

Entropy has begun CCS operations at Glacier with a focus on gathering performance data on the proprietary process design using standard MEA solvent for approximately one month prior to switching to its patent pending Entropy23™ solvent for complete performance benchmarking. Operational updates on Phase 1 performance will be announced as various milestones are achieved.

In addition to its design and solvent formulation, Entropy integrates waste heat recovery to reduce energy in the carbon capture process. Industrial post-combustion emissions typically have excess heat and Entropy's strategy is to leverage this resource to reduce the energy required for the CCS process. Optimization in waste heat recovery can significantly improve the economics of CCS and expand the application to a wide range of industrial emitters.



Tests conducted by the University of Regina showed that the proprietary solvent Entropy23™ had the highest performance in all aspects relative to all other known solvents, including baseline MEA

Partnerships with Emitters

Entropy's Modular Carbon Capture™ technology has the versatility to be applied to many types of emitting facilities. The next application of Entropy's MCC™ technology is expected to be applied on emissions from a once-through steam generator (OTSG) used for thermal oil extraction. To date, there is no existing commercial CCS in operation for in-situ thermal oil production or on an industrial scale boiler.

Entropy has been formally engaged in various capacities by counterparties across several sectors and is exceeding 10 Mtpa of projects under development in varying levels of maturity. Industrial sectors targeted by Entropy have emissions of over 100 Mtpa in Canada and a much larger footprint globally.

Entropy offers two distinct approaches to deploy its technology, either through licensing or through investing in projects in exchange for environmental attributes with third-party emitters. This unique investment approach by Entropy de-risks the projects from the perspective of emitters who are seeking a solution to reduce emissions from their industrial processes.

Looking Ahead – Global Decarbonization

A supportive policy and carbon price framework is necessary to support the investment in CCS projects. Canadian policy has taken a significant step through the Investment Tax Credits (ITC) for CCUS, providing funding of qualified carbon capture expenditures at 50% and of qualified storage, transportation and use at 37.5%.

The Canadian government has also provided guidance on increased carbon tax pricing, however, contractual certainty of carbon price will be necessary for many projects to reach FID.

The United States has provided leadership and gone a step beyond guidance by providing carbon price certainty at US$85/metric tonne for CCS through the 45Q and the Inflation Reduction Act.

CCS can play a key role in global decarbonization, but it can also help provide a pathway for society's need for safe, reliable, clean energy. One such path for achieving the world's triple mandate of safe, politically secure, low-carbon energy is the removal of emissions from the full-cycle process of generating electricity from combined cycle gas turbines (CCGT).

By producing low carbon intensity (low CI) natural gas in upstream gas processing and removing CO2 emissions from the downstream combustion of low CI natural gas, CCS applications will enable generation of green electricity from CCGT power generation.

Looking forward, Entropy is focused on developing solutions for clean energy and scaling up the impact on a climate relevant scale by applying CCS to hard-to-abate sectors that provide essential goods for society, such as natural gas production, in-situ oil production, pipelines, steel, cement, and natural gas-powered electricity generation.

Entropy is excited about future opportunities and is positioned to deliver positive outcomes for emitters, investors, developers, and society at large.

More information

entropyinc.com

Creating value through decarbonization: hydrogen's role in achieving net-zero

Decarbonization of high-carbon intensive processes, industries, and fuels can create added value streams with the right technology. By Christine Newell, Director, ClimateBright™, Babcock & Wilcox.

B&W is involved with several major projects including jointly developing a biomass-to-hydrogen clean energy project with Port Anthony Renewables Limited in Port Anthony, Victoria, Australia using B&W's BrightLoop™ technology

Social and regulatory pressure to lower emissions, coupled with the costs of doing so, can put many businesses at risk. But there are simple, yet impactful actionable steps plant owners and operators can take to build a solid foundation for a successful low-carbon business model while controlling costs.

Regardless of where a business is in its energy transition, owners may discover going green can create new revenue streams and help make a business more competitive.

Some key near-term steps plant owners and operators need to take including familiarizing themselves with greenhouse gas regulations and proposed regulations applicable to their industries, including tax credits, possible penalties and potential sources of government funding. Businesses also should work to create an Environmental, Social, Governance (ESG)/Sustainability Report if they haven't done so already.

Owners and operators also should plan now to source advanced technologies that create value while lowering emissions, source sustainable materials and create partnerships with carbon-conscious suppliers.

Climate Change Urgency Drives an Evolving Market

According the Climate Action Tracker web site, global greenhouse emissions peaked in 2020 at 53 GtCO2e which has led to warming of 1.2°C in 2021 above pre-industrial averages. The intention of the United Nations Framework Convention on Climate Change Paris Agreement, adopted at COP21 in 2015, was to keep warming below 2°C, preferably to 1.5°C, through drastic reductions in emissions.

With varying levels of decarbonization policies, nationally determined contributions (NDCs), and targets, the U.N. predicts the global mean temperature is more likely going to be 1.8-2.7°C by 2100 unless significantly more is done.

Fossil fuels for energy, transportation, and industry are heavy contributors to global warm-

	ETS or Cap-and-Trade (aka cap-and-invest, cap-and-dividend)	Carbon Tax
CO_2 Price	Varies; pre-defines carbon price but changes as emissions limits decrease	Constant
Emissions	Sets a cap, cap drops over time	Varies
Certainty of reducing emissions	High (emission reduction outcome is predefined)	Low (emission reduction outcome is not predefined)
Control	Emissions limits are controlled by offering permits; Pay to emit carbon up to cap; trade credits if under/over limits	Carbon levels restricted on a per ton basis; oil/natural gas/electricity is then taxed; Taxed on rate of carbon (and other GHGs) content of fossil fuels
Carbon Pricing Dashboard Status	32 initiatives covering 38 national and 31 subnational jurisdictions; represents 17%, 10 $GtCO_2e$, of the global GHG emissions	36 initiatives covering 28 national and 8 subnational jurisdictions; represents 5%, 3 $GtCO_2e$, of the global GHG emissions

Carbon Credits and taxes (see https://carbonpricingdashboard.worldbank.org/)

ing prior to 2020 but are expected to fall from 80% of the energy mix to 50% by 2050, according to DNV's Energy Transition Outlook. Oil and coal are expected to continue to have the largest declines, 50% or more reduction each, while natural gas use will remain mostly stable.

Policymakers need to be flexible in adopting new technologies and sources of clean fuels to lower emissions coupled with carbon capture to keep global warming at a minimum.

The Role of Hydrogen in Decarbonization

Excitement around hydrogen and carbon capture to facilitate emissions reductions has been gaining speed in the last few years with new technologies, infrastructure, and policies being developed backed by strong public support. Early adoption in strong markets such as in Europe, set the stage for future successes. The high cost of "going green" is projected to come down over the next decade as reliance on fossil fuels becomes more expensive.

Hydrogen has potential to be used in various applications such as: hydrogen for high-grade heating in steel/cement/pulp and paper processes, ammonia for fertilizers and chemicals, refining processes, blended with natural gas turbines for electricity generation, transportation fuel, or in the production of ammonia and methanol for large container ships. Hydrogen has many benefits and challenges:

• Plentiful, but costly to produce as a low-carbon energy carrier

• Combustible, but it reacts differently than natural gas

• Lightweight, but low energy density is an issue for transportation

• Liquid hydrogen and derivatives overcome this issue, but conversion is not efficient

• Great potential but also poses challenges for wide adoption

The carbon intensity for hydrogen applications varies but is often referred to by color, most typically: gray (high-carbon hydrogen) made with natural gas and no carbon capture, blue (low-carbon hydrogen) made with natural gas and uses carbon capture, and green (clean or green hydrogen) made with renewables or biogenic material with carbon capture. Currently, the cost of producing gray and blue hydrogen is cheaper than producing green hydrogen, but is expected to flip as carbon taxes increase, making blue and green hydrogen the more economical choices.

To achieve net zero targets, the International Energy Agency states that cumulative investment must increase to $1.2 trillion USD by 2030 and $10 trillion by 2050, but forecasts vary widely and at present there are just over $300 billion in identified projects. Only 13% of these projects are at the realized stage where final investment decision has been made or is in construction or operation. The IEA reports demand for low-carbon intensive hydrogen ranges from 100 metric tonnes in 2020 to 500 metric tonnes by 2050 and the demand for hydrogen is closely aligned with decarbonization strategies.

Coupled with carbon capture, blue hydrogen is a cost-competitive bridge to the costlier but more environmentally beneficial green hydrogen. Carbon reduction in hard-to-abate sectors is a key driver in meeting 2050 goals and is expected to require $9.7 trillion with current investment projections coming in short at $5 trillion. Carbon capture and storage (CCS) is included in 11 of the submitted NDCs with 2030-35 targets, and the IEA projects $700 billion per year will be needed between 2030 to 2035 via carbon pricing systems such as taxes and cap-and-trade.

Carbon dioxide is a versatile by-product of energy and hydrogen production and can be captured and stored underground in approved wells or under the seabed, or it can be captured and compressed to be transported to industrial facilities such as steel and cement mills and food and beverage plants for myriad uses. To achieve large-scale, competitive carbon capture, the costs to capture/store/trans-

B&W's ClimateBright Portfolio	Description	Possible Revenue Streams
BrightLoop	Chemical looping with proprietary regenerable oxygen carrier particle to generate hydrogen from a variety of fuels, including biomass, natural gas, petroleum coke, coal, municipal solid waste for waste-to-energy and syngas while creating a concentrated stream of carbon dioxide for sequestration or utilization	Low-carbon intensive hydrogen (sell to off-taker, use at site, credits), liquid nitrogen, ammonia, green steam for power, alternative fuels (green methanol, sustainable aviation fuels, etc.) Carbon dioxide utilization, credits, and tax avoidance
OxyBright	Post-combustion CO_2 scrubber, reduces 100% of CO_2 emissions, produces steam for power	
SolveBright	Post-combustion solvent CO_2 scrubber capturing 80-90% of CO_2 at the stack	

B&W's ClimateBright™ Portfolio

port typically needs to be under $50/metric tonne as the subsidies for fossil fuel powered entities are diminished or ended.

As of early 2022, the Global CCS Institute shows 29 carbon capture projects commercially operational in 11 countries: 1 Australia, 1 Brazil, 4 Canada, 4 China, 1 Hungary, 1 Iceland, 2 Norway, 1 Qatar, 1 Saudi Arabia, 1 UAE, 12 USA. In preparation of meeting net-zero goals, 500 sites in 13 countries have been determined to be capable of storing more than 12,000 billion tonnes of CO2, which is more than enough to meet global demand.

Cap-and-trade and Emissions Trading System schemes set the quantity of emissions reductions and let the market determine the price. By creating supply and demand for emissions allowances, these systems establish a market price for greenhouse gas emissions. A carbon tax sets the price of carbon dioxide emissions and allows the market to determine the quantity of emission reductions. The carbon market is estimated to be $0.4 billion in 2020 and $90-450 billion by 2050, according to CarbonCredits.com.

Government funding to facilitate research and development of new technologies and the build-out of required infrastructure is available from the U.S. Department of Energy, the government of Alberta, Canada, various funding tracks in the E.U., and from other government entities elsewhere. Government support and development of hydrogen hubs and carbon capture hubs including storage is a critical step to reaching net-zero.

The US announced $8 billion to develop at least four major hydrogen hubs and $12.1 billion for carbon management technologies and have Matchmaker programs for each to connect companies and build partnerships. Bilateral partnerships from approximately 35 countries are in talks or have been established to help facilitate a global hydrogen market.

Emerging Hydrogen and Decarbonization Technologies

As a global leader in decarbonization and hydrogen generation technologies Babcock & Wilcox (B&W) is positioned as a major partner in low-carbon intensive hydrogen production and carbon capture with its advanced ClimateBright™ portfolio of solutions. This exclusive portfolio contains the type of groundbreaking, game changing technology that is needed to propel us towards net-zero. B&W has paved the way to create value from waste by-products with revolutionary changes to traditional chemical looping and carbon capture technologies.

B&W continues to expand its decarbonization portfolio to include Direct Air Capture, Long Duration Energy Storage, and Green Steam while also holding themselves to high standards as outlined in their 2022 ESG report. An ESG report is a way for corporations to be held accountable for their sustainable practices.

Being an engineering firm, B&W supports the guidelines provided by Sustainability Accounting Standards Board's framework for Construction and Engineering Services. They are also a proud participant of the United Nations Global Compact, a volunteer initiative with over 16,500 companies in 158 countries determined to have fair and just sustainable future.

B&W recently announced a partnership with Kiewit Industrial to develop the world's largest net-negative CO2 biomass-to-energy facility for Fidelis New Energy using B&W's advanced biomass and proprietary OxyBright™ carbon capture technologies. The project, Project Cyclus, will produce sustainable aviation fuel, renewable diesel, green hydrogen, and bio-plastic feedstock with a net-negative carbon dioxide footprint.

In late 2021, B&W also entered into an agreement with Port Anthony Renewables Limited to jointly develop a biomass-to-hydrogen clean energy project in Port Anthony, Victoria, Australia using B&W's BrightLoop™ technology. When completed, the plant is expected to be part of the largest green hydrogen hub in southeastern Australia.

BrightLoop technology is part of B&W's ClimateBright suite of decarbonization solutions. It utilizes a proprietary regenerable oxide particle to generate hydrogen from a variety of fuels, including biomass, natural gas, petroleum coke, coal, municipal solid waste for waste-to-energy and syngas while creating a concentrated stream of carbon dioxide for sequestration or utilization.

One of the possible major hydrogen hubs in the US may be in the Ohio tri-state area. B&W joined the Stark Area Regional Transit Authority and 60 other companies to form the Ohio Clean Energy Hub Alliance to build support for the hub which is seeking $2 billion in grants from the U.S. DOE.

Tens of thousands of jobs could be created and would help build up the area's hydrogen bus fleet while also lowering the cost of hydrogen from $6-10/kg to $1/kg.

New Business Models

There are other opportunities in this changing market besides joining major hub alliances or developing new technologies. New business models may include reducing emissions to prevent tax penalties and/or become eligible for carbon credits if sequestering, storing, or utilizing carbon depending on market regulations.

If producing blue or green hydrogen, selling to an off-taker, using it on-site, or selling a by-product such as nitrogen, oxygen, or steam could be additional revenue streams. Hydrogen may also be eligible for low-carbon fuel tax credits as indicated in Alberta, Canada and the U.S. planning.

When natural gas prices are high, and coal is no longer an option, having alternative feedstocks (fuel for hydrogen production) is key in carbon-intense industries. By using green feedstocks such as certain biomasses, green hydrogen and green steam can easily be produced. Development of smaller hydrogen and carbon hubs through partnerships and alliances in addition to the government-funded major hubs creates a strong network to meet future supply and demand.

Several technologies already exist or are being developed to support these new business models including chemical looping, CO2 scrubbers, direct air capture, nature-based solutions such as planting trees and growing specific algae, and more. Carbon capture as a service (CCaaS) is a more recent development to fill a gap in the market where a company will take care of a customer's carbon needs from production to storage to utilization. Hydrogen as a reliable energy source is possible and economical with long-duration energy storage (LDES) of more than 60 hours.

Actions

We have less than three decades to meet net-zero targets by 2050 and are currently projected to have a gap of 19-23 GtCO2e to stay under 1.5°C under current pledges. This new low-carbon market provides ample opportunity for small and large companies, new and old, to participate in carbon reduction while adding jobs and increasing revenues.

What can businesses do?

Short-term (1-2 years)

• Determine current greenhouse gas (GHG) emissions output and what penalties may result for failing to reduce emissions within a certain timeframe. Learn local regulatory requirements. Businesses may not qualify for credits even if they are available; some markets are mandatory, some are voluntary.

• Source materials from sustainable companies

• Develop an ESG (Environment, Social, Governance) or Sustainability report showcasing GHG reduction goals

• Create a carbon reduction plan with achievable, incremental steps and contingencies for missing goals (pay penalties, adjust suppliers, etc.)

• Apply to government funding opportunities for technology development and scale up, and/or look for partners and alliances to join

Mid-term (3-5 years)

• Implement blue solutions like B&W's ClimateBright portfolio with a path to green

• A/B test new business models or continually adjust current business models to meet new goals

• Identify ways to fit within a circular economy

• Watch for new carbon storage locations and pipelines

• Watch for new hydrogen supplier hubs and pipelines

Long-term (5-10 years)

• Implement carbon-free solutions

• Partner with new carbon-conscious suppliers

• Tap into hydrogen and carbon networks

• Continue to innovate and reduce carbon until zero or negative

We face many challenges in reducing emissions to meet the Paris Agreement. Transparent assessments of governing policies, access to funding and collaborations, and active participation of all companies large and small will help us achieve net-zero. Under current policy, we are projected to miss the 1.5°C target, landing closer to 1.8°C or even 2.7°C.

Advanced technologies in conjunction with the development of hydrogen and carbon hubs and overall infrastructure, supported by policy, credits, and taxes, may not be enough to decarbonize the globe before overheating past 1.5°C.

Now is time to be an active, impactful partner in the net-zero effort. With a growing suite of advanced low-carbon solutions available, Babcock & Wilcox is excited to collaborate in hard-to-decarbonize industries and find the ideal solution for your needs to create value in this time of transition.

More information

B&W is committed to environmental sustainability, designing, engineering and deploying technologies proven to help preserve the earth's natural resources.

www.babcock.com/hydrogen

The pore rights challenge for CCS projects in the US

Unlike many European Union and other nations across the globe where the rights to sequester CO2 are held by the government, in the United States those rights are mostly privately held. By Dr. Paul Schubert. CEO, Strategic Biofuels.

Furthermore, except for land owned or controlled by state or federal governments themselves, the jurisdiction for determining who has the "pore rights" to store CO2 underground in the "pore space" is left to the individual states. The main challenge is whether those pore rights belong to the surface owners or whether they belong to the mineral rights owners, although a range of other surface and subsurface rights may impact the ability to sequester the CO2.

To date, only seven of the fifty states have provided the legislative framework needed to facilitate advancement of CCS projects within their borders. The individual states that have established legislation have generally vested the pore rights ownership with the surface owners. In the limited number of states there have been court cases that have ruled on which entity involved in the case owns the pore rights. However, each court's decision is highly dependent upon the specifics of the case and therefore may not establish precedents that can be applied statewide. In several states, including Texas, which is the largest energy producer in the US, one court found for the surface owner and another for the mineral rights owner.

Why the pore rights in the US matter

The potential for carbon sequestration as a major contributor to greenhouse gas emissions reduction globally is substantial. According to the Global CCS Institute there are 29 CCS facilities around the world already capturing and storing 40 million tonnes of CO2 per year[1]. Commercial scale CCS facilities in operation span a wide range of industries including gas processing, ethanol, fertilizer, steel, and hydrogen production. According to the CO2 Storage Resource Catalog[2], there are more than 14,000 gigatonnes of CO2 storage capacity worldwide. With 2021 energy-related CO2 emissions estimated by the IEA[3] at just 33 gigatonnes it is apparent that potential availability of storage reservoirs is not a significant challenge.

Recognizing the United States ranks second only to China in annual tonnes of greenhouse gas emissions and first on a per capital basis, co-locating CO2 storage reservoirs with US energy production locations is important for effective CCS deployment. According to a 2021 Congressional Research Report[4] the estimated US storage capacity for CO2 could be as low as 2,618 gigatonnes to as high as 21,978 gigatonnes, with actual capacity dependent on a wide range of factors. Regardless of the actual capacity, the potential to sequester CO2 in the US is enormous given the data from 2019 showing that the electricity generation sector in the US emitted just 1.6 gigatonnes[5].

The absence of the legislative framework needed to facilitate securing the pore rights in most states severely hinders CCS project development. This is further exacerbated by the lack of the regulatory framework needed to advance projects. The US Environmental Protection Agency (EPA) only finalized the regulations for carbon sequestration wells (EPA Class VI wells) in 2018.

The EPA has a limited capacity to handle sequestration well permits and encourages the individual states to secure primacy, which is the right to issue Class VI well permits themselves. However, only two states, North Dakota and Wyoming have obtained primacy so far, with Louisiana expected to be the third. Under the primacy requirement the state's regulations must be at least as stringent as the EPA's for securing and operating a sequestration well. This adds another layer of uncertainty to CCS project development.

Why deciding who owns the pore rights is a problem

It is common in the US for mineral rights to be separated, or severed, from the surface rights. The mineral rights may be further divided into a range of rights which might include separate rights to extract coal, extract natural extract gas, and extract oil. These mineral rights are often fractionalized among multiple parties, often because of family inheritance. The result is that a single tract of land could be owned by hundreds of parties. Clearly, if pore rights belonged to the mineral rights owners the process and cost of securing them would be daunting.

Fortunately for CCS project development in the US, the seven states that have established pore rights ownership so far have all passed legislation stating that the surface owners own the pore rights. These states are Louisiana, Michigan, Montana, Nebraska, North Dakota, Oklahoma, and Wyoming. There are a further seven states where court findings or other legislative or actions indicate they are likely to favor the surface owner. These states are Arkansas, New Mexico, New York, Mississippi, and West Virginia.

A court case in Kentucky[6], Central Kentucky Natural Gas v. Smallwood, found "the mineral owner possesses the exclusive right of production as well as the exclusive right to the storage space left after production has ceased." Although surface owners oppose this ruling. In the absence of action by the state legislators this ruling is likely to have established the ownership question for the entire state.

As mentioned earlier, in Texas, separate court cases have decided in favor each of the potential owners. As a result, unless the state legislature establishes ownership through new laws, development of CCS projects on private land may require acquisition of both the surface and

1. Global CCS Institute, CCS Mythbusters, https://www.globalccsinstitute.com/wp-content/uploads/2022/06/MythBusters-Flyer_FINAL-5.pdf
2. CO2 Storage Resource Catalog, https://CO2storageresourcecatalogue.com/
3. https://www.iea.org/reports/global-energy-review-2021/CO2-emissions
4. Carbon Capture and Sequestration (CCS) in the United States, https://sgp.fas.org/crs/misc/R44902.pdf
5. U.S. Environmental Protection Agency, Draft Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2019, p. ES-7, at https://www.epa.gov/ghgemissions/draft-inventory-us-greenhouse-gas-emissions-and-sinks-1990-2019

mineral rights by the developer. A similar situation exists in Kansas and Colorado. A cautious approach in these and other states where pore rights ownership are unresolved would be to acquire approval from both the surface and mineral rights owners. Obviously, this would require additional time and cost.

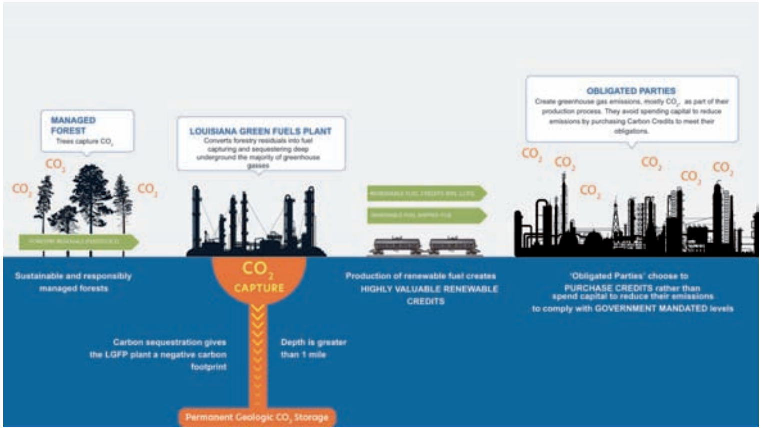
Project development exclusively on state and federal lands offer a different set of challenges. State lands typically include forest, rivers, and other water bottoms. Individual states' approaches to a CCS project's acquisition of pore rights may vary significantly. They may include different payment structures depending on size and location involved. For example, for reservoirs entirely or a majority of the pore space on state lands they may involve payment to the state on the basis of the tonnage of CO2 injected. In contrast, if the percent of the spore space belonging to the state is minimal, a single payment may be made.

The Federal government recently issued guidance regarding the use of pore space on land managed by the Bureau of Land Management (BLM) or other Federal agencies when surface facilities, including injection wells, are on private or state-owned lands or lands managed by another Federal agency[7]. Thus, on federally managed lands, even if owned by the state, federal guidelines take precedence over the state's guidelines on pore rights. However, for states with Class VI well permit primacy, the state's well permitting and operating requirements must be met.

The importance of eminent domain

The use of eminent domain to acquire the pore space over which the injected CO2 will expand over time significantly reduces the risk to CCS project development. Eminent domain, the power of the government to take private property and convert it to public use, is also known as compulsory purchase or expropriation. Some states have defined CCS as being in the public interest, and therefore granted the right to use eminent domain to acquire pore rights.

In the absence of the ability to exercise eminent domain, a CCS project could face legal challenges from individual pore rights owners. Injected CO2 entering pore space for which the rights were not secured represent trespass. Use of eminent domain means that the CCS project cannot be blocked one or more pore rights owners that may oppose the project or wants excessive compensation for their pore space.



The use of eminent domain requires the CCS project to make its best efforts to acquire pore rights from the owners. Owners from which the pore rights that could not be secured can be taken to court in an expropriation action. The issue the judge determines is not whether the pore rights will be transferred to the project, but rather the price that will be paid considering the established fair market value.

The right to use eminent domain for this purpose is dependent on the individual state. Some states have required CCS developers to acquire fifty to sixty percent of the pore rights prior to being able to exercise eminent domain. This effort also serves to establish the current market value of the pore rights. Louisiana has granted CCS project developers the use of eminent domain to acquire all the needed surface and subsurface rights after such a good faith effort at securing them has been made.

CCS project finance considerations

The economics of CCS projects in the US are highly dependent on incentives created by state and federal programs. These incentives can be substantial. The recent passage of the Inflation Reduction Act in the US increased the IRS 45Q Federal tax credit available to geologic sequestration projects from $50 per tonne to $85 per tonne.

Production of renewable fuels incorporating CCS can also secure significant incentives under the Federal government's Renewable Fuel Standard and the California's Low Carbon Fuel Standard Program (LCFS). Notably, the LCFS program provides increasing credits as the carbon footprint of the fuel gets lower, and CCS can substantially contribute to achieving low carbon footprints.

Strategic Biofuels' Louisiana Green Fuels Project is a good example of the low carbon footprint that can be achieved by incorporating CCS with renewable fuel production. The project will use waste materials from the forestry industry to produce renewable diesel fuel as well as all the power the project uses. In the absence of CCS, the fuel would have a carbon intensity of about 23 gCO2e/MJ.

With carbon capture and geologic sequestration from both the fuel and power production the carbon intensity drops to minus 294 gCO2e/MJ. This is about a 394% reduction to the carbon intensity relative to fossil diesel. This qualifies the fuel for the Federal tax credits, Federal Renewable Fuel Standard credits, and significant quantities of LCFS credits if the fuel is delivered to California. The project has already completed the test well program needed to demonstrate the presence of the geologic features and the reservoir capacity required for sequestration. The combination of these incentives with the value of the physical fuel itself results in robust economics for the project.

The future

As is apparent from the above, expansion of carbon capture and storage projects in the US faces significant challenges. Chief among these is the development of the legislative and regulatory framework in the forty-three states without them. In the absence of this, project developers seeking to implement CCS projects in those states face the daunting challenge of securing both the surface and mineral rights to ensure the project can proceed without significant legal challenge.

More information

strategicbiofuels.com

6. "Who Owns Pore Space for Geologic Carbon Sequestration? Renewed Focus on Carbon Capture and Storage Likely to Bring Ownership Uncertainties on Western Split-Estate Lands Back into the Picture", https://www.jdsupra.com/legalnews/who-owns-pore-space-forgeologic-carbon-2984045/
7. US Department of the Interior, Bureau of Land Management, June 8, 2022 https://www.blm.gov/policy/im-2022-041

MechanicalTree design can reduce DAC cost

Researchers from Arizona State University / Carbon Collect have developed a design for a direct air capture system which they believe could capture CO2 at $100 / tonne if built at scale. By Karl Jeffery.

Direct Air Capture technology is similar to carbon capture technology used on flue gases, except where flue gas can be 20 per cent CO2, air is 400 parts per million CO2.

So to get enough CO2 to make the project worthwhile, you need a lot of air coming into contact with the solvents or sorbents. But the rest of it is the same, heating or pressuring the solvents or sorbents to release a stream of pure CO2, for sequestering or some other purpose.

Most Direct Air Capture technologies so far have relied on big fans to blow large quantities of air to the solvent. The technology from Arizona State University instead has the solvent or sorbent placed on large numbers of 1.5m diameter disks piled into a cylinder with space between them.

It relies on wind to blow air across them, but even a very small breeze is enough. So it explains the process as "skimming CO2 out of the air."

The company estimates it could build small scale plants which capture CO2 for $300 a tonne, or large scale farms which can capture at $100 a tonne. By comparison, a recent report from the World Resources Institute estimates the cost of DAC at $250 to $600 a tonne.

The technology was developed at Arizona State University (ASU)'s Center for Negative Carbon Emissions, supported by ASU's "Lightworks" incubator which supports sustainability related projects.

A full scale design is being developed, tested, manufactured and commercialised by a company called Carbon Collect, in which ASU has a shareholding. Carbon Collect has exclusive rights to develop the technology.

The technology is called "the Carbon Collect MechanicalTree system." Reyad Fezzani, Vice Chairman and executive director of Carbon Collect is a former CEO of BP wind and solar, and CEO of BP's global chemicals business.

How it works

The typical design for the MechanicalTree system has 1.5m diameter disks, stacked in a cylinder 10m tall, although it can be built at any scale.

When the disks or 'tiles' have collected enough CO2, normally after 20 minutes, they are lowered mechanically into a 2.5m high chamber at the base of the MechanicalTree.

The chamber is sealed, air is removed using a vacuum pump, and then the tiles are heated or pressurised to create a stream of pure CO2. Then the disks are raised to their full height and the process starts again.

The system does consume energy for this heating / pressurising, for moving the tiles up and down, gas compression, and running the vacuum pumps.

The main intellectual property is the process, the mechanics, and the interaction between the energy system and the mechanical system.

Developing the technology

A commercial scale system, rigged up with instrumentation for testing, has been running since Spring 2022 at ASU's main campus in Tempe.

Researchers are determining performance under different weather conditions and developing a digital twin model.

Carbon Collect plans to build a number of smaller systems quickly so it can improve the design, rather than aim to build large plants which will last for decades. The system will have a modular design.

Ultimately, a 2-3km2 farm of 120,000 Mechanical Trees could capture 10k tonnes per day CO2, or 3.6m tonnes a year. This is equivalent to the daily emissions of 800,000 cars.

The trees could be deployed in clusters of 12 columns, each able to remove 1 tonne of CO2 per day. CarbonCollect envisages building farms at this scale "in the second half of the 2020s".

The farms would need to be built at this scale to get the $100 / tonne capture price, the company calculates. Although it may encounter other challenges in getting there, such as price inflation, availability of materials and logistics, says Reyad Fezzani, Vice Chairman of Carbon Collect.

The company envisages that the first 1000 tonne a day farm, with 12,000 'trees', would have a capture cost of $300 a tonne.

Three designs for farms at this scale have already been completed, with the help of support from the US Department of Energy.

"We're starting to put together the full designs for those, including how each subcomponent of the product is connected and powered," Mr Fezzani says.

The company is testing out a range of different solvents. "There are all kinds of materials that you can use to capture CO2. The objective here is to try to find the most efficient and most cost effective," he says.

"There are ready sorbents out there that you can buy. They don't perform the same way. There are different characteristics for different weather conditions. There's a significant job for us to match the sorbent with the situation."

The challenge is to work out how to "capture as much CO2 as possible, and [maintain] the quality and degradation property of [the sorbent]. It is quite a science in its own right. We have a team that's focused on sorbent and solvent selection."

"All we're doing is basic chemical engineering, trying to simplify it as opposed to increase complexity."

Work is also going into making the tree easier to construct, fabricate and transport, and to build relationships with suppliers.

The design work is being done by engineering consultants and contractors are around the world; the physical testing is being done in Arizona.

Arizona may be a good site for the trees because there is large amounts of renewable energy from solar power, including from the grid. The climate, very dry and hot, may also be particularly good for the technology, Mr Fezzani says.

Once the company has developed the supply chain capability and finished designing operational aspects, it will start looking for sites for larger scale projects, and embarking on commercial and permitting work. "All that is going to take some time," he says.

Basic design for three facilities has already been done, for actual sites in the Mid-West, Southeast and West Coast of the US.

It is necessary to gather a lot of weather data about any specific site being considered, including the temperature profile, wind speed profile and humidity around the year, in order to choose the best sorbent. "You are fine tuning all of your variables to optimise for that weather location," he says. "We're something of a weather company too."

Business models

When the technology has been developed on a smaller scale, it could be sold to companies which use CO2 in their industries including agriculture and beverages.

The Mechanical Tree can be sited next to a customer site. Since the atmosphere everywhere has nearly the same level of CO2, it does not matter where it is.

"If you're a small vertical farm or a greenhouse, you need one mechanical tree of production every day," Mr Fezzani says.

Some greenhouses burn natural gas specifically to make CO2 as a fertiliser, so they would not need to do this any more.

"There's really interesting opportunities to do this at a small scale, and do it quickly," he says.

With a Mechanical Tree, there is no need to use pipelines or trucks, bottling facilities and storage facilities, which CO2 customers would normally need. (And of course, all of this CO2 transport also emits CO2).

There are no economies of scale from building a centralised plant.

For CO2 buyers, the cost per tonne is higher the smaller the volumes used.

One small scale CO2 user has signed a contract with Carbon Collect to receive CO2 at $750 / tonne, which it must find a competitive price compared to what it currently pays for bottled CO2.

A second use case is a factory which generates excess heat, which it could turn into a revenue stream, feeding it into a Mechanical Tree, and being paid by a company which buys CO2 offsets.

A third use case is to use the trees on a very large scale purely for climate reasons, with CO2 pumped into subsurface structures for permanent storage.

"There's really interesting opportunities to do this at a small scale, and do it quickly" - Reyad Fezzani, Vice Chairman and executive director of Carbon Collect

More information

mechanicaltrees.com

CO_2 Emissions Reduction in Corporate Sustainability

The report from the Carbon Dioxide Capture and Conversion (CO2CC) Program focuses on how companies are addressing their sustainability goals through areas like CO_2/GHG emissions reduction (especially through CCUS), carbon reduction, waste recycling and mitigation, and resource utilization.

The report, "The Role of CO_2 Emissions Reduction in Overall Corporate Sustainability Initiatives" summarises known corporate commitments by International Oil Companies (IOCs), National Oil Companies (NOCs) and Global Chemical Companies to reduce CO_2/GHG emissions.

CO_2 emissions reduction is an area that is dominating corporate sustainability initiatives and attracting attention in the hydrocarbon processing industries. Ultimately, it's becoming more and more clear that sustainability is an increasingly integral and core aspect in both company culture and decision making.

The scope of the report covers crucial efforts that highlight the methods and mentalities being applied to address environmental sustainability to promote clean air and water, responsible use of resources, and promotion of good biodiversity. It highlights that there are many approaches to sustainability, and it is becoming increasingly important to identify:

- How companies define sustainability
- How companies then structure and implement efforts for results
- How companies respond to those efforts and improve results

Sustainability is not a new concept in the hydrocarbon processing industries. Much effort and technological innovation has been required (and will continue to be) to comply with clean air regulations, like reducing NOx and SOx emissions. What has evolved quite quickly is the attention that is being given to the reduction of greenhouse gases (GHG), mainly CO_2 and CH_4.

The petrochemical and chemical industries have both overlapping and different sets of goals and objectives when it comes to sustainability when compared to oil and gas and refining. Reducing CO_2 emissions and then utilizing CO_2 as a raw material into traditional products is seen as a "cornerstone of sustainability plans".

It is worth noting that although the report is a refining (i.e. downstream O&G) and petrochemicals assessment, the linkage to upstream O&G is undeniable in several areas. This falls into 3 categories:

1) Carbon Intensity of feeds and fuel supplies. As the facilities look further and deeper into the supply chains and total life cycles, the carbon intensity of supply will be a factor over time in the enterprise's carbon footprint and CSR scorecard.

2) The comparison and contrasts of enterprises that are vertically integrated and as such have a spread of the operational footprint across the enterprise, those contrasts of non-integrated refineries and chemicals facilities will be exposed.

3) In the case of emissions controls and technologies (especially in the CCUS landscape) the upstream will be critical to integrate. In the case of CCUS, the CO_2 capture facility will need to have a construct to assure safe and permanent storage of the CO_2 in geologic formations. This is essential to capture the tax credits provided by 45Q – as well as any long term off take to satisfy the investments made on CO_2 capture technologies.

As the technologies mature, the projects become reality, and the market reaches a level of certainty sufficient for individual investment and risk analysis, it will likely enable individual company investment and balance sheet exposure.

Coupled with a global tax on carbon or structured carbon exchange mechanism these investments could then become a reality, but such a transition is difficult to project, but can be considered as impactful in a +/-5 year time horizon.

Scope of Report

The opening of the report addresses how companies define sustainability and how they then structure and implement efforts for results. The involvement and strong presence by the investment community has created a marketplace momentum that is undeniable. The effects ripple throughout the global community not just for those that are in the oil and gas and petrochemical world, but suppliers, energy segment providers, investment houses, shareholders, and in general, the court of public opinion.

In the petroleum refining and chemical industries, there are several overall trends taking place to address the reduction of GHGs, including relevant GHG mitigation techniques such as carbon capture and utilization (CCU) and carbon capture and storage (CCS).

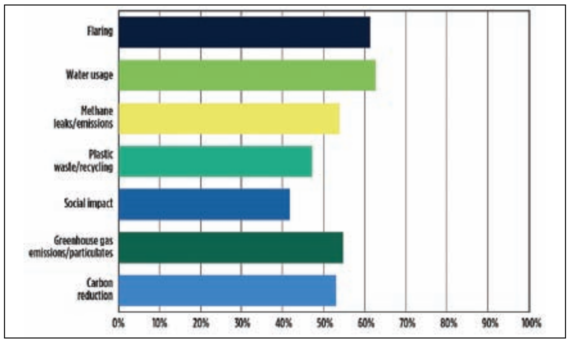
In late 2019, Gulf Energy Information conducted a survey (gulfenergyinfo.com/sustainability-leadership/2019/november/understanding-sustainability-in-oil-and-gas) to try to better understand sustainability in the oil and gas industry. Their survey found:

- 49% of companies have a sustainability initiative
- 29% do not and were not working on creating one

An interesting finding was that the vast majority (65%) view their company's sustainability initiative as a competitive advantage instead of originating from either social (26%) or investor (9%) pressure.

Corporate commitments

Ways in which the oil and gas industry is addressing sustainability include organizaions such as the Oil and Gas Climate Initiative (OGCI) where funds in excess of $1B have been pooled to fund early stage research as well as start-up project development to impact carbon emissions, or the Alliance to End Plastic Waste (AEPW) with an investment of similar magnitude to tackle the challenge of 8 million tons of plastic waste entering oceans every year.



Key technologies and issues for the oil and gas industry to address which can improve sustainability. (Source: Gulf Energy Information survey; see link in text)

Corporate commitments to reducing GHG emissions are largely influenced by the Paris Climate Agreement and the UN SDGs. A variety of technological approaches are being considered or already being utilized in order to reduce CO2 and GHG emissions, amongst other efforts to improve sustainability.

While numerous European and North American oil majors (the IOCs) have made public commitments to net-zero goals, the same can't be said for National Oil Companies (NOCs). However, they may have actionable plans in place to reduce their CO2/GHG emissions but many have not made the net-zero commitment.

For the Chemical Industry, the sustainability strategies will obviously differ from oil majors. For one, chemical companies typically have lower Scope 1 and 2 emissions when compared to their upstream peers.

Low carbon and clean energy investments

Capital expenditure on low-carbon, clean energy innovations and technologies is a marker showing long-term commitment to a pathway of GHG emissions reduction. A broad range of efforts would be required to decarbonize the refining and petrochemicals sectors and to ensure their long-term sustainability.

CCUS represents at least a low-carbon option for numerous industries and can make a significant impact in certain "hard to abate" industries like steel and cement production.

The CCS supply chain starts from sources of CO2 emissions from industrial or petrochemical manufacturing and power generation activities. Technologies and projects that capture and store CO2 would likely have the knock-on effect of further commercialization and cost reduction to less than $20/ton CO2

According to the Global CCS Institute, cost reductions are one of the prime reasons why investment in CCS today is important as the learning that results from deploying CCS will inevitably deliver cost reductions. The report summarises corporate capital CCS investments to date.

Metrics

Emissions can be classified into three categories based on their source across the lifecycle. The U.S. Environmental Protection Agency's classification for emission scopes were used. These are:

• Scope 1 emissions are direct emissions, includes on-site fossil fuel combustion and fleet fuel consumption.

• Scope 2 emissions are indirect emissions from sources, includes emissions that result from the generation of electricity, heat or steam.

• Scope 3 emissions are from sources not owned or directly controlled by the source but related to its activities such as employee travel and commuting, solid waste disposal and wastewater treatment and other consumption associated emissions from the value chain.

The measurement of sustainability is crucial towards improvement and in the achievement of targets and benchmarks in a competitive marketplace, as well as in achieving long-term continuous progress.

The 2030 Agenda for Sustainable Development adopted in 2015 by all United Nations forms the basis of all sustainability-related activities across economies and economic sectors. The Agenda is defined by 17 Sustainable Development Goals (SDGs), which are an urgent call for action by all countries in a global partnership.

Outlook

There are many challenges to consider when it comes to measuring the contribution to real shareholder value and competitive differentiation that go beyond compliance in CO2 Emissions Reduction and Corporate Sustainability:

• Contribution to real shareholder value and competitive differentiation are questionable in investments that go beyond compliance and could be a useful back check on company performance. The circular economy and plastics are very likely worthy of the most attention given the impact on supply and demand for the gas and oil businesses.

• When it comes to assessing CO2/GHG emissions reduction strategies, examples show how companies are reducing CO2 emissions in their products, their plants, and their supply chains. Capital spending on areas like renewable energy, carbon capture, utilization, and storage (CCUS), biofuels, plastics recycling and/or the circular economy, and resource conservation are analyzed.

• There is significant work being done in the areas of ocean and river clean ups where waste is prevalent and contributes to the global view of plastics. The ability to create a circular economy that can return such waste to a feedstock that can be competitively aggregated and costed will be a driving force for long term viability of the industry.

• Water consumption is becoming an even greater challenge for process industries and the ability to create a circular economy in the use of water will also be critical.

• Land use and community impact continues to be a challenge when moving investments into emerging markets and countries.

Next articles

This is a series of articles summarising recent key reports from The Catalyst Group Resources Carbon Dioxide Capture and Conversion (CO2CC) Program. Look out for forthcoming issues featuring: Progress Towards Operating a Viable Business in CO2; Catalogue of Most Important Scientific Advances in CCUS Over the Past 3 Years; and Permanent Sequestration of CO2 in Industrial Wastes/Byproducts.

More information

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

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

CO2 liquefaction using ammonia absorption technology

Combining ammonia absorbtion technology with carbon capture and storage systems can lead to energy efficiency through process integration. By Stephen B. Harrison, Managing Director, sbh4 consulting.

With the current growing global energy demands and effects of greenhouse gas (GHG) emissions, focus on decarbonisation has never been more important. Consequently, carbon capture and storage (CCS) technologies are expected to play a significant role for carbon dioxide emissions control. One major downfall of CCS's efficiency is the amount of waste heat rejected into the ambient. However, in certain scenarios, this can be mitigated through the process of waste heat recovery.

There are many examples of how waste heat can be recovered to ensure energy efficiency. For example, domestic condensing boilers recover low grade heat from the combustion flue gases to pre-heat the returning central heating water optimise their energy efficiency for space heating applications.

Despite measures to recover as much usable energy from the process as possible, many industrial processes such as steel production, cement making, and power generation result in 'waste heat'. This is energy that is left over from the process which is available at a lower temperature than what can be utilised in the main process and is often released to the atmosphere via cooling towers.

The concept of process integration means that waste from one process is used as a useful input for another. An example of waste heat utilisation is the use of high temperature industrial heat pumps (HTIHPs) to elevate the temperature of waste heat to a useful level. For example, to generate steam at 120 °C from waste heat at only 80 °C. Another application of waste heat recovery is to drive a refrigeration cycle to create deep cold temperatures.

Deep cold from waste heat

The technology behind the use of waste heat to generated deep cold is the ammonia / water absorption cycle. The operating principle relies on ammonia being highly soluble in cold water, but less soluble in hot water. A pump is used to recirculate ammonia in a water solution from a cold reservoir to another, where the mixture is heated - ideally using waste heat from another process.

The Yara Gerda liquid CO2 carrier

As the mixture of ammonia in water is heated, ammonia is driven into the vapour phase at a high pressure, which can then be used in a classical condenser, expansion valve and vaporiser refrigeration cycle. The ammonia gas is then returned to the cold-water bath where it is re-absorbed into the water and the cold-water bath is chilled by heat exchange against cooling water to remove the heat energy from the refrigeration system.

The basic technology related to ammonia / water absorption chillers has been around for 160 years. The earliest patent on the topic was prepared by the French inventor Ferdinand Caré in 1860. Since then, the innovations around this technology have not only enabled a lower temperature to be achieved but means that it can also be applied to gas liquefication and small-scale LNG.

Ammonia absorption chillers have been implemented for natural gas liquefaction, so they are proven in modern industrial environments. In contrast to classical vapour compression refrigeration cycles, the energy inputs are power for a pump and heat. Additionally, the electricity demand, cost and maintenance requirements for pumps are less that those that are required for a gas compressor.

Conventional CO2 liquefaction

For several decades, an established process of CO2 capture, purification, and liquefaction has emerged. It is used extensively on biogas plants or breweries to yield CO2 for industrial gases applications. The first stage of the process involves the use of an amine solvent to absorb CO_2 from the biogas reactor or brewery fermenter. Then, the CO2 is purified on an activated carbon adsorption bed to remove any traces of contaminants, such as mercury or hydrogen sulphide.

Following the purifiers, the CO2 is dried on a pressure swing absorption (PSA) system loaded with a molecular sieve adsorbent material. This equipment is sometimes known as a regenerative dryer and purified CO2 from later on in the process is used to purge the driers.

The last stage consists of liquefaction and purification. The dry CO2 gas enters a condenser where it is liquefied to act as the reflux liquid in a distillation process. Operation of the condenser and distillation column at high pressure of around 20 bar means that the CO2 can be liquefied using conventional mechanical refrigeration cycle chillers that operate at -30 °C and can use ammonia as a refrigerant gas.

As an alternative to the mechanical refrigeration cycle, which requires a large ammonia compressor, the ammonia absorption refrigeration cycle can be used to recover waste heat and reduce the electrical power consumption of the CO2 liquefaction process.

Integration of ammonia absorption technology into CCS schemes

At present, the majority of CO2 liquefaction is conducted to create CO2 as an industrial gas for commercial applications, food freezing or beverage carbonation. In the future, it is likely that the requirement to liquefy CO2 from carbon capture and storage (CCS) schemes for GHG emissions reduction will overtake commercial CO2 capture as the main reason for CO2 liquefaction.

In some CCS schemes, the CO2 can be compressed and transported to permanent underground storage locations by pipeline. In other schemes, this will not be an economically viable option due to the major capital investment required to develop the pipeline CO2 transmission infrastructure. In these cases, CO2 will be liquefied and transported by road, rail, or ship.

The dominant carbon capture technology at present is an amine based solvent process. CO2 is absorbed into the solvent and then subsequently boiled out to regenerate the solvent in the reboiler of a stripping column. The reboiler requires abundant steam to drive the CO2 out of solution. Steam leaving the CO2 stripper reboiler has the potential to be used in the ammonia chiller refrigeration cycle to ensure energy efficiency through process integration.

More information

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Northern Lights and Yara sign first CO2 storage contract

Yara and Northern Lights have signed the world's first commercial agreement on cross border CO2 transport and storage.

Yara and Northern Lights have agreed on the main commercial terms to transport CO2 captured from Yara Sluiskil, an ammonia and fertiliser plant in the Netherlands, and permanently store it under the seabed off the coast of western Norway. When the final contractual details are firmed up, this will be the first ever cross border CO2 transport and storage agreement.

It will set the standard for other industrial companies across Europe looking to use Northern Lights – and other emerging CO2 transport options and stores in the North Sea – as a key part of their decarbonisation strategies.

"Yara is our first commercial customer, filling our available capacity in Northern Lights. With this we are establishing a market for transport and storage of CO2. From early 2025 we will be shipping the first tonnes of CO2 from the Netherlands to Norway. This will demonstrate that CCS is a climate tool for Europe", said Børre Jacobsen, Managing Director of Northern Lights.

Yara Sluiskil has already cut 3.4 million tonnes of CO2 emissions per year from its ammonia and fertiliser production since 1990. Significant volumes of carbon dioxide are reused in greenhouse plant production, as an ingredient for carbonated drinks and for other purposes such as urea and AdBlue, a diesel product to reduce harmful gases from diesel engines. From early 2025, 800,000 tonnes of pure CO2 will be captured, compressed and liquefied in the Netherlands, and then transported to the Northern Lights store at 2,600 metres under the seabed off the coast of Øygarden.

"Action to decarbonise industry is urgent and Yara is a frontrunner. I am very pleased to announce that we are now on our way to removing CO2 emissions from our production plant in Sluiskil. This will take us a step further towards carbon-free food production and accelerate the supply of clean ammonia for fuel and power production," said Svein Tore Holsether, CEO Yara International ASA.

Northern Lights is the transport and storage part of the Longship project, funded 80% by the Norwegian government. Building on over 20 years of offshore CO2 storage in Norway, the government has worked closely with Norwegian industrial emitters and Northern Lights to create the world's first open access full value chain CCS model. As part of its funding, the government stipulated that Northern Lights develop a commercial business model and offer its service to the rest of Europe.

The Longship model shows that CCS is doable, safe, and cost-effective. It has also helped to develop a commercial model and a market to support it.

More information

www.norlights.com

www.yaracleanammonia.com

UK CCS could be worth £100 billion to local businesses says report

A UK Government report finds action is needed now to make sure net zero drive benefits UK jobs and economy but the industry could be worth £100bn to the offshore oil and gas supply chain by 2050.

Supply chain companies in the UK offshore oil and gas sector are in prime position to win work in carbon capture and storage (CCS) if urgent action is taken by governments and industry, a report from OEUK finds.

CCS has been recognised as a critical technology to help energy intensive sectors, like cement and power generation, meet their net zero goals. The Government's Net Zero Strategy says the UK will need to capture 50m tonnes a year by 2035.

The report, commissioned by the Department for Business, Energy and Industrial Strategy (BEIS) and produced by industry body OEUK through the North Sea Transition Deal, finds that offshore oil and gas supply chain companies already have some capabilities in areas including plant design and engineering, plant fabrication, and construction.

It identifies 13 actions for government and industry, including the need for support from government through early-stage funding and additional licensing rounds.

It finds:

• The UK has most of the components necessary for a successful CCS sector; a big potential market for exports of technology and expertise; large industrial clusters; extensive gas transport infrastructure; and a good scientific understanding of the geological requirements needed for long-term CO2 storage

• CCS could be worth £20bn to the offshore oil and gas supply chain in the next ten years, and £100bn by 2050

• The UK has an estimated total storage capacity of 78 gigatons, one of the largest in Europe and enough to hold two centuries' worth of the UK's current emissions

• Government should speed up Track 2 clusters and introduce additional licencing rounds for storage sites

• The supply chain, although suitably experienced, is fragile and the UK is at risk of losing it to more attractive opportunities elsewhere in the world if it does not secure a first-mover advantage

Securing this work in the UK will particularly benefit communities in Aberdeen, Inverness, Liverpool, North Wales, East Anglia, Lincolnshire, Yorkshire and Teesside, where the existing offshore energy industry is well-placed to expand into new sectors, including CCS.

OEUK Supply Chain and Operations Director Katy Heidenreich said, "Carbon capture and storage is going to be a key tool in our fight against climate change. It offers a huge opportunity for the UK offshore energy supply chain to help energy intensive industries cut emissions."

"If we get this right, it could unlock £100 billion of work for UK manufacturing employers by 2050. This will support UK jobs, cut emissions, boost the economy and develop skills which can be exported globally."

"Lots of progress has been made, but without urgent action the UK will miss out on the opportunity to secure a leadership position in this exciting new sector."

"Our report sets out how we will continue to work with government to seize a first mover advantage, benefitting the economy, jobs and local communities while achieving our net zero goals."

Conclusions and next steps

1. Encourage industry and supply chain collaboration on visibility and planning – particularly for fabrication, development of storage, and transport

A consistent theme throughout the research was a call for greater visibility on volume and specification of requirements to enable confidence and planning within the supply chain, especially for participants not directly connected to the main CCS projects.

2. Create a clear industry classification system for products and services

A single, clear consistent way of describing supply chain for CCS would be valuable, improving collaboration and understanding.

3.Work to develop domestic skills

Two areas of the CCS supply chain cover a major slice of capital expenditure but where the capability and capacity of the UK supply chain is uncertain. These areas are major plant fabrication for capture; and onshore and offshore pipeline manufacture and supply. With the procurement process for these areas expected to take place 2022-24, early action will be needed to understand the UK opportunity.

4. Quantitative capacity planning which considers the aggregate demand of other energies on the supply chain, particularly on workforce and skills

5. Maintain momentum

The supply chain has stressed the importance of capitalising on the momentum that CCS has gathered since the cluster projects and the confirmation of funding support for Track 1 projects were announced.

More information

oeuk.org.uk

Vital but limited role for CCUS in UK Net Zero

A new report from the Energy Transitions Commission sets out the vital, albeit limited role of Carbon Capture, Utilisation & Storage on the path to net-zero by 2050.

In its latest report, "Carbon capture, utilisation and storage in the energy transition: Vital but limited", the Energy Transitions Commission (ETC), describes the complementary role carbon capture, utilisation and storage (CCUS) has alongside zero-carbon electricity, clean hydrogen and sustainable low-carbon bioresources in delivering a net-zero economy by mid-century.

Massive clean electrification is the backbone of global decarbonisation. However, electrification, hydrogen and sustainable low-carbon bioenergy combined cannot reduce gross emissions completely to zero. In addition, it is almost certain that cumulative CO2 emissions between now and 2050 will exceed the "carbon budget" consistent with a 1.5°C climate objective. So, to limit temperature rises to 1.5°C, carbon removals will be required alongside deep and rapid cuts in emissions.

Carbon Capture and Utilisation or Storage must therefore play three vital but limited roles in the energy transition:

• To decarbonise those sectors where alternatives are technically limited (e.g. industrial processes which by their nature produce CO2 such as cement);

• To deliver some of the carbon removals that are required in addition to rapid decarbonisation if global climate objectives are to be achieved;

• And to provide a low-cost decarbonisation solution in some sectors and geographies where CCUS is economically advantaged relative to other decarbonisation options locally, or captured carbon could be a useful input to a product.

"As a low-carbon, but not zero-carbon technology, CCUS has a complementary role to play in decarbonisation alongside massive clean electrification, hydrogen and sustainable bioresources. Collective action by government, corporates and investors is needed now to ensure that CCUS can scale-up and play this vital but limited role in industrial decarbonisation and deliver some of the carbon removals essential to keeping 1.5°C alive," said Adair Turner, Chair, Energy Transitions Commission.

The ETC's report assesses the roles which CCUS must play on the path to net-zero and what must happen to ensure it can do so. The key conclusions are:

• By 2050, the world will likely need to capture and either use or store 7-10 Gt/year of CO2 (equivalent to c. 18-25% of today's CO2 emissions):

- Of this 3-5 GtCO2/year will be needed to achieve net zero emissions in industrial and energy applications (such as cement, steel and hydrogen production) where the use of electricity, hydrogen, or sustainable low-carbon bioenergy doesn't provide a complete solution to decarbonisation. This use of CCUS would offset the continued consumption of 9 million barrels per day of oil (90% lower than today) and 2,700 BCM of gas per year (over 30% lower than today) while still achieving a zero-emission economy.

- Another 4-5 GtCO2/year will be needed to achieve engineered carbon dioxide removals.

• Provided strong regulations are in place, CCUS can be technically reliable – achieving CO2 capture rates of 90% and above, and securely locking up carbon for long durations. This can be achieved at costs which enable it to play an economically valuable role on the path to net zero.

• The current pace of development of CCUS is far short of what is required. This reflects past confusions about where CCUS is most needed, inadequate investment, and controversies which have generated public opposition.

• A combination of private investment and supporting public policy is required to ensure that CCUS can play its vital but limited role going forward.

A plausible but ambitious deployment trajectory could see 0.8 GtCO2/year of carbon capture capacity operating by 2030 across a suite of technologies, at over 300 facilities. Achieving this will require action from governments and industry to reduce project development time, develop shared transport and storage infrastructure and ramp up investment.

The total investment in CCUS infrastructure is estimated at up to $5 trillion by 2050. This is less that 5% of the total investment needed for the energy transition and equivalent to 0.1% of projected global GDP over this period. In the next decade, the bulk of the investment (90%) will be spent on point source capture, transport and storage, only c.10% will be DACC related. DACC investments will however ramp up in subsequent decades.

The majority of CCUS costs are in CO2 capture and typically reflect the concentration of CO2 in the gas stream, with more diffuse sources (e.g. air) requiring more energy to isolate the CO2 than higher concentration sources (e.g. fossil industrial processes). The private sector can finance most of the costs with both industry and governments playing a role in developing incentives (e.g. carbon pricing, low-carbon products), and developing shared transport and storage infrastructure via industrial hubs.

"Recognising that CCUS is one vital tool in the decarbonisation portfolio, alongside others such as accelerating clean electrification, immediate action is required by government, corporates and investors to turn plans into reality and increase the deployment of high capture CCUS in the next decade. Reduced development time, strong regulation, greater investment and shared infrastructure models are all essential to make this possible," said Ita Kettleborough, Director, ETC.

More information

Read the full report:

www.energy-transitions.org

Dutch industrial decarbonization policy effectively supports CCS but needs push

The study conducted by DNV on behalf of the NGO Clean Air Task Force (CATF) shows that replacing existing grey hydrogen production with low carbon or green hydrogen alone could meet 60% of the Dutch industrial emissions target, but requires the acceleration of policy support.

DNV, the independent energy expert and assurance provider, has found that policies implemented to support CCS in the Netherlands have so far been successful in encouraging industrial decarbonization.

DNV has also found that despite its availability in quantities that could feed a solid market, hydrogen (either blue or green) is not yet sufficiently incentivized by policy mechanisms to bring confidence to investors and industry. However, a recently announced redesign of the hydrogen subsidy scheme, if implemented, could kick-start the hydrogen economy and accelerate decarbonization.

Clear ambitions for deep industrial decarbonization

To drive the energy transition, the Netherlands requires its domestic industries to reduce GHG emissions by 59% by 2030, and become climate neutral by 2050. The challenge for the Dutch industry is to decarbonize in adherence to the Nationally Determined Contribution to the Paris Agreement (NDC), while maintaining international competitiveness.

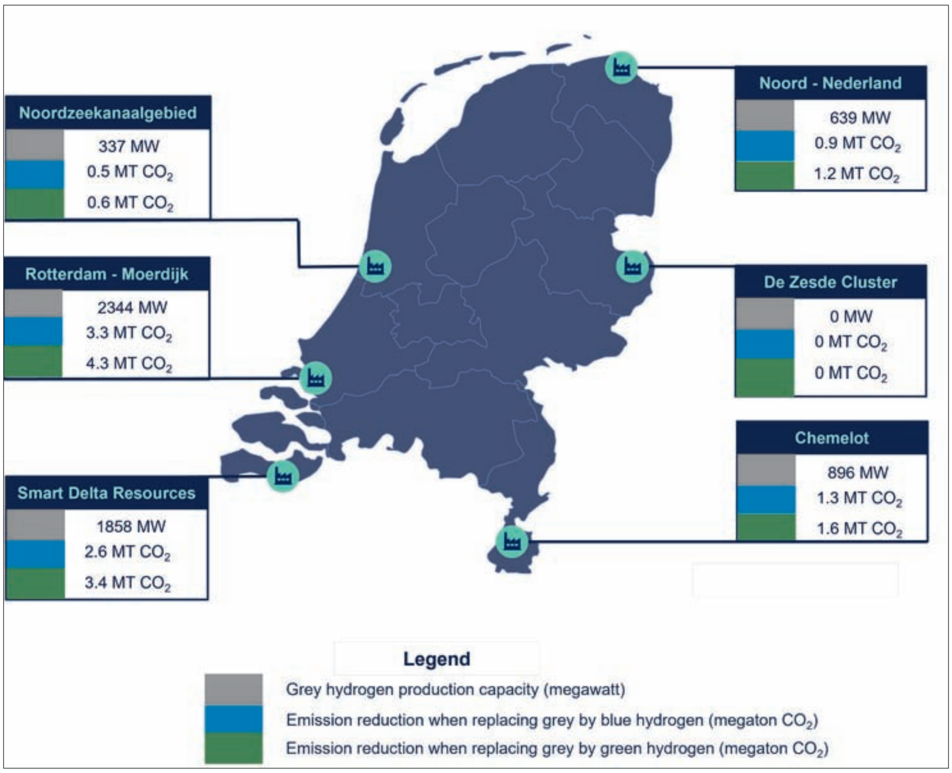


Figure 1: More than 60% of the industrial emissions target can be met by replacing grey hydrogen production with low-carbon or green hydrogen, however this requires acceleration of policy support

Public ambitions have driven the adoption of policy instruments prioritizing well-established and cost-effective decarbonization solutions over emerging technologies such as green hydrogen and electrification. The Dutch government has therefore established a Sustainable Energy Transition subsidy scheme (Stimulering Duurzame Energietransitie – SDE++), working as contract-for-difference scheme that compensates the additional costs for adopting low-carbon technologies that are already used or close to deployment, such as CCS.

Though CCS is mainly perceived as a transitionary technology to prevent fossil fuel lock-in (with subsidies scheduled to end after 2035), SDE++ backing has been crucial in enabling its early deployment in the Netherlands, and proving it to be a cost-effective solution for industrial decarbonization. Subsidized CCS projects can contribute to up to 7.8 megatons of CO2 emission reduction by 2035.

Cluster energy policies, shared infrastructures and a subsidy mechanism that has removed carbon price uncertainty have brought forward successful projects, and DNV finds that CCS policy has been a success in the Netherlands thus far.

On the other hand, hydrogen projects are not sufficiently incentivized under SDE++ to align with emission reduction targets, and their profitability remains low in the Netherlands – despite DNV's analysis that the significant amount of grey or fossil hydrogen currently produced (exceeding 6 GW) could support solid market opportunities for green or low-carbon hydrogen.

Blue hydrogen has the potential to develop the hydrogen economy in the Netherlands and pave the way for green hydrogen in the longer term. Announced projects, if executed, could lead to a reduction of up to 5.2 megatons of CO2 emissions by 2030. Replacing grey hydrogen with blue hydrogen through the application of CCS could reduce industrial emissions by more than 8.5 megatons (nearly 60% of industrial emissions target). Replacing the existing grey hydrogen with green hydrogen can reduce emissions by more than 11 megatons (nearly 78% of industrial emissions target).

Public support is currently insufficient to enable the scaling up of green hydrogen projects, since its correction amount within SDE++ is determined by the indexed Title Transfer Facility (TTF[2]) gas price, and thus does not take power price into consideration. This exposes operators to power market risks, and scaling costs cannot be recovered within the current framework.

Following recent announcements, new SDE++ tender categories for costlier technologies [3] are expected to be introduced by the government during the 2023 subsidy auctions. DNV analysis finds that such a redesign of the SDE++ scheme would support investment in emerging technologies, and could radically change the Dutch hydrogen landscape by improving the business case for green and blue hydrogen.

To go even further than this proposed policy evolution, DNV also finds that including both gas and power prices in SDE++ corrections would reduce uncertainty and improving hydrogen's bankability.

Projects amounting to a total capacity of 7GW of green hydrogen by 2030 have already been announced. However clarity on the timeline and modalities of the new mechanisms is required to give confidence to investors and bring these projects to fruition.

Prajeev Rasiah, Executive Vice President for Energy Systems, Northern Europe at DNV said: "The Netherlands is strategically positioned to take a leading role in the energy transition, with good conditions for offshore wind close to the country's industrial clusters, a network of some of the world's largest and busiest seaports, and extensive natural gas infrastructures that can be utilized for both domestic and cross-borders hydrogen and CO2 transport.

"Part of the success of the energy transition will be determined by public engagement and the availability and scope of effective policy instruments. Our analysis finds significant achievements in cost-effective decarbonization in the Dutch industry thanks to targeted support. While there still is a margin for improvement where emerging technologies are concerned, the progress we already see should inspire policymakers in the EU and the world to support and accelerate the elevation of industrial decarbonization technologies".

"These results give us important insights on how other European countries can look to kickstart their industrial decarbonization efforts," stated Magnolia Tovar, Global Director Zero Carbon Fuels at CATF, who played a key role in supervising the study on the part of CATF. "We hope that this study will help raise the profile on the kinds of policy mechanisms that governments can implement in order to move the needle on this long-overlooked piece of the climate challenge."

More information

Read the full report at:

www.dnv.com

North Sea Port could become carbon hub

Fluxys, ArcelorMittal Belgium and North Sea Port have started a feasibility study for the Ghent Carbon Hub project, an open-access CO2 storage and liquefaction hub in the Ghent part of North Sea Port.

Besides the use of carbon-neutral energy, carbon capture, utilisation and storage (CCUS) is essential for CO2 intensive industries to achieve net zero emissions, especially in hard-to-abate sectors with processes inherently generating CO2 emissions.

Pascal De Buck, CEO Fluxys, said, "We are delighted to launch this CO2 infrastructure project with ArcelorMittal Belgium and North Sea Port. Together with our partners, we offer strong and complementary know-how and expertise for providing reliable and efficient decarbonisation solutions, essential for achieving climate change objectives and ensuring the long-term viability of the economy. Ghent Carbon Hub is an integral part of the full-scale Fluxys CO2 approach, offering emitters in North Sea Port and the wider area the opportunity to convey their captured CO2 through our backbone."

Ghent Carbon Hub is set up as an open-access hub to transport and liquefy CO2 from emitters, provide buffer storage and load the liquefied CO2 onto ships for onward permanent storage.

The feasibility study has now started and commissioning is targeted for 2027. Ghent Carbon Hub will have a capacity to process 6 million tonnes of CO2 per annum (MTPA), equivalent to around 15% of Belgian industrial CO2 emissions.

The project will benefit from Fluxys' experience in terminalling activities, while Fluxys is also developing an open-access CO2 transmission backbone in Belgium. Ghent Carbon Hub connects into Fluxys' CO2 backbone, allowing CO2 emitters from the North Sea Port area and other industrial clusters to transport their captured CO2 to the hub or locations of reuse.

Manfred Van Vlierberghe, CEO ArcelorMittal Belgium, said, "ArcelorMittal Belgium has a passion for sustainability and circularity. We aim to reduce our CO2 emissions by 35% by 2030 compared to 2018, and to become climate neutral by 2050. The combination of a new Direct Reduced Iron (DRI) plant alongside a sustainable, state-of-the-art blast furnace enables the creation of unique synergies in ArcelorMittal Belgium's roadmap to climate-neutral steelmaking."

" But we are also focusing on other decarbonisation initiatives, such as CCS, where we capture the CO2 and transport it to a CO2 hub within North Sea Port for storage. We are able to reduce our environmental impact faster, thanks to projects such as this, which embody the cooperation and innovation that we need in order to realise our ambitious climate objectives."

More information

www.fluxys.com

www.arcelormittal.com

Projects and policy news

CCUS planned capacity nearing 1 billion tonnes per annum

www.woodmac.com/market-insights/topics/ccus

The US Inflation Reduction Act bill set to boost CCUS uptake but more is needed to meet net zero goals by 2050 says a Wood Mackenzie report.

The planned global CCUS capacity pipeline has reached 905 million tonnes per annum (mtpa), with more than 50 new projects announced this quarter. These findings come from Wood Mackenzie's 'CCUS Market Update for Q2 2022' report.

Lucy King, Senior Research Analyst and author of the report, said, "Despite continued momentum in the CCUS pipeline, much more progress is required to meet 2050 greenhouse gas targets. Currently, the CCUS capacity pipeline is close to aligning with Wood Mackenzie's 1.5-degree pathway to 2030, but it will need to grow seven-fold by 2050 to reach the capacity required for net zero."

"The biggest challenge is the lack of embedded policy and regulation for CCUS projects. For most countries, the rate of growth and demand for CCUS is outpacing the respective government's ability to legislate. Despite this, we expect 2022 to be a pivotal year for CCUS, with many countries formulating strategies, policies and regulation to support its deployment" King said.

The US is a global leader in CCUS, supported by its 45Q tax credit incentive for carbon sequestration launched in 2008. On 16 August 2022, President Biden signed the Inflation Reduction Act into law, which will enhance and extend the 45Q tax incentive.

"The Inflation Reduction Act bill will further accelerate the US' planned CCUS capacity pipeline, which is currently at almost 250 Mtpa. It will incentivise smaller-scale capture projects, attract more industries, and promote investment into technologies including Direct Air Capture."

Great strides have also been made for licensing and permitting for geological CO2 storage throughout Q2 of 2022. The industry has seen an increase in licensing activity in Norway, Russia and Australia, with the UK launching the 'first of its kind' CO2 storage licensing round which consists of 13 areas across the North Sea.

North America and Europe continue to emerge as hotspots for CCUS activity, according to latest Wood Mackenzie research. North America accounts for over two thirds of current global capacity in 2022, with activity mainly focused in Alberta, the Gulf Coast and US Midwest.

Going forward, North America's share of global CCUS capacity is expected to reduce to 2030 as hub projects across Europe scale up. China and Southeast Asia are forecasted to have the biggest demand for CCUS in the 2040s, but this will require further regulatory and policy implementation.

UK Government Announces Shortlist of CCUS Phase 2 Projects

www.ccsassociation.org

The Carbon Capture and Storage Association has welcomed the announcement of shortlisted bidders in Phase 2 of the CCUS Cluster Sequencing Process.

The Phase 2 competition is for carbon capture projects that wish to connect to the carbon dioxide transport and storage infrastructure that will be developed through the initial "Track 1" clusters (HyNet North West, East Coast Cluster and Scottish Cluster in reserve).

Following the submission deadline in January 2022, 41 CCUS and Hydrogen projects from across the UK were considered eligible by BEIS. Of the 41 eligible projects, 20 projects have today been shortlisted for possible support from Government, once it has established that the projects represent a 'value for money' investment for the taxpayer.

The Government support will be in the form of revenue contracts to cover the cost of operating with carbon capture and storage, as well as potential access to capital support from either the £1bn CCS Infrastructure Fund (CIF) or the Net Zero Hydrogen Fund. The next step for the shortlisted projects is expected to be bilateral negotiations with BEIS to finalise the contracts.

Ruth Herbert, Chief Executive at the CCSA, said, "I am delighted to see the government providing certainty to business today by confirming the Phase 2 shortlist. These world-leading projects can now move forward and prepare for the next stage of the process, which we hope will advance swiftly."

"This announcement also sends a very strong signal that Carbon Capture, Utilisation and Storage (CCUS) and Net Zero remains a priority for the UK Government, particularly since it comes during a change in leadership. CCUS is critical in achieving Net Zero and positioning the UK as the world's first at-scale hydrogen economy. It will transform our industrial regions – driving jobs and growth through inward investment and export opportunities."

"That 41 eligible projects applied to Phase 2 demonstrates the scale of interest in CCUS in the UK. We look forward to getting further clarity on the timetable for future phases and the selection of further clusters in the Autumn, as well as progress on the Energy Bill – all crucial if we are to meet the government's ambition of four operational clusters by 2030, remain on track to achieve Net Zero by 2050 and secure our place as a global leader in CCUS technology."

U.S. DOE launches $2.6 Billion funding programs to slash carbon emissions

www.energy.gov

Two bipartisan infrastructure law programs will decarbonize power generation and heavy industries and create regional transport networks for captured CO2 emissions.

The Biden-Harris Administration has issued Notices of Intent to fund two programs that will advance carbon capture demonstration projects and expand regional pipeline networks to transport CO2 for permanent geologic storage or for conversion into valued end uses, such as construction materials.

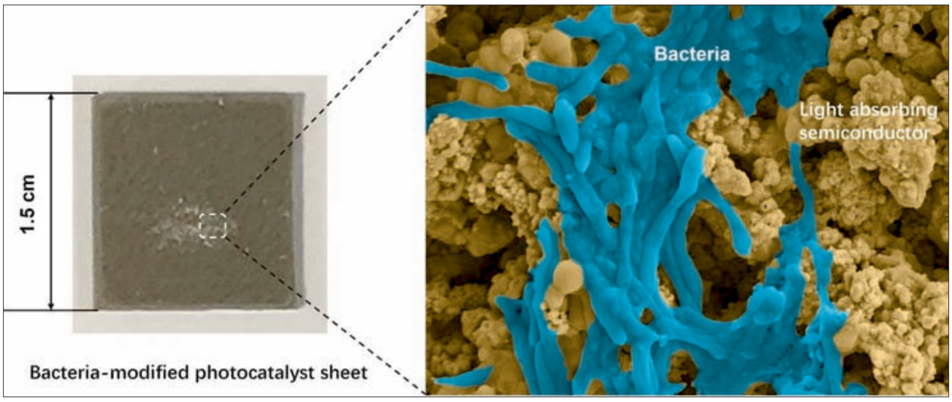
The two programs – the Carbon Capture Demonstration Projects Program and the Carbon Dioxide Transport/Front-End Engineering Design (FEED) Program – are funded by a more than $2.6 billion investment from President Biden's Bipartisan Infrastructure Law.

Using bacteria to convert sunlight, water and CO2 into high value chemicals

Northumbria researchers have developed a synthetic semiconductor device which means that the conversion can take place without the assistance of organic additives, creation of toxins or use of electricity.

Northumbria University's Dr Shafeer Kalathil is among a team of academics behind the project, which uses a chemical process that converts sunlight, water and carbon dioxide into acetate and oxygen to produce high-value fuels and chemicals powered by renewable energy.

As part of the process, bacteria are grown on a synthetic semiconductor device known as a photocatalyst sheet. The aim of the project is to curtail the rise in atmospheric CO_2 levels, secure much-needed green energy supplies and alleviate the global dependence on fossil fuels. A paper detailing the findings of the team's research has been published in scientific journal Nature Catalysis.



Photocatalyst sheet containing light-absorbing particles and bacteria. Credit: Northumbria University

Dr Kalathil, Vice Chancellor's Senior Fellow, is working on the project with Erwin Reisner, Professor of Energy and Sustainability at the University of Cambridge, Dr Qian Wang, associate professor at Nagoya University in Japan, and partners from Newcastle University.

Dr Kalathil said: "Several incidents have demonstrated the fragility of the global energy supply, such as recent soaring gas prices in UK, the outbreak of conflicts and civil wars in the Middle East and the ecological and humanitarian threat of a nuclear meltdown in Fukushima, Japan. The search for alternative energy sources is therefore of major global importance.

"Our research directly addresses the global energy crisis and climate change facing today's society. We need to develop new technologies to address these grand challenges without further polluting the planet we live on.

"There has been an increase in electricity generation from renewable sources such as wind and solar, but these are intermittent in nature. To fill the gap when the wind doesn't blow or the sun doesn't shine, we need technologies that can create storable fuels and sustainable chemicals. Our research addresses this challenge head on.

"As well as securing additional much-needed energy supplies, our sustainable technology can reduce greenhouse gas emissions and play a key role in the global drive to achieve net zero."

The project was supported by funding from the European Research Council, UK Research and Innovation, and Research England's Expanding Excellence in England Fund, which supports higher education research units and departments to expand and increase their activity. The Research England grant was secured via the Hub for Biotechnology in the Built Environment (HBBE), a joint initiative between Northumbria and Newcastle University, which has received a total of £8 million from Research England to conduct project work.

Dr Kalathil, who is heavily involved with the HBBE, said: "The aims of the HBBE fit with what we're trying to achieve with our research – to address key environmental concerns facing our society today and in the future. This emerging field of research represents an interdisciplinary approach that combines the strengths of microbes, synthetic materials and analytical techniques for chemical transformation, and provides an excellent platform to produce high-value, environmentally friendly fuels and chemicals at scale. We're already in discussions with international chemical manufacturers and cosmetics producers, and the ultimate aim is to develop our technology on a commercial scale."

There are multiple benefits of this research, which is designed to inspire budding scientists to design and develop new technologies for sustainable energy production. The work also highlights the expertise of Northumbria's Department of Applied Sciences, which covers an exciting and extensive portfolio of subjects including biology, biomedical sciences, chemistry, forensic science, food and nutritional sciences. Many of Northumbria's courses in this field are professionally accredited by the Royal Society of Chemistry, Institute of Biomedical Science, the Chartered Society of Forensic Science and Association for Nutrition, or approved by statutory regulatory bodies such as the Health & Care Professions Council.

The paper, 'Bacteria–photocatalyst sheet for sustainable carbon dioxide utilization', is published in scientific journal Nature Catalysis

More information

www.northumbria.ac.uk

A simple, cheap material for carbon capture

Using an inexpensive polymer called melamine — the main component of Formica — chemists at Berkeley have created a cheap, easy and energy-efficient way to capture carbon dioxide.

The process for synthesizing the melamine material, published in the journal Science Advances, could potentially be scaled down to capture emissions from vehicle exhaust or other movable sources of carbon dioxide. Carbon dioxide from fossil fuel burning makes up about 75% of all greenhouse gases produced in the U.S.

The new material is simple to make, requiring primarily off-the-shelf melamine powder — which today costs about $40 per ton — along with formaldehyde and cyanuric acid, a chemical that, among other uses, is added with chlorine to swimming pools.

"We wanted to think about a carbon capture material that was derived from sources that were really cheap and easy to get. And so, we decided to start with melamine," said Jeffrey Reimer, Professor of the Graduate School in the Department of Chemical and Biomolecular Engineering at the University of California, Berkeley, and one of the corresponding authors of the paper.

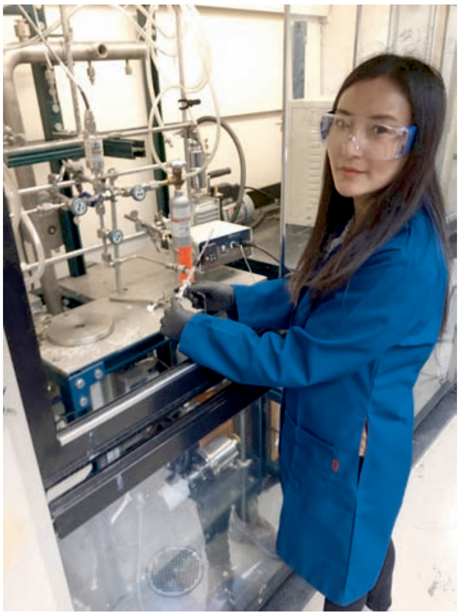
The so-called melamine porous network captures carbon dioxide with an efficiency comparable to early results for another relatively recent material for carbon capture, metal organic frameworks, or MOFs. UC Berkeley chemists created the first such carbon-capture MOF in 2015, and subsequent versions have proved even more efficient at removing carbon dioxide from flue gases, such as those from a coal-fired power plant.

But Haiyan Mao, a UC Berkeley postdoctoral fellow who is first author of the paper, said that melamine-based materials use much cheaper ingredients, are easier to make and are more energy efficient than most MOFs. The low cost of porous melamine means that the material could be deployed widely.

"In this study, we focused on cheaper material design for capture and storage and elucidating the interaction mechanism between CO2 and the material," Mao said. "This work creates a general industrialization method towards sustainable CO2 capture using porous networks. We hope we can design a future attachment for capturing car exhaust gas, or maybe an attachment to a building or even a coating on the surface of furniture."

With current methods carbon capture is far from commercially viable. The best technique today involves piping flue gases through liquid amines, which bind CO2. But this requires large amounts of energy to release the carbon dioxide once it's bound to the amines, so that it can be concentrated and stored underground. The amine mixture must be heated to between 120 and 150 degrees Celsius (250-300 degrees Fahrenheit) to regenerate the CO2.

In contrast, the melamine porous network with DETA and cyanuric acid modification captures CO2 at about 40 degrees Celsius, slightly above room temperature, and releases it at 80 degrees Celsius, below the boiling point of water. The energy savings come from not having to heat the substance to high temperatures.



Haiyan Mao studied the new material using solid-state nuclear magnetic resonance. (Photo courtesy of Haiyan Mao, UC Berkeley)

Mao said that tests confirmed that formaldehyde-treated melamine adsorbed CO2 somewhat, but adsorption could be much improved by adding another amine-containing chemical, DETA (diethylenetriamine), to bind CO2. She and her colleagues subsequently found that adding cyanuric acid during the polymerization reaction increased the pore size dramatically and radically improved CO2 capture efficiency: Nearly all the carbon dioxide in a simulated flue gas mixture was absorbed within about 3 minutes.

The addition of cyanuric acid also allowed the material to be used over and over again.

A new family of porous networks

Mao and her colleagues conducted solid-state nuclear magnetic resonance (NMR) studies to understand how cyanuric acid and DETA interacted to make carbon capture so efficient. The studies showed that cyanuric acid forms strong hydrogen bonds with the melamine network that helps stabilize DETA, preventing it from leaching out of the melamine pores during repeated cycles of carbon capture and regeneration.

"What Haiyan and her colleagues were able to show with these elegant techniques is exactly how these groups intermingle, exactly how CO2 reacts with them, and that in the presence of this pore-opening cyanuric acid, she's able to cycle CO2 on and off many times with capacity that's really quite good," Reimer said. "And the rate at which CO2 adsorbs is actually quite rapid, relative to some other materials. So, all the practical aspects at the laboratory scale of this material for CO2 capture have been met, and it's just incredibly cheap and easy to make."

More information

india.cchem.berkeley.edu

Computer simulations help carbon capture material research

National Institute of Standards and Technology scientists have set out to discover new materials that can capture carbon dioxide from the atmosphere.

Direct air capture materials already exist, but they either cost too much money or consume too much energy to be deployed on a global scale. NIST scientists are using computer simulations to rapidly screen hypothetical materials that have never been synthesized but that might have just the right physical properties to make this technology scalable.

“The traditional way of screening materials is to synthesize them, then test them in the lab, but that is very slow going,” said NIST chemical engineer Vincent Shen. “Computer simulations speed up the discovery process immensely.”

Shen and his colleagues are also developing new computational methods that will accelerate the search even more.

"Our goal is to develop more efficient modeling methods that extract as much information out of a simulation as possible,” Shen said. “By sharing those methods, we hope to speed up the computational discovery process for all researchers who work in this field.”

Direct air capture is important because humanity has already profoundly altered Earth's atmosphere—one third of all the CO2 in the air got there as a result of human activity. "Carbon capture is a way to reverse some of those emissions and help the economy become carbon neutral more quickly," said NIST chemist Pamela Chu, who leads the agency's recently launched carbon capture initiative.

Once CO2 is captured, it can be used to manufacture plastics and carbon fibers or combined with hydrogen to produce synthetic fuels. These uses require energy but can be carbon neutral if powered by renewables. Where renewable energy isn't available, the CO2 can be injected into deep geological formations with the goal of keeping it trapped underground.

NIST scientists use computer simulations that calculate a potential capture material’s affinity for CO2 relative to other gases in the atmosphere. That allows them to predict how well the capture material will perform. The simulations also generate images that show how carbon capture works on a molecular scale.

Porous crystalline materials show particular promise for capturing CO2. These materials are made up of atoms arranged in a repeating three-dimensional pattern that leaves voids between them. In this conceptual illustration, the gray bars represent a crystalline material, and the red spheres are the voids.

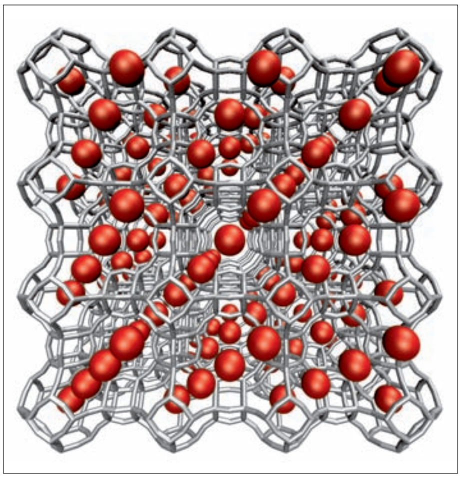
Electrons are distributed unevenly within the crystal structure, creating an electric field that is attractive in some places and repulsive in others. The contours of that field depend on the types of atoms in the crystal and their geometrical arrangement. If all the forces line up just right, CO2 molecules will be drawn into the voids of the crystal by electrostatic attraction.

Porous crystalline materials can be synthesized with various types of atoms, and the atoms can be configured into many different geometries. The permutations are virtually endless. Computer simulations allow scientists to explore that vast universe of possibilities.

The computer simulations combine the rules of physics with statistical methods to predict which direction CO2 molecules would move when they come into contact with a capture material—whether they would be drawn into the voids, diffuse out into the surrounding air, or just bounce around randomly in a state of equilibrium.

Most simulation methods predict the behavior of a system at a specified temperature, pressure and density. But modeling methods from NIST allow researchers to extrapolate that data to different conditions.

"Say you've estimated the behavior at one temperature, but you want to know what



A conceptual illustration of a porous crystalline material. The red spheres represent voids where CO2 might collect. Credit: NIST

would happen at a different temperature. Typically, you would have to run a new simulation," Siderius said. "With our tools, you can extrapolate to different temperatures without having to run a new simulation. That can save a lot of computing time."

Currently, the best-performing process for industrial-scale carbon capture works by bubbling air through a chemical solution. But capturing the CO2 is only half the process. It then has to be removed from the solution so it can be stored and so the solution can be used again. This requires heating the solution to a high temperature, which takes a lot of energy.

The NIST researchers hope to find a material that will extract CO2 from the atmosphere at normal temperatures and pressures but release it in response to relatively small changes in heat or pressure. The ideal process will be low cost, both financially and energy-wise, and not produce toxic end products.

More information

www.nist.gov

Capture & utilisation news

Removr partners with CarbFix for first industrial Direct Air Capture pilot

www.removr.no

www.carbfix.com

Removr, a Norwegian company that develops solutions for removing CO2 directly from the atmosphere, has entered into an MoU with CO2 storage leader Carbfix.

The partners aim to co-develop a demonstration project for a Direct Air Capture (DAC) facility in Iceland with a minimum capacity of 300 tons CO2 per year to come on stream in 2023. As part of the MoU, the partners have also decided to explore the potential for co-developing a large-scale DAC plant in Iceland.

“Delivering our first industrial DAC pilot will be an important milestone towards our ambition of developing the world’s first solid sorbent 1-million-ton plant in 2027. We are working on possible locations for the pilot in Iceland which has one of the world’s most attractive framework conditions for our industry, with all necessary regulations in place, access to clean energy and storage, and a highly competent ecosystem,” said Einar Tyssen, CEO of Removr.

Carbfix, the world’s first mineral storage operator, has developed a solution that turns CO2 into stone in less than two years enabled by high reactivity in the basaltic formations in Iceland, with the company’s operational track-record stretching back to 2012. Carbfix has already been awarded two large EU grants from the European Innovation Fund for Project Silverstone, to implement full scale CCS at the Hellisheidi geothermal power plant, and Coda Terminal, a CO2 transport and storage hub at Straumsvík, Iceland.

Removr’s technology is based on zeolites that capture CO2 molecules in microporous pellets, which has been used for decades in the space and petroleum industry, and its application to DAC has been proven through four successful small-scale pilots since 2016. The company follows a stepwise verification process in developing an industrial scaled up DAC farm.

“We are excited to welcome Removr as one of the first companies to deploy in our DAC Innovation Park in Iceland. It will be an important step to accelerate the development of new emerging DAC technologies and to demonstrate the direct air capture and storage chain in the relevant environment,” said Edda Sif Pind Aradóttir, CEO of Carbfix.

HeidelbergCement proceeds to FEED study for Indiana pilot

www.lehighhanson.com

$3.7 million funding for the study has been granted by the U.S. Department of Energy. It will evaluate the feasibility of the project in Mitchell, Indiana, aiming to capture 95% of the local cement plant’s CO2 emissions.

HeidelbergCement is further expanding its portfolio of large-scale CCUS projects with a new initiative at the cement plant of HeidelbergCement’s US subsidiary Lehigh Hanson, Inc. that aims to capture 95% of the CO2 emissions from the newly renovated production facility and store them in a local onshore reservoir in the Illinois Basin.

This corresponds to an emission reduction of approx. 2 million tonnes of CO2 per year, making it HeidelbergCement’s largest CCUS project globally.

“CCUS continues to be a key part of our climate strategy,” said Dr Dominik von Achten, Chairman of the Managing Board. “With now eight large-scale initiatives worldwide, our CCUS project portfolio keeps growing and is scaling up fast. Our ongoing projects in Europe and Canada are progressing very well. In Mitchell, we will build on the experience of those projects to supply carbon-free cement to our customers in the important US market at large scale.”

Lehigh Hanson’s Mitchell plant has been substantially upgraded in recent months to significantly increase energy efficiency and lower the company’s carbon footprint. Full production is anticipated to start in early 2023. The new facility will more than triple its current capacity to approximately 2.6 million tonnes.

To advance the carbon capture project, Lehigh Hanson will now conduct a site-specific FEED study. In addition to evaluating the cost and performance of the overall project, the study will examine social, economic, and environmental impacts

Mantel launches carbon capture technology

mantelcapture.com

The company has raised $2 million seed funding to accelerate development and deployment of the first liquid carbon capture material that can operate at high temperatures.

The $2 million investment was led by The Engine, the venture firm spun out of MIT that invests in early-stage Tough Tech companies. New Climate Ventures also participated in the seed round. Mantel’s solution is the first high-temperature, liquid-phase carbon capture system.

Designed to operate at the high temperatures found inside boilers, kilns, and furnaces, this approach is inherently efficient and therefore lower-cost, the company claims. The funding will accelerate Mantel’s technology development, prototype testing and initial deployment. Additionally, the expansion of carbon capture tax credits in the new Inflation Reduction Act greatly enhances the opportunity.

Founded in 2022 by Cameron Halliday, CEO, Danielle Colson, COO, and Sean Robertson, CTO, Mantel was spun out of MIT and research completed with Professors T. Alan Hatton and Takuya Harada. After lab-scale flow loop demonstration is achieved, the company plans to use fresh capital to build a commercial scale demonstration plant.

Mantel’s molten salts selectively absorb CO2 and regenerate a pure stream of CO2 that can be either stored or used. By uniquely combining liquid phase materials with high operating temperatures this approach can reduce energy losses by more than 60%, and cut costs in half.

“There is a thermodynamic benefit to carrying out a separation process at high temperatures and addressing the thermodynamics is the only way to significantly decrease the cost of carbon capture.” said Cameron Halliday, co-founder and CEO of Mantel. “By using liquid phase chemistry we can overcome the challenges holding back existing high temperature approaches, enabling carbon capture’s critical role in the energy transition.”

Mantel is building a platform of solutions to reduce emissions in hard-to-abate industries such as industrial heat, cement, steel, and hydrogen.

Stanford develops 'lab on a chip' for CO2 storage analysis

A tiny new device allows scientists to directly observe and quantify how rocks change in the presence of acids, enabling more accurate assessments of sites for underground storage of carbon dioxide.

Scientists at Stanford University have developed a new solution for the challenge of making sure that when carbon dioxide is injected underground, it actually stays put.

"Injection of carbon dioxide in storage formations can lead to complex geochemical reactions, some of which may cause dramatic structural changes in the rock that are hard to predict," said Ilenia Battiato, the study's primary investigator and an assistant professor of energy resources engineering at Stanford's School of Earth, Energy & Environmental Sciences (Stanford Earth).

Earth scientists for years have simulated fluid flow, reactions, and rock mechanics to try to predict how injections of CO2 or other fluids will affect a given rock formation.

Existing models, however, don't reliably predict the interplay and full consequences of geochemical reactions, which often produce tighter seals by effectively plugging pathways with dissolved minerals – but can also lead to cracks and wormholes that may allow buried carbon dioxide to affect drinking water or escape to the atmosphere, where it would contribute to climate change. "These reactions are ubiquitous. We need to understand them because they control the effectiveness of the seal," Battiato said.

One of the chief modeling challenges centers on the wide range of time and spatial scales over which interacting processes unfold simultaneously underground. Some reactions fizzle out in less than a second, while others continue for months or even years. As reactions progress, the evolving mix and concentration of various minerals in any given patch of rock, and changes to the geometry and chemistry of the rock surface, influence the fluid chemistry, which in turn affects fractures and possible pathways for leaks.

Lab on a chip

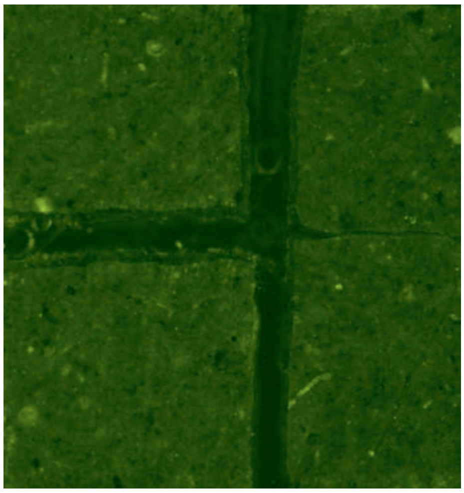
The new solution, described Aug. 1 in Proceedings of the National Academy of Sciences, uses a microfluidics device, or what scientists often refer to as a "lab on a chip." In this case, the researchers call it a "rock on a chip," because the technology involves embedding a tiny sliver of shale rock into a microfluidic cell.

To demonstrate their device, the researchers used eight rock samples taken from the Marcellus shale in West Virginia and the Wolfcamp shale in Texas. They cut and polished the slivers of rock to bits no bigger than a few grains of sand, with each one containing varying amounts and arrangements of reactive carbonate minerals. The researchers placed the samples into a polymer chamber sealed in glass, with two tiny inlets left open for injections of acid solutions. High-speed cameras and microscopes allowed them to watch step by tiny step how chemical reactions caused individual mineral grains in the samples to dissolve and rearrange.

Minerals dissolve in a 3 mm square sample of Marcellus shale during the injection of acid. Dynamic flow and reactive transport experiments are performed by using a fluorescent microscopy technique, which allows for clear images to be captured every 100 microseconds. (Ling et al. 2022, Proceedings of the National Academy of Sciences)

The idea of miniaturizing research that once required large labs cuts across Earth sciences, biomedicine, chemistry, and other fields, said study co-author Anthony R. Kovscek, the Keleen and Carlton Beal Professor at Stanford Earth and a senior fellow at Stanford's Precourt Institute for Energy.

"If you can see it, you can describe it better. These observations have a direct connection with our ability to assess and optimize designs for safety," he said. Today, Kovscek says geologists on drill sites may examine rocks under a microscope, but no current technologies approach the level of detail possible with this new device: "Nothing of this sort exists for really looking at how the grain shapes are changing."



Minerals dissolve in a 3 mm square sample of Marcellus shale during the injection of acid. Dynamic flow and reactive transport experiments are performed by using a fluorescent microscopy technique, which allows for clear images to be captured every 100 microseconds. (Ling et al. 2022, Proceedings of the National Academy of Sciences)

Optimizing for safety

Improving reactive transport models is a matter of growing urgency, given the role of carbon removal in government plans for addressing climate change and the hundreds of millions of dollars now flowing to the nascent technology from private investors. Existing projects for removing CO2 directly from the atmosphere are operating only at pilot scale. Those that catch emissions at the source are more common, with more than 100 projects in development worldwide and the U.S. government now preparing to spend $8.2 billion through the bipartisan infrastructure bill on carbon capture and storage from industrial facilities.

More information

earth.stanford.edu
doi.org/10.1073/pnas.2122520119

Using the railway network to capture CO2 for under $50 / tonne

Researchers from the University of Sheffield are working with US-based CO2Rail to design Direct Air Capture equipment which can be used within special rail cars placed with already running trains.

Rail systems around the world could help mitigate climate change and clean the air of CO2 by capturing the sustainable energy generated when trains break and decelerate.

US-based startup, CO2Rail Company have been working with a team of researchers, including engineers from the University of Sheffield, to design Direct Air Capture (DAC) technology that removes carbon dioxide from the air, which can be used within special rail cars placed with already running trains in regular service.

The DAC rail cars work by using large intakes of air that extend up into the slipstream of the moving train to move ambient air into the large cylindrical CO2 collection chamber and eliminate the need for energy-intensive fan systems that are necessary with stationary DAC operations.

The air then moves through a chemical process that separates the CO2 from the air and the carbon dioxide free air then travels out of the back or underside of the car and returns to the atmosphere.

After a sufficient amount has been captured, the chamber is closed and the harvested CO2 is collected, concentrated, and stored in a liquid reservoir until it can be emptied from the train at a crew change or fuelling stop into normal CO2 rail tank cars. It is then transported into the circular carbon economy as value-added feedstock for CO2 utilisation, or to nearby geological landfill sites.

Each of these processes are powered exclusively by on-board generated, sustainable energy sources that require no external energy input or off-duty charging cycles.

When a train pumps the brakes, its energy braking system converts the train's forward momentum into electrical energy in much the same way as a regenerative electric vehicle. Currently, this energy is dissipated on trains in the form of heat and discharged out of the top of the locomotive during every braking manoeuvre.

Co-author of the research, Professor Peter Styring from the University of Sheffield's Department of Chemical and Biological Engineering and Director of the UK Centre for Carbon Dioxide Utilization, said, "Currently the enormous amount of sustainable energy created when a train brakes or decelerates is simply lost. This innovative technology will not only use the sustainable energy created by the braking manoeuvre to harvest significant quantities of CO2, but it will also take advantage of many synergies that integration within the global rail network would provide."

"The technology will harvest meaningful quantities of CO2 at far lower costs and has the potential to reach annual productivity of 0.45 gigatons by 2030, 2.9 gigatons by 2050, and 7.8 gigatons by 2075 with each car having an annual capacity of 3,000 tonnes of CO2 in the near term."

Unlike stationary DAC operations, which require large areas of land to build equipment and to construct renewable sources of energy to power them, CO2Rail would be transient and would generally be unseen by the public. The potential impact of this technology was recently energised when European transport organisations announced earlier this month that they are committed to tripling high-speed rail use by 2050 to curb CO2-heavy air travel.

Eric Bachman of CO2Rail Company, said, "On average, each complete braking manoeuvre generates enough energy to power 20 average homes for an entire day so it is not a trivial amount of energy."

"Multiply this by every stop or deceleration for nearly every train in the world and you have about 105 times more energy than the Hoover Dam produces within that same period, and that was a hydro-electric construction project that took six years and cost $760 million in today's dollars."

He added, "Imagine stepping onto a train each morning, seeing the CO2Rail cars attached, and knowing that your commute to work each day is actually helping to mitigate climate change."

"It will work the same with freight, if there is a choice between rail and another mode of transportation, I think this technology will sway many shippers."

The team, which includes researchers from the University of Sheffield, University of Toronto, MIT, Princeton, business, and industry, found each direct air capture car can harvest about 6,000 metric tons of carbon dioxide from the air per year and more as the technology develops. Moreover, since trains are capable of hosting multiple CO2Rail cars, each train will harvest a corresponding multiple of CO2 tonnage.

With its sustainable power requirements exclusively supplied by train-generated sources that are without incremental cost, savings of 30 – 40 per cent per tonne of harvested CO2 can be realised from energy inputs alone.

This, along with other significant savings such as land, brings projected cost at scale down to less than $50 per tonne and makes the technology not only commercially viable but commercially attractive.

Professor Geoffrey Ozin from the University of Toronto and co-author of the study, said, "At these price points and with its tremendous capabilities, CO2Rail is likely to soon become the first megaton-scale, first gigaton-scale, and overall largest provider of direct air capture deployments in the world."

The team is also working on a similar system that can remove the CO2 emissions from the exhaust of diesel-powered locomotives.

The research entitled: "Rail-Based Direct Air Carbon Capture" is published in the Future Energy section of the journal Joule.

More information

co2rail.com

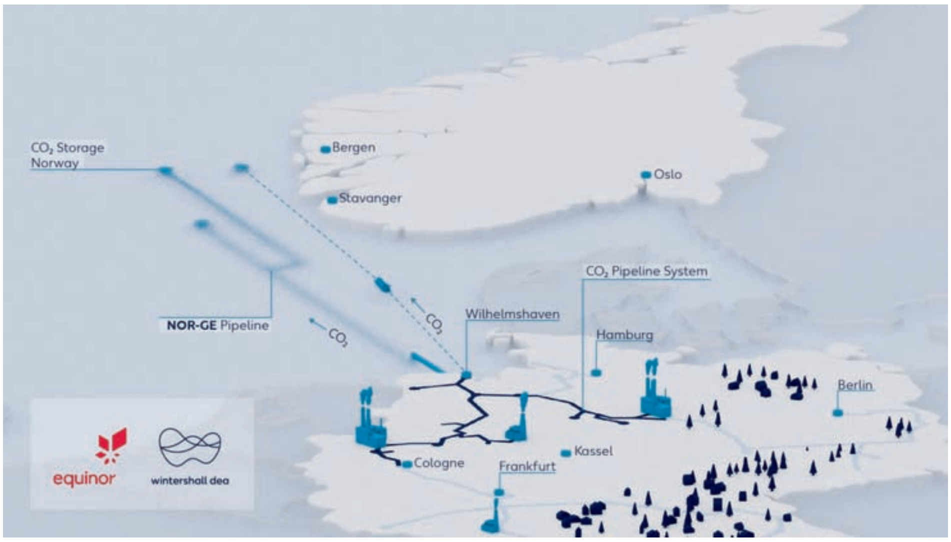
Transport and storage news

Equinor and Wintershall Dea partner up for large-scale CCS

www.equinor.com

wintershalldea.com

The companies have agreed to pursue the development of an extensive CCS value chain connecting continental European CO2 emitters to offshore storage sites on the Norwegian Continental Shelf.



The Norwegian-German (NOR-GE) CCS project has the ambition to make a vital contribution to reducing greenhouse gas emissions in Europe aiming to establish the value chain and infrastructure for the safe transportation, injection, and storage of CO2 in suitable reservoirs on the Norwegian Continental Shelf.

“This is a strong energy partnership supporting European industrial clusters’ need to decarbonise their operations. Wintershall Dea and Equinor are committed to the energy transition and will utilise the competence and experience in both companies to work with governments and partners to help reach the net-zero target,” said Anders Opedal, CEO and President of Equinor.

Through the partnership, both companies are responding to the European demand for large-scale decarbonisation of carbon-intensive industries that need safe and large-scale underground CO2 storage to abate unavoidable emissions from their processes. The partnership intends to connect Germany, the largest CO2 emitter in Europe, and Norway, holding Europe’s largest CO2 storage potential.

“Wintershall Dea and Equinor will work together to establish technical and commercial solutions for the development of cross-border CCS value chains in Europe and work with governments to shape a regulatory framework that can enable it. We will build on our close cooperation and open the next chapter of German-Norwegian partnership,” said Mario Mehren, CEO of Wintershall Dea.

An approximately 900-kilometre-long open access pipeline is planned to connect the CO2 collection hub in Northern Germany and the storage sites in Norwayprior to 2032. It is expected to have a capacity of 20 to 40 million tonnes of CO2 per year – equivalent to around twenty per cent of all German industrial emissions per year. The project will also consider an early deployment solution where CO2 is planned to be transported by ship from the CO2 export hub to the storage sites.

Wintershall Dea and Equinor also plan to jointly apply for offshore CO2 storage licences, aiming to store between 15 to 20 million tonnes per year on the Norwegian Continental Shelf.

“Carbon Capture on the Ocean” project receives award

www.mhi.com

The award was received in recognition of the world’s first marine-based CO2 capture system on actual voyage to successfully separate and capture CO2 from flue gas.

The project, a joint venture between Mitsubishi Shipbuilding Co., Ltd., a part of Mitsubishi Heavy Industries (MHI) Group, Kawasaki Kisen Kaisha, Ltd. (K Line) and Nippon Kaiji Kyokai (ClassNK), has received the “Marine Engineering of the Year 2021 (Doko Memorial Award)” from the Japan Institute of Marine Engineering (JIME).

This prize, awarded for outstanding technical achievements in the fields of marine engines and equipment, offshore instruments, and related marine engineering, aims to draw attention to the innovativeness and importance of these achievements both in Japan and around the world, and support the further advancement of associated scientific and industrial technologies.

The award-winning "CC-Ocean" project aims to capture CO2 at sea by converting an existing CO2 capture system for onshore power plants to a marine environment. The system was installed on board the CORONA UTILITY, a coal carrier for Tohoku Electric Power Co., Inc. operated by K Line, with demonstration testing conducted for approximately six months starting in August 2021.

The amount, ratio, and purity of the captured CO2 were all in line with plan, demonstrating the feasibility of capturing CO2 from the flue gas of marine engines onboard ships, where operating conditions differ from those on land.

As an integral part of MHI Group’s energy transition strategy, Mitsubishi Shipbuilding has established the MARINE FUTURE STREAM vision as a growth strategy, setting the goals of “a decarbonized marine world” through renewable energy and the carbon cycle, and “a safe and secure society” through autonomous operation and electrification, and working to generate and implement ideas for marine-related innovation. Going forward, as a marine systems integrator, Mitsubishi Shipbuilding will continue to promote decarbonization in the marine industry, focus on achieving carbon neutrality, and contribute to the reducing of environmental loads on a global scale.

This project was conducted with support from the Maritime Bureau of Japan under the Ministry of Land, Infrastructure, Transport and Tourism (MLIT), as part of its assistance project for research and development of technological advancements in marine resource development.