Carbon Capture Journal

CCUS in Asia

Lignik: converting CO2 into sustainable building materials

Appraisal of CO2 capture schemes from a Saudi Aramco gas processing facility

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Global Status of CCS 2022 - sector well placed for deployment

World's first commercial scale CO2-to-methanol plant

Celebrating success and sharing lessons learned at Boundary Dam

Breakthrough discovery in carbon conversion for ethylene production

Converting CO2 to solid minerals underground for more stable storage

Repositioning CCUS for China's Net Zero future

China has committed to achieving carbon neutrality before 2060, representing a serious pledge from toplevel leadership while providing an enormous task to realise in just forty years. If CCUS is to play the intended critical role in China's net-zero effort, more work needs to be done to achieve the technology suite's potential.

There are 55 CCUS-related policies and around 40 CCUS projects of varying sizes and stages of development in China as of June 30, 2022, says a Global CCS Institute report, "Repositioning CCUS for China's Net Zero future" by Yi Wu.

China is now at the stage of demonstrating integrated CCUS projects at commercial scale. While CCUS is the subject of growing attention, challenges still remain for large-scale deployment and commercial operation, including lack of policy incentives and high up-front investment costs.

However, it is also notable that China is potentially the world's largest CCUS market due to the considerable emissions reductions required to achieve the 30/60 goal.

The report reviews the status of carbon targets, examines the trends and challenges for CCUS in China, and looks at the push across low-carbon industrial transformation. The report identifies a potential role for international cooperation in accelerating the commercial deployment of CCUS in China.

Through knowledge sharing and joint projects, international cooperation can enhance public acceptance, close technological gaps, realize broader collaboration, and reduce costs and risks.

China's 30/60 climate targets

In 2015, China submitted a Nationally Determined Contribution (NDC) to the UNFCCC, which stated an intent to reach carbon peaking by 2030. The target was further strengthened by President Xi Jiping's announcement in September 2020 that China will peak its carbon emissions before 2030 and achieve carbon neutrality before 2060.

The updated NDC also includes several other ambitious targets as outlined in this timeline (huaxia, 2020a, 2020b, 2021d, 2022; Xinhua, 2021; huaxia, 2021c; Ministry of Foreign Affairs of the People's Republic of China, 2020; UN, 2021). Government ministries, local provinces and industry have begun to take action within their jurisdictions.

The country announced its "1+N" policy mechanism, "1" indicating the general guiding policy, "N" representing key sectoral and sub-sectoral plans for carbon peak and carbon neutrality.

SECTOR	ACTION ENTITY	ACTIONS
Oil & Gas	China Oil and Chemical Industry Federation & 17 companies	Published a joint statement focused on: low carbon and green development of energy, energy efficiency improvement and production lines using CO_2 as raw materials for utilization or storage.
	SINOPEC	Aims to achieve carbon peaking before 2030 and carbon neutrality around 2050.
	CNPC	Aims to peak carbon around 2025 and achieve near-zero emissions by 2050.
	CNOOC	Released a business strategy on offshore gas and LNG, and research on carbon peaking and carbon neutrality.
Steel	Sectoral action plan draft completed	Aims to achieve carbon peaking by 2025, reducing carbon emissions by 420 million tonnes (30% less than carbon peak), and realize deep decarbonization by 2060.
	Baowu Steel	Aims to peak by 2023, reduce carbon emissions by 30% from peak by 2035, and achieve carbon neutrality by 2050.
	Hebei Steel	Aims to peak emissions in 2022, reduce carbon emissions by 10% and 30% from peak by 2025 and 2030 respectively, and become carbon neutral by 2050.
	Baogang United Steel	Aims to peak emissions in 2023, reduce carbon emissions by 50% from peak by 2042, and reach net zero by 2050
	An Steel	Aims to reduce emissions by 30% from peak by 2035 and aims to become one of the first net-zero large steel industry companies in China.
Aluminium	Sectoral action plan draft(under consultation)	Aims to peak emissions by 2025 and reduce carbon emission by 40% compared to peak by 2040.
Building Materials	Major administration agency (MIIT)	Urged the industry to develop action plans for carbon peaking, promote low carbon technologies and focus on major sub-sectors and companies.
Transport	Ministry of Transportation	Continuing to support new energy vehicles and electrification of public transportation.
Forestry	National Forestry and Grassland Administration	Nature-based solutions: forestry rate to reach 26% (of Chinese territory) with a forestry volume stock of 2.1 billion cubic meters by 2035.
Power	State Grip Corporation of China	Published carbon peaking and carbon neutrality plan, focusing on clean energy transition, coal-fired plants retrofitting low-carbon solutions and technology development.
	China Energy	Renewable energy installation to reach 70-80 million kilowatts within 5 years; launched a series of research projects on clean use of coal.
	Huaneng Group	More than 50% of low carbon and clean energy installation within the whole group by 2025, with total clean energy installation to reach 80-100 million kilowatts in the next five years.
	China Three Gorges Project Corporation	Aims to achieve carbon neutrality by 2040, while Datang Group will peak by 2025, with 50% of energy clean sources.
	China Huadian Corporation	Increasing new energy installation by 75 million kilowatts, with non-fossil fuel energy installation and clean energy installation accounting for around 50% and 60% respectively; realize carbon peaking by 2025.
	the State Power Investment Corporation	Aims to achieve carbon peak by 2023.
Internet	Alibaba, Tencent, Baidu	Aims to achieve net-zero by 2030.

Actions in different sectors. Energy- and emissions-intensive sectors have responded actively to government announcements surrounding the new climate goal. From "Repositioning CCUS for China's Net Zero future"

Conclusions

2020 was a milestone for CCUS in China, with national targets and policy frameworks driving renewed interest and focus in the technology suite. As a proven and mature technology essential to realising deep decarbonization, CCUS is essential to support high-value manufacturing industries and economic development, as advocated for by the Chinese Government in recent years.

The "1+N" policy mechanism is gradually taking shape, pushing local governments and industries to play a more active role in achieving decarbonisation goals. CCUS is increasingly recognized as an essential technology for the country to realize its climate ambition.

While most projects remain at the demonstration level, the first large-scale project finished construction in February 2022, and there are more in the pipeline. The country is taking well-considered steps towards commercial deployment and exploring the most feasible model for China.

International cooperation, as promoted repeatedly by government and industry leaders, will play a critical role in building understanding of CCUS. Increased cooperation will ultimately lead to the closing of technological gaps, the coordination and strengthening of public acceptance of CCUS, as well as further accelerating the pace of CCUS deployment in the world's biggest market.

More information

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Front cover: The proposed Mammoth project is the follow-up to ORCA, the world's first commercial direct air capture with carbon storage (DACCS) facility in Iceland. It was one of the highlights of the year's developments listed in the Global Status of CCS 2022 (pg. 9)

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Leaders - CCUS in Asia

Lignik: A step-change for CO2 utilisation in the construction industry
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Breakthrough discovery in carbon conversion for ethylene production
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Offshore carbon storage needs to scale up for UK Net Zero goals
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Lignik: A step-change for CO2 utilisation in the construction industry

The article provides an overview of Lignik technology for CO2's conversion to 100% renewable materials that replace brick, concrete and steel, and enable low-cost prefabricated construction. By Adeel Ghayur, CO2CRC.

The Lignik concept was conceived in Pakistan with the overarching aim of developing a technology that: (1) captures CO2; (2) creates value for CO2 by converting to commercially viable product/s; and (3) replaces bricks, concrete and steel in the construction industry [1]. This would allow meeting the twin challenges of emissions reduction and housing shortfall in Pakistan.

In the last decade the research shifted to Australia [2] where it went through an extensive research and development (R&D) process towards commercial maturity and large-scale prefabricated construction. Today, all this R&D work has culminated into Lignik construction material that can sequester 10 metric tonnes (ton) of CO2 in a 100 square metres (m^2) house. This translates to an annual potential of billions of tons of CO2 sequestration into the constructed buildings across Asia and the globe.

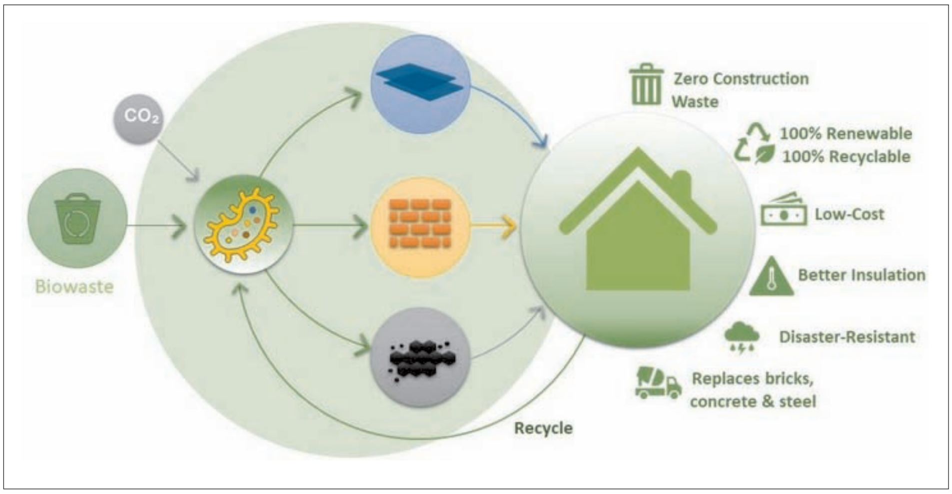

Figure 1: Microbial Manufacturing Process for a Lignik House and its Properties

Lignik Technology

In the Lignik process (Figure 1), naturally occurring capnophilic microbes feed on CO2 and biowaste to produce product/s that can be used as construction materials, thus sequestering CO2 into the constructed building. Microbes get their hydrogen and energy from the biowaste for the capnophilic process. In this process, biowastes are fractionated into three basic components which are then upgraded into the final three products via capnophilic, carbonisation, and closed-cell structurisation processes that consume CO2.

Three products obtained are: composite, bioadhesive and carbon fibres. CO2 needs to be pure for all three processes. While the process can tolerate significant impurities, the purity is needed to ensure the final product does not contain any harmful contaminants for human habitation as the impurities would end up in the building structure. The CO2 can be captured onsite and supplied in any form to the fermenter, including gaseous form or as carbonate salts. The microbial process regenerates the salts for the next cycle of CO2 capture.

As shown in Figure 1, the process yields three sustainable products—composite, bioadhesive, and carbon fibre—that could replace brick, concrete, and steel for the construction sector. Chemically identical to other forms of composite, adhesive, and carbon fibre, these products have properties superior to the brick and concrete construction, thus giving way to less material requirement for the construction. Material demand is further reduced via 3D-printing with near zero waste. All this leads to a reduction in the cost of the constructed building.

The low material consumption also leads to lower overall weight, thus allowing for container transportation of the buildings. These materials are better insulated against heat and cold thus reducing energy requirements and further decreasing carbon emissions. Lignik material based houses can be designed to offer better disaster resistance e.g., during earthquakes and water damage. This would require structural engineering related requirements for disaster prone areas to be incorporated in the building design. Finally, the Lignik process can do hundred percent recycling of its own products which promotes circular economy with no waste.

Lignik in Pakistani and Asian Construction Industry

Rapid population growth and urbanisation have created new housing challenges for Asian cities, termed as housing crunch by the Asian Development Bank [3]. The result is an urban housing shortage, which is nowhere more apparent than in Pakistan; the world's fifth most populace country. Pakistan is currently facing a shortfall of over 12 million homes, set to increase with a fast-growing population.

In Pakistan, nearly all homes are of double brick-concrete construction with high bricks, concrete and steel demand. The bricks are produced in inefficient polluting brick kilns with high CO2 emissions. A typical 100 m^2 house in Pakistan requires upwards of 10,000 bricks with a carbon footprint of nearly 10 ton of CO2 in the bricks alone [2]. Other materials like steel and cement bring the total emissions to above 40 ton.

In addition to the greenhouse gas (GHG) emissions, unsustainable materials extraction for the construction industry is leading to several social and environmental issues. These include fertile topsoil degradation for clay mining leading to food insecurity, and ecosystem damage due to sand mining. Social issues include criminalisation of the industry, bonded labour and continuously increasing costs. This is happening not only in Pakistan but in many Asian countries.

Asian countries are urbanising at an unprecedented rate with affordable housing not keeping pace with the current and projected future demands. According to the International Energy Agency, by 2050, construction equivalent to 70 billion m2 of floor area will occur in the Association of Southeast Asian Nations (ASEAN), China and India alone [4].

This scale of construction would require more than 160 billion ton of materials with associated CO2 emissions of 28 billion ton. This type and scale of construction stands at odds with the Asian countries' focus towards developing their economies, job creation, sustainable poverty reduction, transitioning to green and resilient development, and meeting 2050 emissions reduction targets.

The above figures underpin the importance of developing renewable feedstock based construction materials that reduce GHG emissions, substitute unsustainably extracted materials and sequester CO2. Here, buildings constructed out of hundred percent renewable Lignik can be a part of the efforts to achieve the sustainability and emissions reduction targets of Pakistan, Asia and the world. As Lignik is hundred percent recyclable, the CO2 is effectively removed from the atmosphere via perpetual orycycling [5].

Technology Advantages

CO2 sequestration potential

• As all Lignik materials are made from CO2, each building sequesters around 1 ton of CO2 per 10 m^2 of construction. Thus, a 100 m^2 house sequesters around 10 ton.

• Each production facility has the annual potential to sequester up to 1.5 million ton CO2 using current commercially available machinery. Research, development and demonstration (RD&D) has the potential to further increase this capacity.

• There is global potential to annually sequester billions of ton of CO2 using hundred percent renewable housing.

• The CO2 sequestration is permanent as the material is specifically designed for perpetual recycling without creating waste.

Compared to competing microbial processes

• Unlike bioethanol biorefineries, the Lignik process does not consume food thus eliminates the food versus fuel issue (Figure 2). It consumes non-food and biowastes that are produced as a waste component of food crops. This also eliminates the issue of land-use as no food-growing land is earmarked to grow non-food crops for this process.

• Unlike bioethanol and biogas processes, Lignik process does not emit CO2 as a waste product.

• Microbes consume hydrogen from biowaste, thus eliminating the need of energy intensive hydrogen supply.

• It is the only microbe-based process in the world wherein each facility could be scaled up to 1.5 million ton of annual CO2 sequestration into renewable products using current commercial equipment.

• Techno-economic simulations have already shown the process is commercially viable for Australia and produces low-cost products. This implies, the process may have better economics in developing countries with lower production costs.

• Naturally occurring microbes were specifically selected over genetic engineered ones to reduce any potential future risk to our environment.

Compared to competing CO2 utilisation technologies

• Lignik process is geolocation independent and can be placed anywhere with the availability of any biowaste such as crop waste, food waste, marine waste and so forth.

• There is no cost associated with CO2 utilisation as the process produces commercially viable products.

• The Lignik products are hundred percent recyclable compared to competing carbonation products.

• There is no CO2 energy penalty as the microbes derive their energy and hydrogen from the biowaste. No external energy source is required for the Lignik process.

• Lignik process is a negative emission technology that can sequester more CO2 (at least 58% more) than other any other capnophilic process.

Compared to construction carbonation technologies

• The constructed building is hundred percent recyclable.

• The constructed building does not consume bricks, cement and steel, all of which are associated with high CO2 emissions. This also helps to reduce emissions from hard-to-abate industries (e.g., cement, steel, etc.).

• The building construction does not degrade natural ecosystems, while brick and concrete based carbonation technologies are associated with topsoil degradation for clay extraction and ecosystem damage for sand mining.

• The feedstock is renewable thus the supply is constant. In comparison, developing countries are fast running out of sustainably mined clay and sand for brick- and concrete-based carbonation technologies.

Related Costs

Techno-economic simulations show that the upfront capital cost for a commercial scale facility in Australia is Australian dollar ($) 200 million. This facility can produce enough materials for the construction of 10,000 houses, annually. This equates to sequestering of 100,000 tonnes of CO2 per year. This capital cost does not include the cost for the construction of the houses; it is only for the production of the intermediary chemical materials. The detailed techno-economic simulations were done for an Australian site. The annual operating costs were $42 million. There were no CO2 capture costs as the facility would be commercially profitable. These costs would vary depending upon the location of the facility.

Status and Next Step

The Lignik process has been further developed by CO2Tech (subsidiary of CO2CRC) as a part of its R&D work on CO2 utilisation and circular bioeconomy. The technology has achieved following milestones:

• Development of the Lignik process,

• Sourcing of microbes, and

• Preparation and analysis of sample Lignik panels.

Currently, panels made out of these materials are undergoing accelerated weathering tests to assess the life span of the Lignik material. The long-duration weathering and ageing test results would be available in 2023.

Concept study for a demo-scale facility and detailed techno-economic simulations for a commercial scale facility were completed last year. The techno-economic study shows the project is commercially viable. CO2Tech is engaged in a yearlong project to develop a market strategy and panels for an industrial partner.

Figure 2: Lignik Technology Comparison with Negative Emission Technologies

CO2Tech will be engaging in an industry funded short-term R&D project to explore further cost-reduction avenues for prefabricated houses. It is also in early discussion with industrial investors to potentially fund the construction of a display house made out of these materials for demonstration purposes.

CO2Tech proposes a pilot housing project in Pakistan or any other developing country to be aligned with a socio-economic plan to help uplift the standards of the community. Such a project may be carried out in collaboration with donor agency/s and may include but not limited to buildings for schooling, remote clinics, and other facilities.

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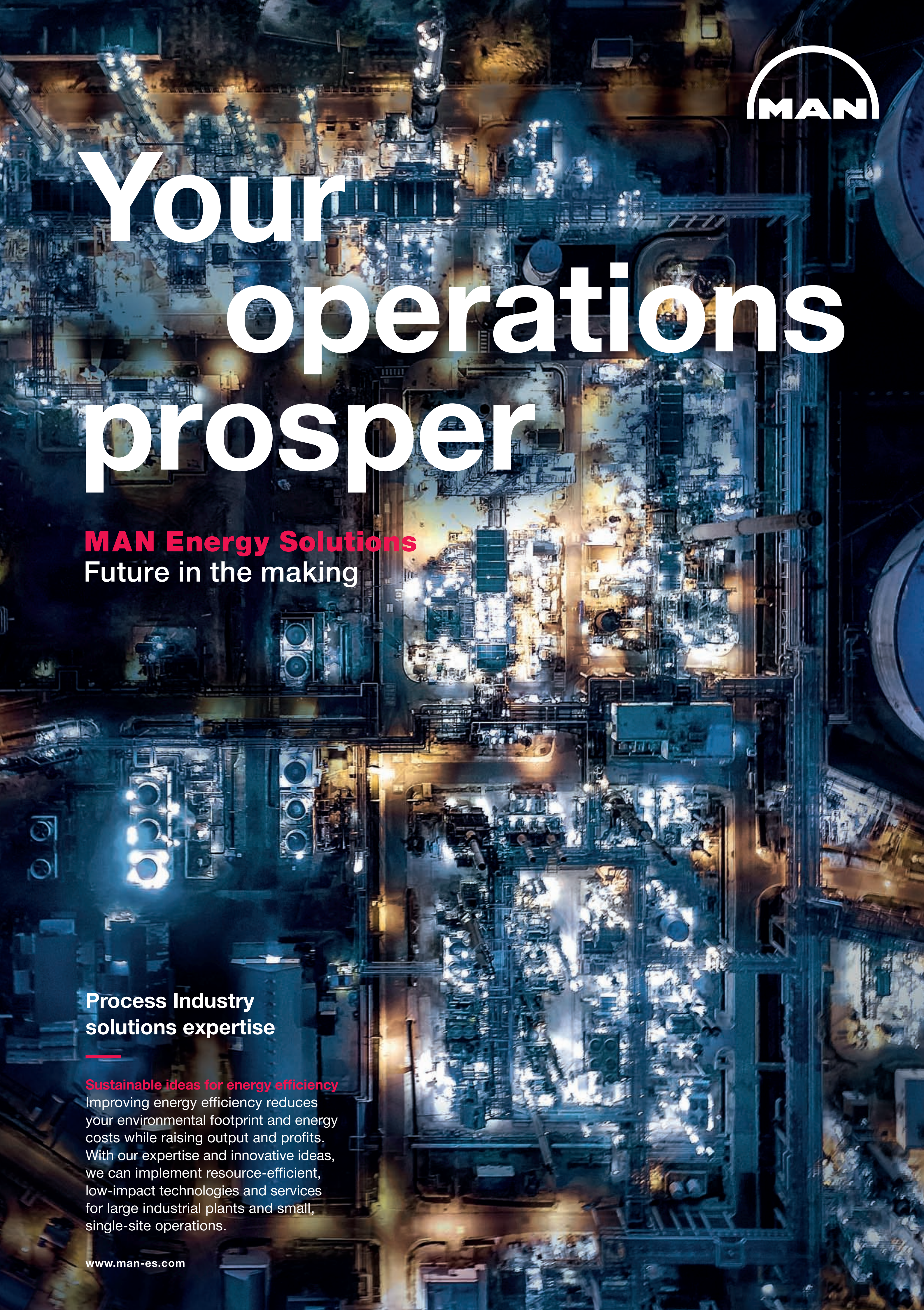
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Appraisal of CO2 capture schemes from gas processing facility

Based on an under construction Saudi Aramco gas plant, the authors compared alternative CO2 capture schemes to appraise their costs and benefits.

By Abdulrahman H Al-Askar, Graham J Hollingsworth, Khalifah E Al-Salem, Saudi Aramco

The new Gas Treatment Process plant has a significant tail gas CO2 rich stream flow, which would conventionally be emitted to atmosphere. With a view to minimizing the process' carbon footprint, alternative CO2 Capture schemes for handling the stream are herein appraised of their costs and benefits.

CO2 Capture Schemes

Base Case Thermal Oxidizer Operation without CO2 Capture

The CO2 rich stream is routed through the process thermal oxidizer, where the fuel gas is burned to oxidize the stream, and the hot flue gas is used to generate high-pressure steam passing through a waste heat boiler. CO2 from the CO2 rich process stream is combined with CO2 from the burned fuel gas and emitted to atmosphere via the stack.

CO2 Capture, Utilizing Multistage Centrifugal Compressor

The CO2 capture scheme considered takes a CO2 rich stream, compresses it and transfers it to be captured in a depleted gas cavity, or to enhance oil recovery, via reservoir injection.

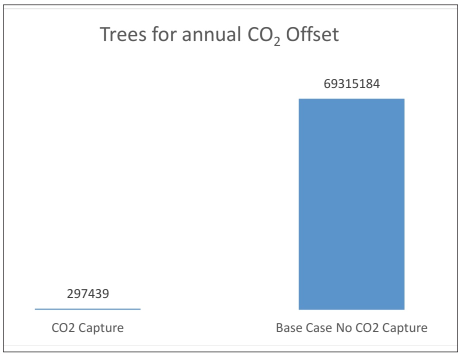

Figure 1 - Calculation of CO2 offsetting by trees [1]

The costs presented are limited to the process plant, excluding the CO2 capture reservoir.

The Costs and Benefits

Any appraisal of CO2 capture schemes must consider all the costs and benefits.

Benefits

- Enhanced oil recovery
- Reduced CO2 emissions

Enhanced Oil Recovery

Through the injection of the CO2 rich tail gas in the bottom of a water flooded reservoir, enhanced oil recovery can be achieved [2],[3] by induced gas flotation, and pressurization of the reservoir. Currently methane injection is applied for enhanced oil recovery. Substitution of CO2 injection for oil recovery, frees the methane for sale, and enhances the net energy return.

The CO2 injected will be partially sequestered in the reservoir, and partially separated from the oil recovered, allowing the closed cycle of CO2 beneficial usage to be continued. Net energy return is a key factor to maximize benefit, and minimize CO2 production in doing useful work. See Figure 2.

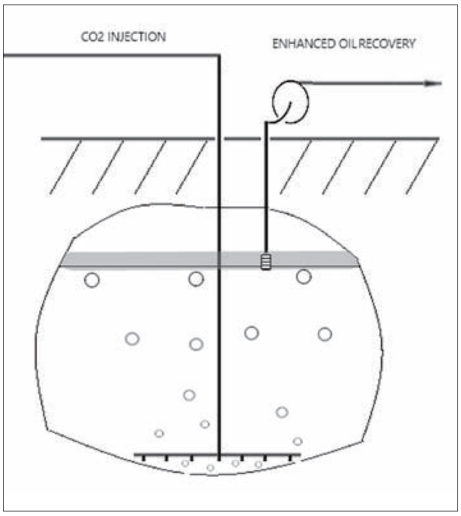

Figure 2 - Enhanced Oil Recovery

Reduced CO2 Emissions

The proportion of CO2 which is injected into the oil reservoir, or gas cavity, that is retained indefinitely, is subject to critical assessment. It is clear that with enhanced oil recovery, the induced gas flotation process results in CO2 rich oil recovery, which would have to be separated and reinjected for the CO2 to be retained in a closed cycle of productive usage.

With a Tail Gas stream of 28 mol% CO2 (40 wt%), and the bulk of the remainder being N2 and H2O, the stream composition is similar to exhaust emissions from hydrocarbon combustion processes. To compress the atmospheric pressure stream to 250 barg, requires considerable power, and some cooling.

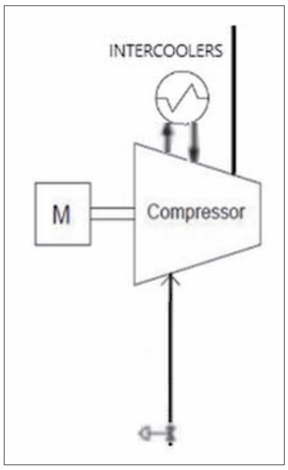

Figure 3 - Motor Driven Multistage Compressor Train with Intercoolers employed for CO2 Rich Stream Capture

A train of two multistage compressors in series are selected to achieve the discharge pressure sought [4], handling 50% of the CO2 rich stream's flow. Three of these trains are required for a 3 x 50% configuration, to have a standby 50% train, to achieve the required plant availability.

The power required for the compressors will be generated by the site's cogeneration facility. Steam production is currently the governing demand for the cogeneration plant, leading to an excess of electricity generated that is sold to the national grid. Thus, there is no additional CO_2 generated for the CO_2 capture compressors' operating power. Figure 3, 4, 5.

Costs

• Additional CAPEX and OPEX

• Reduced Steam Generation

The CO_2 capture schemes' operating and capital costs, when amortized over 20 years, can be reduced to an annual cost. The appraisal calculation assumes the high CO_2 stream flow has negligible intermittency, but factors can be applied for percentage utilization.

Additional Fuel Gas consumption

The CO_2 capture scheme's high discharge pressure requires significant compression power. This would normally result in increased fuel gas consumption, but in this particular case the excess site power generation can be productively used on site, resulting in no additional fuel gas consumption.

The CO_2 rich stream would nolonger flow through the thermal oxidizer, allowing reduced thermal oxidizer burner fuel gas consumption on standby. See Figure 6.

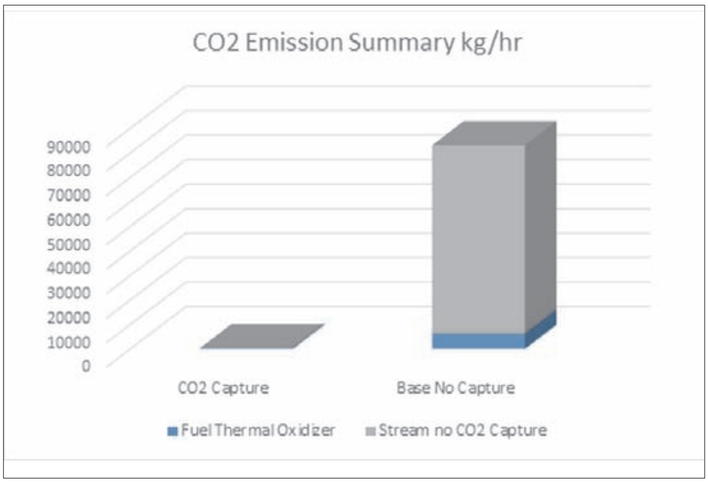

Figure 4 - CO2 Emission Summary: Emission Base Case, with no CO2 Capture, versus Emission with CO2 Capture Scheme, remaining emission resulting from minimum standby Thermal Oxidizer Burner setting

Additional Electricity Consumption

The electrical power required for the thermal oxidizer combustion air fan is 500kW. This is dwarfed by the 34300kW power required to compress the CO_2 rich stream from atmospheric pressure to 250 barg for injection for carbon capture. See Figure 7.

Process Generated CO2

The total CO_2 generated by the process considered includes the CO_2 rich stream itself plus the CO_2 generated burning fuel gas in the thermal oxidizer treating the CO_2 rich stream. In the particular site case considered with surplus electricity, CO_2 is not considered for electricity generation. See Figure 8.

Additional CAPEX and OPEX

The base case has no costs for CO_2 capture, other than lost opportunity costs. The annualized costs for operation considered are only

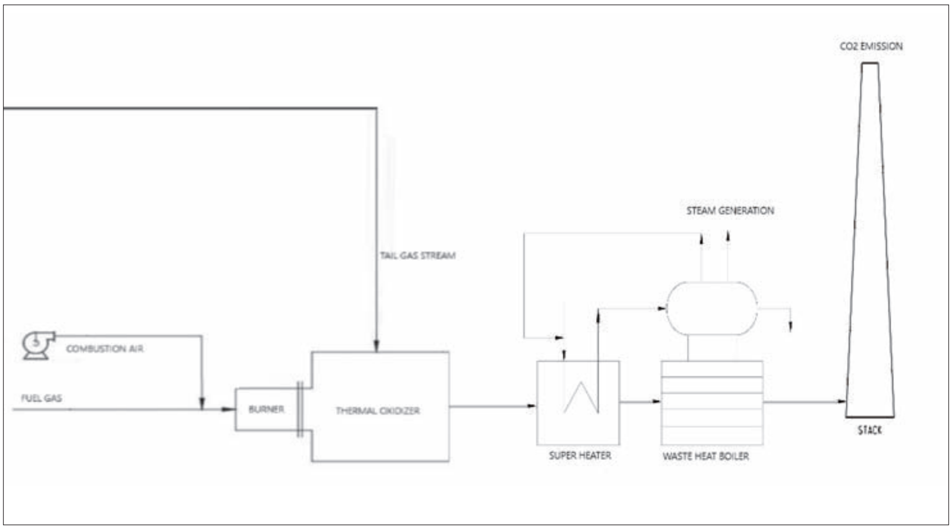

Figure 5 - Tail Gas Stream Treatment Process, with Thermal Oxidizer, Waste Heat Boiler, and Emission to Stack

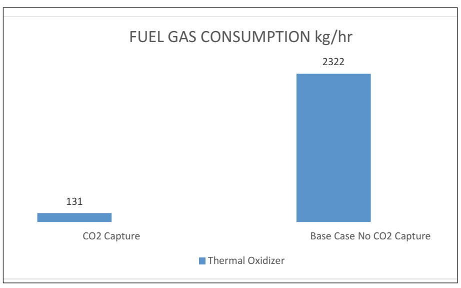

Figure 6 - Additional Fuel Gas consumption

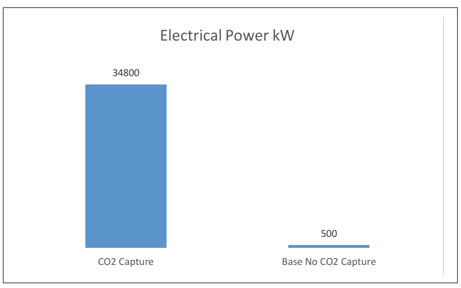

Figure 7 - Additional Electricity Consumption

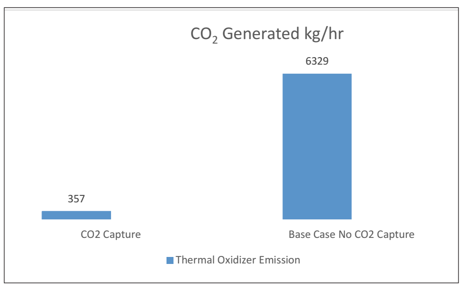

Figure 8 - Process Generated CO2

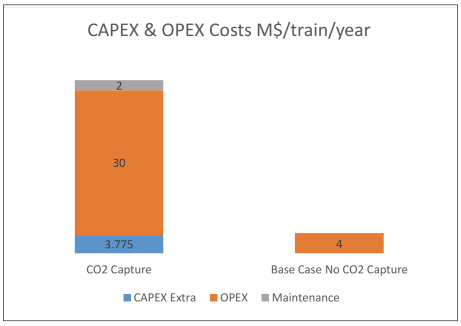

Figure 9 – Additional CAPEX and OPEX

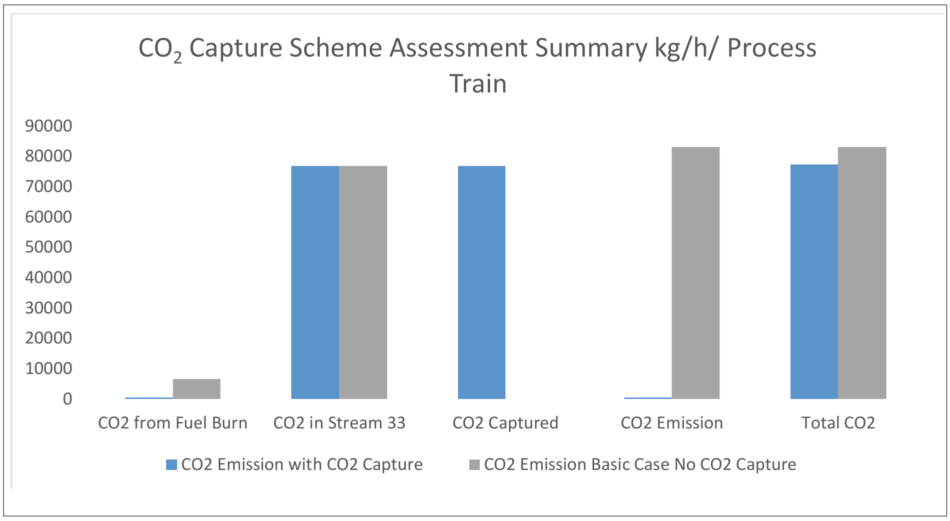

Figure 11 – CO2 Capture Scheme Assessment Summary

for the fuel gas consumed in the thermal oxidizer. No capital expenditure cost is considered as the thermal oxidizer is required for all scheme options, to handle other process streams, with toxic and flammable components. See Figure 9.

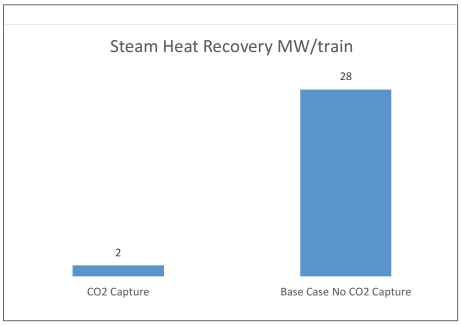

Figure 10 – Reduced Steam Generation

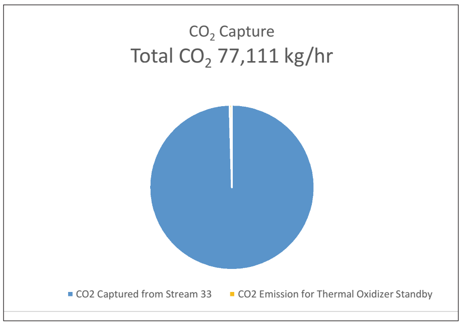

Figure 12 – Metrics: CO2 capture

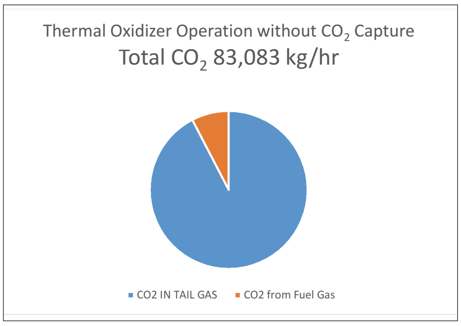

Figure 13 – Metrics: CO2 emissions

Reduced Steam Generation

For the base case with no carbon capture there is higher thermal oxidizer burner fuel consumption than when on standby with carbon capture. This is offset by the heat recovery steam generator's steam production. I.e., there is reduced steam generation available as a plant utility with the CO2 capture schemes, which may necessitate alternative provision. See Figure 10.

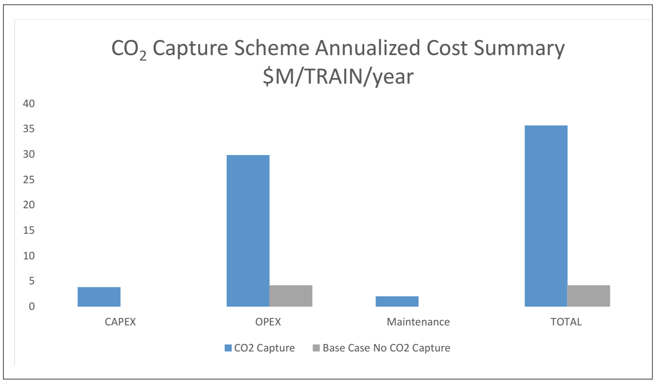

Figure 14 – Metrics: cost

CO2 Capture Scheme Assessment Summary

The full assessment of the merits of proceeding with a carbon capture scheme can only be concluded with the quantified benefits of any enhanced oil recovery process and carbon credit scheme.

The metrics for the costs, emissions and fuel consumption help inform a reasoned consideration. See Figures 11, 12, 13, 14.

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CCS sector well placed for deployment following recent findings

The outlook for the carbon capture and storage industry is bright but the scale of deployment required remains very apparent. A positive for the sector is that there has never been a better time than the present for deployment to be ramped up.
By Jamie Burrows, Head of Business Development – CCUS, Energy Systems at DNV.

When considering the latest edition of the industry's flagship report, the Global Status of CCS[1] published annually by the Global CCS Institute, and with supportive policy and regulation emerging, it is becoming less a question of whether we need CCS, but instead how do we deploy – and how do we deploy faster.

An uncomfortable conclusion of DNV's recently published Energy Transition Outlook report is that we are heading towards 2.2°C of global warming. Reaching net zero will be virtually impossible without CCS to capture emissions that are technically difficult or economically unfeasible to eliminate. Closing the gap between our current 2.2°C trajectory - and the 1.5°C future our planet needs - requires significant deployment of carbon capture technologies, including those that remove CO2 from the atmosphere.

CCS is now well proven and understood. Some industries, including cement and chemical production, lack credible alternatives to the use of CCS to decarbonise. Blue Hydrogen production is reliant on the availability of CCS to store CO2 from the reforming process. Likewise, CCS infrastructure is fundamental to the deployment of large-scale technology-based CO2 removal via Bioenergy with carbon capture and storage (BECCS) and Direct Air Carbon Capture and Storage (DACCS).

There are now some 30 facilities in operation globally storing over 40 million tonnes of CO2 annually. The 2022 annual status report highlights that the CCS project pipeline has been growing for the last four years. With 61 facilities added to the pipeline in the last 12 months, the total number of facilities in operation and development has grown to 191, representing a capture capacity of 244 million tonnes per annum.

In most 1.5°C consistent pathways, the use of

Increase in the capacity of CCS projects from 2010 until September 2022 (the final bar represents the project development status as of mid-September 2022). From "Global Status of CCS 2022"

Carbon Dioxide Removal technologies is substantial and so it is reassuring to note that progress has been made in the deployment of one such critical technology, with the Orca Direct Air Capture facility in Iceland beginning operation. The facility is the largest of its kind in the world and marries Climeworks technology with the Carbfix storage technique. It is also one of the first projects to store CO2 through mineralisation in the subsurface, which could lead to storage opportunities in new locations.

The United States continues to lead the world on CCS deployment with 15 operational facilities and this trend is expected to continue with further policy enhancements recently announced. Last year's Infrastructure Investment and Jobs Act included $12bn of funding over five years for various elements of CCS deployment. Through the Inflation Reduction Act, the 45Q tax credit has been increased to provide up to $85 per tonne for CO2 stored from point sources and $180 per tonne for CO2 captured from the atmosphere. The amendments also defer the start of construction timing to 2032 and allow developers to elect for direct payments for the initial five years.

Unsurprisingly we are seeing many new projects emerge in the United States with the Institute noting 70 currently in development and more announced since publication of the report. A huge CCS cluster is in development around the Houston Ship Channel, with some 14 companies having indicated their involvement. A number of projects have emerged in the Midwest that plan to capture CO2 from Bio-ethanol production. Such projects are considered a form of BECCS and offer a competitive way to deliver high permanence Carbon Dioxide Removals at scale.

One slight headwind to US deployment has been the permitting process for storage sites which is taking longer than planned. The US EPA has regulatory authority over CO2 sequestration projects through its Underground Injection Control program. Several states are planning to follow North Dakota and Wyoming to take primacy for Class VI wells and it is hoped this will help to speed up the process.

The Canadian Government continues to support CCS deployment and introduced an investment tax credit as part of the 2022 federal budget covering different elements of the CCS value chain. Canada's first CCS storage hubs are being developed in Alberta while the Institute also highlights storage evaluations being performed in Ontario.

Similar progress is being made in Europe. The construction of the Northern Lights project in Norway remains on time, with first injection anticipated in 2024. An important milestone for deployment was reached with the first commercial agreement for cross border CO2 transport being signed between Northern Lights and Yara in the Netherlands.

The Danish Government has announced €5bn worth of support over the next decade for CCS deployment. Further large-scale CCS projects are being enabled by the EU innovation fund in Germany, France, Poland, and Sweden.

In the UK, several important developments have occurred which have laid the groundwork for delivery of the Government's stated aim of storing 20-30 Mtpa by 2030. The Energy Security Bill, currently being legislated, provides the secretary of state with the powers to financially support CCS, and licensing and regulatory provisions for associated infrastructure.

Following announcement of Track 1 clusters[2], in August 2022, 20 emission sources were announced as being short-listed as potential sources of CO2 for storage via the Hynet and East Coast cluster infrastructure. These include gas fired power, hydrogen and industrial applications such as energy from waste refineries, fertilizer and cement production which demonstrates the decarbonisation versatility CCS clusters can offer. Notably shortlisted projects include Whitetail Clean Energy, a project that proposes to use the Allam-Fetvedt cycle to create power.

Many countries in Southeast Asia are reliant on fossil fuels to drive growth and are home to emissions intense industries. The important role CCS can play in such economies, enabling growth and decarbonisation, is highlighted by the Institute. In Malaysia, the Kasawari and Lang Lebah projects, operated by Petronas and PTT Exploration and Production (PTTEP) respectively, will store CO2 produced with hydrocarbons.

Notably PTTEP is also planning to move ahead with a CCS project in Thailand at the Arthit offshore gas field and has started to examine potential deployment across a number of industrial emission sources.

Like Malaysia, Indonesia is one of countries leading CCS deployment in Southeast Asia. The Government has released a draft of its CCS specific legal and regulatory framework while notable projects progress. SKK Migas, the Indonesian Regulator, approved the expansion of BP's Tangguh LNG project and the development of the associated Vorwata CCUS project late 2021.

The project is expected to begin operation in 2027. Repsol's Sakakemang CCS project is expected to begin storing 2.5Mtpa by 2027. Beyond CO2 associated with Hydrocarbons, Pertamina has announced a collaboration with Air Liquide to deploy carbon capture technology at the Balikpapan refinery.

Whilst a policy-based business model is still lacking in China, CCS deployment has taken steps forward in the country that has the greatest volume of greenhouse gas emissions. In August 2022, China's first one million tonne CCUS project entered operation. The project developed by SINOPEC captures CO2 from the Qilu Petrochemical plant.

The Institute report refers to Huaneng having started construction of the world's largest coal fired power CCUS project, capturing 1.5Mtpa. Once operational, this will become an important reference for decarbonisation of such facilities elsewhere in the region.

In the Middle East, a number of national governments have made climate commitments, including the United Arab Emirates, Saudi Arabia and Oman, the trio having all made net zero pledges. The Institute points out that potential CCS growth in the Middle East is being driven by both climate commitments and the potential to act as a hub for low carbon Hydrogen. The Middle East holds a significant stock of the world's oil and gas reserves.

Today, there are three operating CCS projects in the region. At the Ras Laffan gas liquefaction plant in Qatar, 2.2Mtpa of CO2 are captured. ADNOC's Al Reyadah project captures 0.8Mtpa of CO2 at a steel plant in Abu Dhabi. Saudi Aramco captures 0.8Mtpa of CO2 at its Hawiyah Natural gas processing plant.

Expansion plans are being developed at Al Reyadah and Ras Laffan where it is hoped each facility will increase capacity to circa 5Mtpa in the coming years.

With COP27 taking place in Egypt and COP28 in the UAE, the Middle East will provide the setting for focussed discussions on decarbonisation in the coming years. At the heart of delivering the Paris agreement is each country's Nationally Determined Contribution: a national plan signalling targets and strategies for emissions reductions. Analysis of NDC submissions to date shows CCS is increasingly recognised in these critical documents with the technology featuring in 21 current NDCs.

The Institute report highlights that to deliver climate commitments we need to scale up current capacity more than 100 times by 2050; this represents not only an infrastructure challenge, but also an opportunity for the Carbon Capture industry. It is one that the industry must meet head on, but it is well placed to do so.

About the author

Jamie Burrows is Head of Business Development – CCUS, Energy Systems at DNV. In this role he works closely with DNV's clients worldwide to provide the necessary expertise and guidance to enable deployment of Carbon Capture technologies. Prior to joining DNV, Jamie was Client Engagement Manager for the Global CCS Institute.

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More information

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How to succeed at CCUS by overcoming major challenges

Choosing the right technology partner is essential in overcoming challenges in developing successful CCUS projects. By Steven King and Viswadeb Ganguly, Flowserve.

Carbon capture utilization and storage (CCUS) technologies offer significant opportunities for industry and society to avoid emitting carbon dioxide (CO2), a greenhouse gas (GHG) known to contribute to climate change, into the atmosphere.

CCUS is the process of capturing CO2 formed from a broad range of sources such as power generation, transportation, cement production, pulp and paper, and other industrial processes. Then the CO2 can be utilized as a feedstock in industrial processes and/or stored underground.

In cases where it is not used at the capture site, the CO2 is compressed and transported for use in a range of applications such as conversion to fuels, chemicals, food packaging and agriculture. In the sequestration process, it is injected into depleted oil and gas reservoirs, saline formations or other geological reservoirs, where the CO2 is trapped for permanent storage.

As companies prioritize energy transition initiatives to reduce GHG emissions, they're also taking significant steps to operate more efficiently. CCUS is among the most critical. Advancement of CCUS technologies could drive down capital and operating costs as much as 40% by 2035, according to some projections.

However, the global CCUS infrastructure will need to grow to support this increase in demand. Other major CCUS challenges also must be addressed for companies and nations to achieve global climate goals and meet marketplace demands from emerging applications that can utilize CO2.

CCUS growth forecast

CCUS has the potential to grow significantly over the next 25 to 30 years.

- 2021 - 40 Mt of CO2
- 2030 - 1.8 Gt of CO2
- 2050 - 7.6 Gt of CO2

Source: International Energy Agency (IEA)

Four CCUS processes explained

CCUS systems capture CO2 from power generation or industrial facilities that combust either fossil fuels (coal, natural gas or oil) or biomass as a feedstock. CO2 is captured by one of three methods in power or industrial plants. A fourth method, direct air capture, is typically used as a stand-alone process not directly connected to an industrial facility.

If not used on-site, the captured CO2 can be compressed and transported for various uses, including supercritical CO2 (sCO2) power plants. The captured CO2 also can be injected into deep geological formations (such as depleted oil and gas reservoirs) for permanent storage via marine, truck and/or pipeline transportation.

Supporting net zero goals

There's a narrow but viable pathway to achieve net zero CO2 emissions by 2050, according to the IEA.

Pre-combustion	*Post-combustion*	*Oxyfuel combustion*	*Direct air capture*
CO_2 is trapped by partially burning the feedstock fossil fuel to form a synthetic gas and separate the CO_2. It also separates hydrogen (H_2), which can be stored for use as a fuel. This is the second-most commonly used CCUS technology.	CO_2 is scrubbed from the exhaust gases after burning the feedstock fossil fuel. It's been used for decades in enhanced oil recovery processes and represents 70% of CCUS processes.	CO_2 is separated by burning the feedstock fossil fuel in 100% oxygen, instead of air. The resulting exhaust gases consist mostly of water vapor, which is cooled and condensed, and pure CO_2, which is collected.	18 plants worldwide extract CO_2 from the atmosphere. They compress it for underground storage or reuse it in food processing. It's also combined with H_2 to produce synthetic fuels.

The four main methods of carbon capture

The energy sector is responsible for a large percentage of GHG emissions. However, in order to achieve net zero energy goals, CO2 emissions reductions will be required in areas in addition to the energy sector.

Traditional fossil fuels are expected to remain an essential feedstock for some time to keep up with energy demand. Nonetheless, CO2 and other GHGs emitted during power generation and industrial processes must be reduced. CCUS solutions are viewed globally as emissions-reduction technologies that should be applied across the energy landscape.

CCUS provides significant value in the transition to net-zero carbon.[1] According to the IEA, CCUS can:

• Be retrofitted to existing power, industrial and many other applications, which could otherwise still emit 8 billion tons (Gt) of CO2 by 2050

• Address emissions in sectors where other technological options are limited, such as in the production of cement, iron and steel, or chemicals

• Produce synthetic fuels for long-distance transport, notably including aviation

• Enable low-cost, low-carbon H2 production

• Remove CO2 from the atmosphere by combining it with bioenergy or direct air capture to balance emissions that are unavoidable or technically difficult to abate

Infrastructure limits CCUS adoption

Infrastructure is the weakest link of the carbon capture industry.

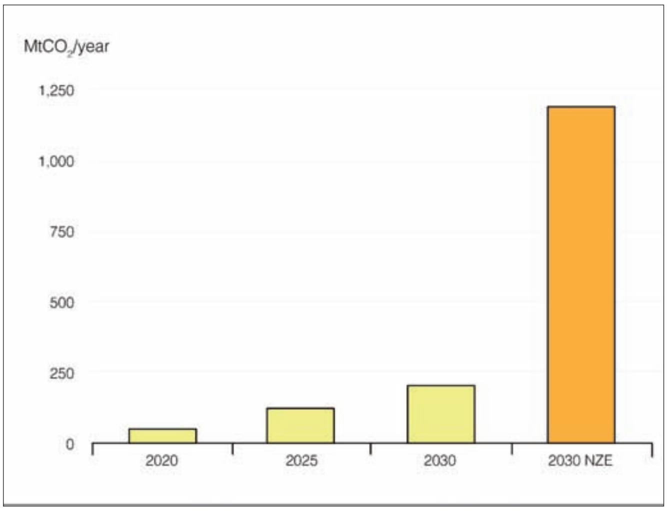
It's a surprising reality, given that CO2-capturing technology has been in use since the 1950s for enhanced oil recovery (EOR). For decades, companies viewed carbon capture as an expense; a tiny market existed for captured CO2. And limited access to a reliable transportation infrastructure to get the product from its source for sale to end users only increased its cost. Until recently, there's been little demand to transport captured CO2 for disposal at remote underground sites.

What's needed are cross-country pipelines to move CO2 safely and affordably. Fortunately, the marketplace is evolving as companies discover how to convert CO2 into a profit center.

In its Net Zero Emissions by 2050 Scenario, the IEA states that CO2 transport and storage infrastructure underpins the widespread deployment of carbon capture. This includes carbon dioxide removal (CDR) via direct air capture with storage (DACS) and bioenergy with CCS (BECCS).

There are 8,000 km (4,971 miles) of CO2 pipeline — mainly in North America.[2] In addition, there are seven dedicated geological CO2 storage operations with a combined capacity of 10 Mt/year[2]. That's not enough to reach net zero carbon objectives.

To fill the gap, infrastructural projects are being designed or are under construction. They will connect multiple sources of captured CO2 into transportation systems to move the CO2 to permanent sequestration points. Based on projects currently in development, dedicated CO2 storage capacity could reach around 110 Mt CO2 /year by 2030, according to the IEA. That capacity will be far less than the nearly 1,200 Mt CO2 /year expected to be captured and stored by 2030.[2]



More CCUS projects needed. Annual CO2 storage capacity, current and planned vs Net Zero Scenario, 2020-2030. Source: "CO2 Transport and Storage," IEA (September 2022)

Operating in a complex carbon landscape

There's not a one-size-fits-all solution for carbon capture. It's a complicated issue due to the sheer number and variety of CO2 sources.

The United States alone has 3,400 fossil fuel-fired power plants.[3] Another 7,600 of the largest U.S. industrial facilities report releasing CO2 and other GHGs that account for about 50% of the total U.S. emissions.[6]

Another factor is the concentration of CO2 released in a facility's processes.

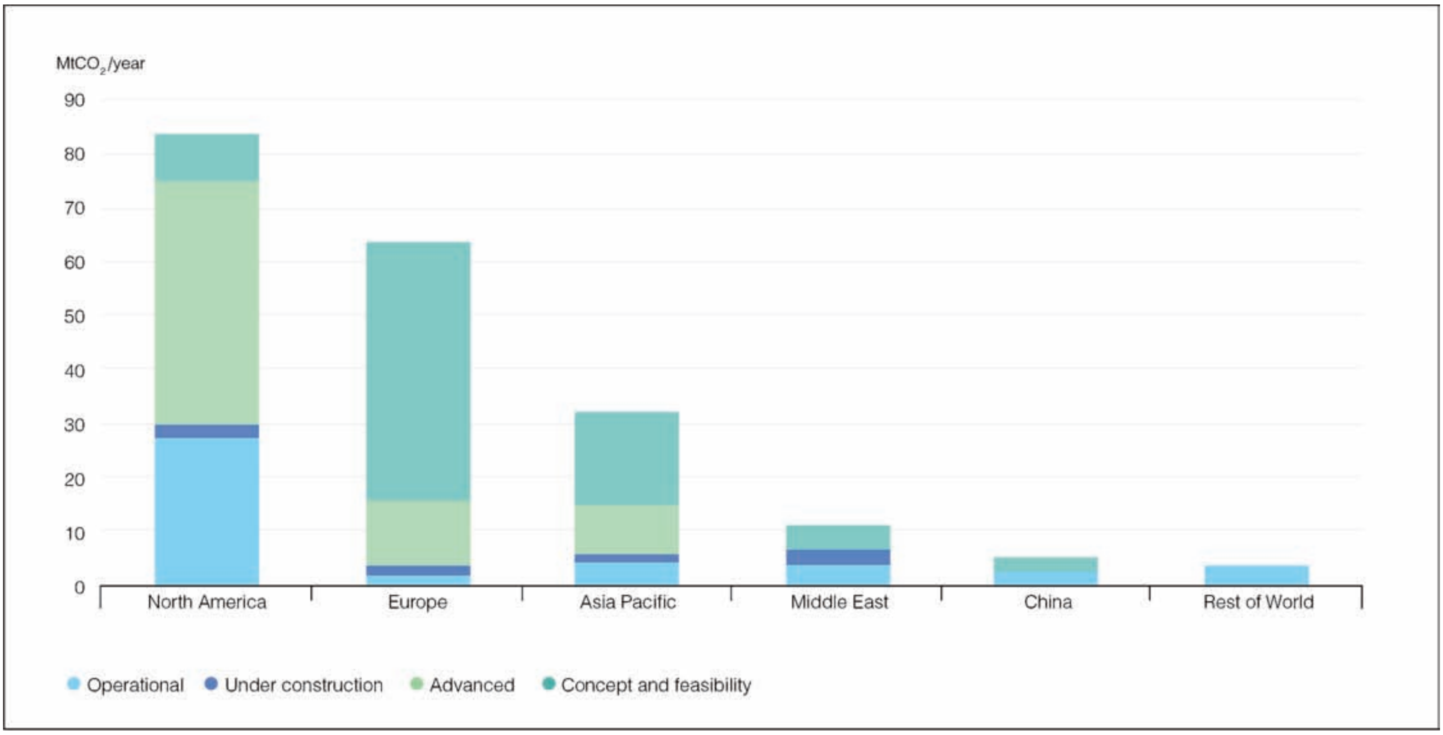
Power plants burning coal or natural gas emit more CO2, so it's readily available in flue exhaust in such concentrations that make capturing it economical. Retail distribution centers, however, may consume large amounts of energy to power material handling systems; but the CO2 concentration on-site is low. That weakens the business case for CCUS.

Also lacking are pipelines and fleets of barges, ships and trucks to transport CO2 captured at plants to centralized facilities for processing and distribution. Many industrial facilities are located in remote areas or in locations with geology that does not support underground CO2 storage. In some instances, sequestration sites can be in other states hundreds of miles away.

As a result, the infrastructure to transport CO2 will need to increase at least at the same rate as capture and storage capacity.[2]

It's also likely that more than 50% of captured CO2 will be stored at dedicated storage sites.[2] This represents a large shift away from EOR methods in which captured CO2 is injected underground to boost oil field production. Much of the CO2 escapes into the atmosphere in the process. Today, nearly 75% of captured CO2 is used for CO2 -EOR.[2] More than 20% is stored in dedicated storage sites, and the remainder of CO2 captured from industrial processes is used in other applications such as agricultural greenhouses and to produce industrial products.

Investment in CCUS infrastructure is accelerating. There are about 90 full-chain projects to capture, utilize and store CO2 in development. In addition, the IEA reports a growing number of companies are choosing what's called a part-chain approach to focus on CO2 capture, transport or storage. There



CO2 infrastructure projects in the pipeline. Source: IEA (2022)

are 150 hubs planned to transport and/or store CO2 away from where it's captured. These can reduce commercial risks and promote efficiencies.

Most storage projects aim to inject CO2 into one of the storage hubs under development. These multi-user hubs will capitalize on economies of scale to support decarbonization of entire industrialized zones. Operated by consortiums, they also will provide multiple companies that operate plant sites far away from industrialized zones with an affordable CCUS solution for transportation and storage or CO2 reprocessing.

Multi-user hubs represent about one-third of CO2 transport and storage infrastructure in development.[2]

Encouraging decarbonization with public policy

Governmental support and regulation are driving CCUS adoption as nations recognize the importance and urgency of developing CO2 capture, transportation and storage infrastructures. Several countries recently have enacted policies with financial incentives that will speed up CCUS projects.[3]

In the United States, 2022's Inflation Reduction Act (IRA) places a high value on carbon capture technologies. The law increases the 45Q tax credit for carbon sequestration projects up to $85 per ton of CO2, depending on the amount captured and stored. That's up from the original $45 per ton. The IRA creates a new market in which companies can differentiate their products based on how little CO2 is released during production.

It also significantly increases the credit value for direct air capture (DAC) of CO2. In effect, public policy incentivizes industries for removing historical or legacy CO2 emissions for which they are responsible.[4]

The United States Infrastructure Investment and Jobs Act, signed into law in 2021, included $5 billion in support for CO2 transport and storage development. It also extended the deadline to begin these projects from 2026 to 2033.

Other nations are encouraging expansion of CCUS. Many have or are deploying similar policies and incentives:[5]

• Canada offers a 37.5% tax credit for transport, storage and use equipment.

• Denmark plans to spend at least $2.2 billion on CO2 transportation and storage infrastructure.

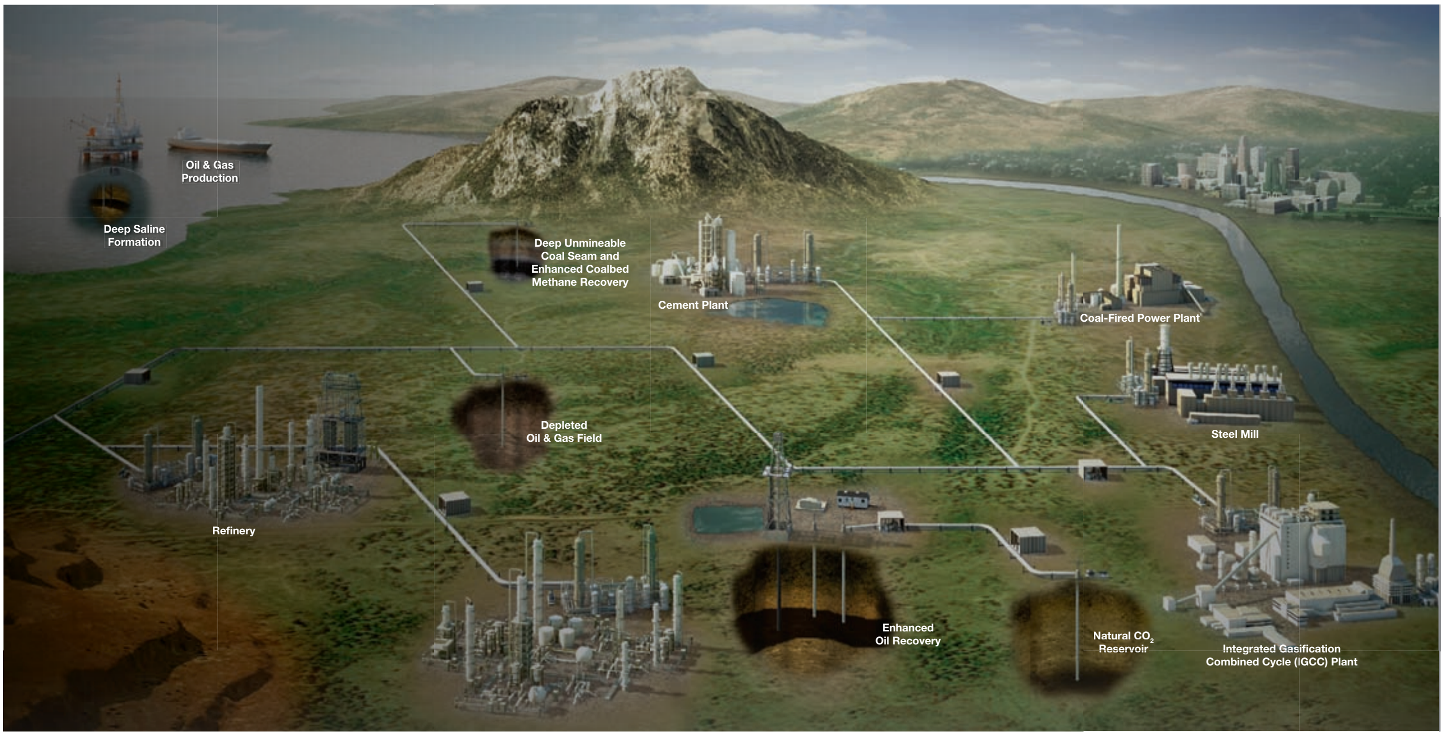
• The European Commission updated its TEN-E regulation to make geological CO2 storage infrastructure eligible to receive Connecting Europe Facility subsidies.

• Korea will invest up to $2 billion in CCUS projects by 2030.

These tax incentives and other governmental support measures are enough to encourage expanded CCUS activities. However, they're not a sustainable way for businesses to operate at the scale required to reach net zero objectives.

This global challenge to reach net zero emissions is the biggest one to CCUS, as many countries are not yet industrialized and cannot justify CCUS policies.

Companies cannot pursue environmental strategies simply because they're virtuous; the financial costs are too great to bear long-term. They need equipment, systems and technological advancements that make it possible for CCUS to become an economic value-add, instead of depending on governmental subsidies or tax credits.



CCUS flow control equipment: Pumps, seals, valves and automation

CCUS flow control equipment

Examples of equipment needed for carbon capture, storage and transportation include:

Pumps and seals

1. API 610 pumps
2. ISO and ASME (ANSI) chemical process pumps; mechanical seals

1. 1: capture and process
2. 2: pipeline (mainline)
3. 3: pipeline (booster)
4. 4: pipeline (injection)

Isolation valves, control valves and automation

3. 1: capture and process
4. 2, 3, 4: transportation and storage

Successfully lead CCUS projects with an expert partner

To accomplish your energy transition objectives, you'll need more than just an equipment supplier. Choose an ideal partner with the right products, engineering prowess, service and industry expertise to help your company identify opportunities to enhance CCUS process efficiency and cost-effectiveness.

Look for successful experience in developing and implementing flow control systems for capturing, transporting and storing CO2. These experts will understand how pumps, valves and seals should work in complete systems. As a result, they can help you engineer, design, commission and maintain end-to-end CCUS solutions so they perform optimally to achieve your company's decarbonization and business objectives.

Steven King is a member of the Energy Transition Group at Flowserve and an expert in carbon capture, utilization and storage (CCUS). Viswadeb Ganguly is the director of application development and strategic partnership at Flowserve.

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More information

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Titanium and Carbon Fibre: material solutions for underground CO2 storage

CRA-Tubulars have developed a temperature, pressure and corrosion resistant Titanium lined Composite Tubular that offers significant advantages for CO2 injection applications and is being supported by Shell through its GameChanger program.

Carbon capture and storage spending is set to quadruple by 2025, with cumulative global expenditure over the next three years topping $50 billion. There are 56 commercial CCUS projects already in operation globally, with additional 140 CCUS plants to open by 2025, capturing at least 150 million tpa of CO2.

Compared to traditional energy projects, there are various additional challenges to develop integrated CCUS projects economically whilst meeting technical and integrity requirements. Major Energy Companies are supporting innovation to develop solutions to meet those challenges. Shell recently partnered with Dutch Technology start-up, CRA-Tubulars, through their GameChanger program for the Titanium lined Composite Tubulars (TCT) to improve injecting CO2 in subsurface wells.

This unique development uses the high strength of Carbon Fiber Reinforced Composites whilst avoiding permeation of well effluent with a Titanium liner whilst meeting API-5C industry standards and dimensions. This idea gives Shell so much confidence in this development it is both financially and technically supporting the certification process.

One of the biggest challenges with CCUS is dealing with the corrosive nature of liquid CO2 if left with corrosive impurities. Carbon Steel and metal alloys can effectively manage dry and purified CO2 gas injection, however, contaminated streams require surface processing or injection will initiate CO2 corrosion downhole. This topside equipment to condition the CO2 stream requires additional investment with lots of maintenance to be effective. It adds some 40% to the energy consumption of a powerplant if installed at a CAPEX of several 100 million dollars. If this conditioning can be omitted by using high corrosion resistant tubing, the savings are high.

Another issue is the low temperature operating envelope CCUS wells are supposed to handle; However, low temperature performance (-100 ˚C), in steel and alloys causes brittleness. A reduction of surface CAPEX for integrated decarbonisation projects to dry and clean CO2 injection streams require a different solution.

Lastly, CCUS wells will be under high scrutiny for maintaining integrity throughout its lifecycle, requiring materials that are reliable for the full life of the well and comply with strict government regulatory requirements.

Prevent Corrosion Rather Than Treat Corrosion

Titanium has exceptional corrosion resistance due to its stable, continuous, and tightly adhered protective Titanium di-oxide layer that forms almost immediately on the metal's surface when exposed to air and moisture. It acts as a barrier to damage and corrosion. Ti-oxide is very smooth and Hydrophobic (fluid repellant). Flow performance simulations have shown a 15% fluid flow performance improvement compared with low Chrome alloy which has a surface roughness of 53 Micron; Titanium has a roughness of 0.59 micron.

Since Titanium does not foul by salts or other deposits nor suffers from surface roughness deterioration over time, this flow advantage remains. Industries, such as shipping, apply this unique property to avoid marine fouling and improve speed with lower fuel consumption.

Low temperature brittleness Due to Temperature swings

Another challenge comes from temperature swings, as the CO2 changes from liquid or critical state to gas entering the wellhead and the low pressure resulting from depleted reservoirs or in case of leaks to the outside during its operating life. A liquid CO2 leak expands into gas with a corresponding temperature drop (Joule-Thomson effect). Temperatures could drop as low as -50 ˚C potentially even to -70 ˚C. Most other metal alloys will have problems retaining their strength, unless choosing high nickel alloy tubing at a very high price.

When liquid carbon dioxide exhibits this phenomena in metal tubulars, it can cause cold brittleness cracking which leads to failures. Similar to a used CO2 filled fire extinguisher, the Joule-Thomson effect is responsible for the temperature drop.

Liquid carbon dioxide is the liquid state of carbon dioxide (CO2), which cannot occur under atmospheric pressure. It can only exist at a pressure above 5.1 atm (5.2 bar; 75 psi), under 31.1 ˚C (88.0 ˚F) (temperature of critical point) and above −56.6 ˚C (−69.9 ˚F) (temperature of triple point).

This wide temperature swing of CO2 causes expansion and contraction, which seel and alloys are sensitive to. When an injection or production string is anchored into the bottom-hole assembly, often an expansion joint is installed to allow compensation of the expansion and contraction phenomenon. This is a typical configuration for liquid streams, however in a gas well, elastomers are a potential leak path. So, what to do with a stream that will vacillate between liquid and gas states on its journey downhole and into a formation?

Figure 1 - Cross section of a bicycle tyre

Cutting Costs with New Materials

To address the above challenges, we need to find materials that are noncorrosive and can withstand dramatic temperature swings and manage the downhole stresses.

Using the strength of Carbonfibre reinforced composite in combination Titanium liner to manage corrosion and act as an non-permeaing barrier offers a solution, similar to a bicycle tube as shown in Fig 1.

Aero grade epoxy resin and Titanium have a long track record of use at very low temperatures. Jetfighters are exposed to -60 ˚C, reusable liquid rocket fuel tanks are exposed to -100 ˚C, whilst Titanium is used for liquid Helium storage tanks. No metal alloy comes close to these conditions.

This type of tubular is designed to withstand high levels of temperature swings without cracking or failing. Titanium is naturally inert to CO_2 corrosion (specifically in the presence of associated water or impurities) so no need for topside scrubbing equipment and the associated maintenance costs. No need for chemical injection systems and the ongoing costs of dosing over the life of the well. Sounds radical and science fiction to use Titanium for downhole application like this, is there a precedent?

Looking to the Skies to Solve Issues Downhole

Titanium and Carbon fiber reinforced composite has been the material of choice in demanding aerospace applications overcoming operating temperature ranges from sea level to outer space for decades. Breakthroughs in aerospace were achieved with Titanium and Carbonfibre reinforced composite. CO_2 sequestration can benefit from the technology and lessons learned from our high-flying cousins.

Certainly, Titanium is a miraculous material and that comes at a dear price. Aerospace applications use it in small quantities, but how could such a pricey material be cost effective to be used in OTCG applications in the Energy sector?

Repurposing Old Ideas with New Materials

Solid Titanium pipe would be costly, but it is economic when used as a thin inner layer in contact with the corrosive fluids and add high grade composite material as an outer layer to manage the tri-axial stresses. In every day life, tyres have a heavy rubber fiber tire gives strength and exterior protection to a thin inner tube of rubber. A similar approach works with Titanium and carbon fiber.

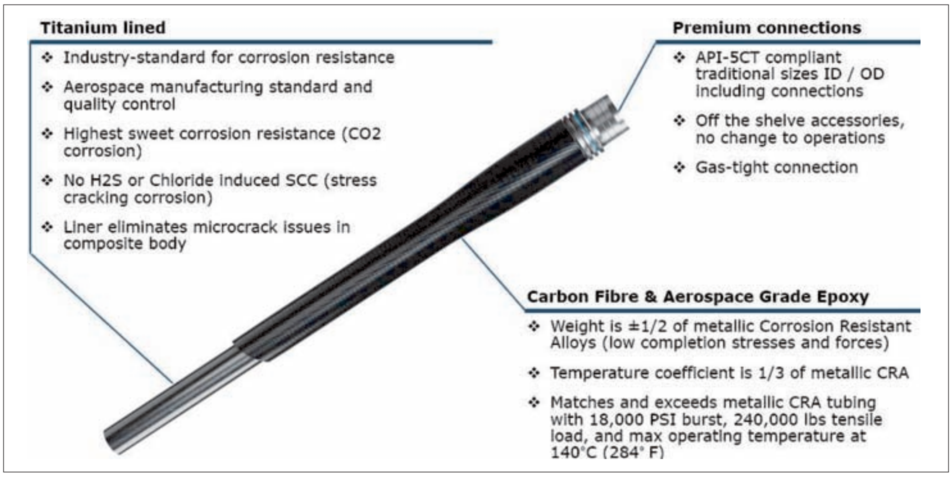


Figure 2: TCT features and benefits

When it comes to outer shell strength and protection, we can learn from aerospace; Carbon fiber reinforced composite is the proven material of choice to handle loads to and beyond Mach 3 and extreme temperature swings . Carbon fiber reinforced composite is remarkable in that the manufacturing process can address tri-axial stress in a bespoke fashion. The geometry of the carbon fiber strands can be adapted to individual applications. Unlike steel that adds strength through weight, carbon fiber maintains a light hook load while outperforming conventional metallic alloys. There is also the added benefit of flexibility and buoyancy that benefits deviated installations.

Carbon fiber reinforced composite has propelled the aerospace industry to new heights, and it very well can enable the energy industry to breakthroughs in the new energy landscape.

CCS project developers are now considering TCT in their concept design stages as an alternative for Corrosion Resistant Alloy (CRA) materials.

TCT – summary of benefits

• TCT is unique in that it can maintain strength and performance in such a wide temperature envelope (-76 ˚F to 284 ˚F). Not susceptible to cold brittleness cracking.

• TCT's Titanium liner is naturally inert to CO_2 with water or impurities induced corrosion and requires no topside scrubbing nor any additional chemical injection costs.

• TCT is rated up to 15,000 PSI for half the weight of steel equivalent tubing.

• TCT has a patented connector with Metal-to-Metal seal, is hydraulicly connected to eliminate galling, which will be API-5C5 and ISO 21329 certified by the end of 2022.

• TCT is API-5CT with regard to dimensions & Titanium liner and connector is NACE-MR0175 Compliant.

• TCT is made of Titanium whose pricing is more stable and accessible than nickel in today's market (under pressure from energy transition for EV's).

• TCT is corrosion resistant inside and out

• TCT is bespoke and can be engineered to individual well requirements.

If CCUS is going to be a major part of our decarbonization objectives, we need to find a way to contain CO_2 safely and securely. TCT by CRA-Tubulars is offering a disruptive technology that help overcome the challenges of carbon capture, sequestration, and lifecycle management.

CRA-Tubulars are in final stages of API-5CT and 5C5 certification and currently working with operators in field trials.

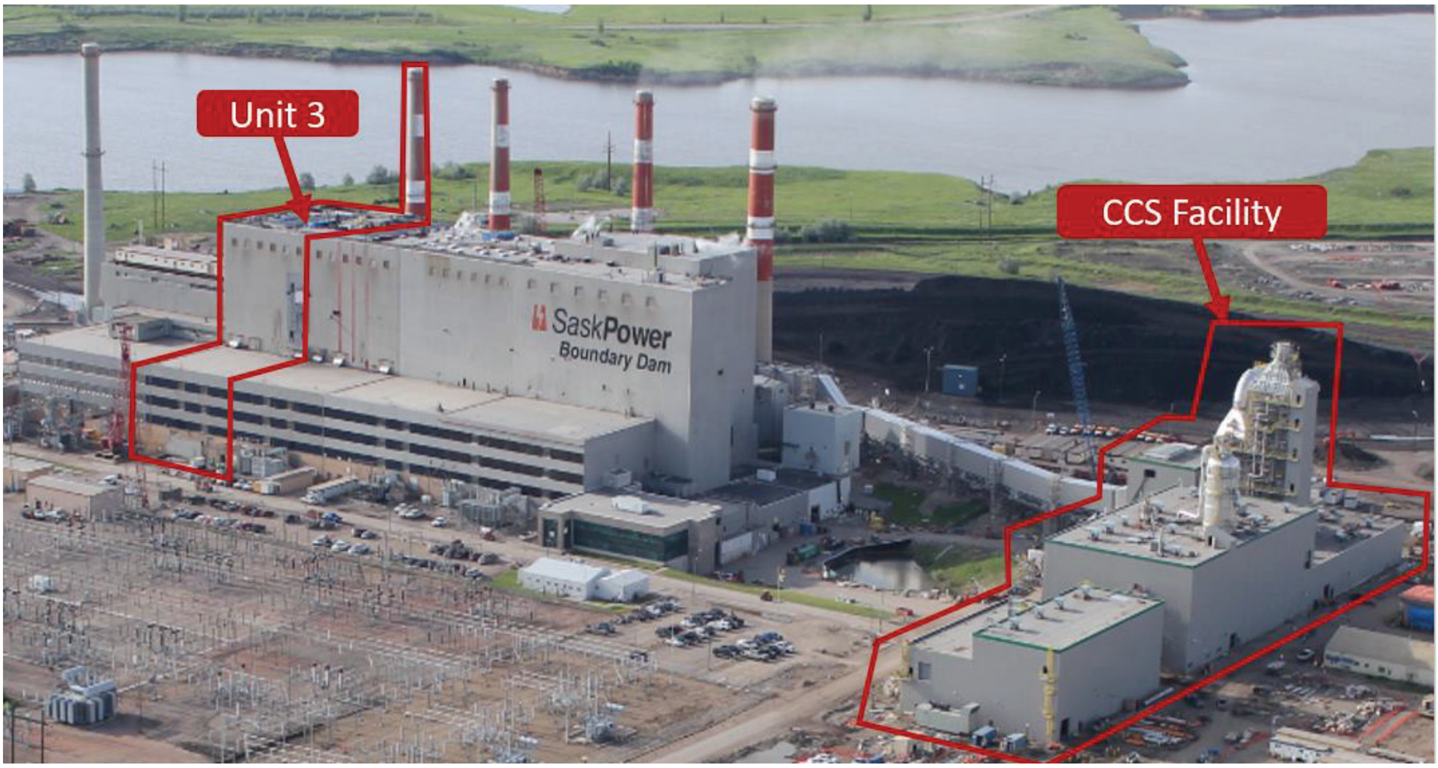
More information

www.cra-tubulars.com

Celebrating success and sharing lessons learned at Boundary Dam

As the world's first commercial carbon capture and storage (CCS) project, SaskPower's Boundary Dam Unit 3 (BD3) CCS facility is no stranger to outside attention.

By Prof Niall Mac Dowell, Acting Vice President, Strategy & Stakeholder Relations, International CCS Knowledge Centre



Boundary Dam continues to draw visitors from around the globe who are interested in seeing the world's first fully integrated CCS plant in action, and to learn more about how the project came to life.

This summer, the BD3 CCS facility was in the spotlight at the Carbon Sequestration Leadership Forum's annual mid-year technical meeting in Norway. I had the honour of representing SaskPower and the International CCS Knowledge Centre at the conference and accepting a Global Achievement Award on their behalf.

This pioneering project has now captured and safely stored more than 4.5 million tonnes of CO_2 since it began operation in 2014 – equivalent to taking 900,000 cars off the road for a year.

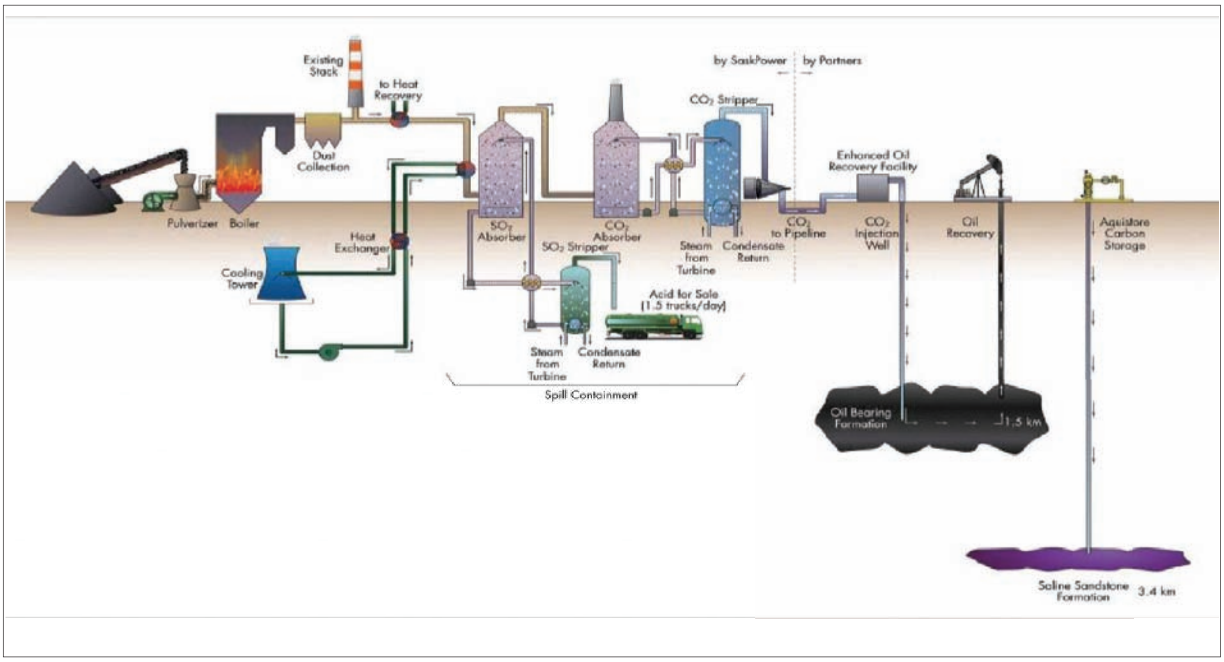
The conference provided an opportunity to celebrate this important achievement, and also to consolidate the knowledge gained from the BD3 CCS facility. The ambition is that these insights can enable the next generation of CCS projects to be even more successful.

From the outset, the BD3 CCS facility was a commercially driven project focused on continuing to deliver reliable and affordable electricity for the province of Saskatchewan by extending the life of the coal-fired Boundary Dam Power Station. The project was conceived in 2005, long before national carbon pricing and net zero emissions targets were in place.

While it was becoming clear that regulations to limit emissions from coal-fired power were on the horizon, the key drivers of the project were high natural gas prices that made a CCS retrofit more attractive than conversion to gas-fired generation, along with an existing market for CO_2 at the enhanced oil recovery (EOR) operations in the nearby Weyburn-Midale area.

Construction on the BD3 CCS facility and Unit 3 turbine upgrade began in 2011, generating more than 5 million person-hours of employment and a workforce of 1,700 people during peak construction. The CCS plant was delivered with only a few months' delay and only four per cent over budget — not bad at all for a first-of-a-kind project!

The capture plant began operation in 2014, and its performance to date shows that the capture plant is capable of its design capacity of removing 90 per cent of the CO_2 emissions from the exhaust sent from Unit 3 of the Boundary Dam Power Station. Throughout its operating life, the CCS facility is estimated to have captured an average of 89 per cent of the emissions in the flue gas it has processed, while the capture rate has exceeded 90 per cent last year (94 per cent) and so far this year (91 per cent).



The full chain CCS process

From an engineering perspective, this demonstrates the real-world application of CCS to provide substantial greenhouse gas reductions from power generation and other heavy-emitting industrial sectors.

There are also significant practical learnings from the operational experience accrued from BD3 that new CCS projects can leverage to improve performance, reduce costs and minimize the risks related to large-scale CCS deployment.

A critical lesson has been the ongoing challenge of managing fly ash in the flue gas from the coal-fired power plant. Knowing very well that there is a significant amount of fly ash in the flue gas going to the CCS plant, project engineers designed pre-treatment systems to remove 99.5 per cent of the ash before it enters the carbon capture process. Unfortunately, it turns out that even the residual 0.5 per cent caused serious problems as it accumulated over time and led to a variety of problems that affected the performance and efficiency of the CCS facility.

These challenges have been addressed over time, and this experience has shown that careful characterization of flue gas in the project design is vital to the successful performance of CCS facilities. Tackling this challenge has led to many learnings in how to manage particulates, and it has helped to refine the process in a way that is applicable a broad range of heavy industry sectors, such as cement.

Conversely, some systems — such as flue gas coolers and waste heat recovery systems — have performed better than anticipated. Further, some of the contingency planning and uncertainty surrounding new technology that was prudent for a first-of-its-kind facility has been shown to be unwarranted for newer projects thanks to our better understanding of the technical and regulatory risks of CCS projects.

Importantly, the BD3 CCS project has also generated extensive experience arising from the underground storage of CO2. The emissions that have been sent to long-standing EOR operations currently operated by Whitecap Resources, as well as the Aquistore project approximately three kilometres away from the Boundary Dam Power Station, have been the focus of significant long-term monitoring which has demonstrated that proper storage of CO2 in deep geologic formations is safe, permanent, and does not affect ground water or topsoil. This is key for providing confidence to investors and regulators in the development of future CCS projects.

The experience gained from the BD3 CCS facility is being deployed in a growing number of feasibility studies and consultation work the Knowledge Centre is conducting on CCS projects being considered across a wide range of industries, from power generation and cement manufacturing to mining, oil and gas production, chemical processing and hydrogen development.

Achieving and the world's ambitious climate goals won't happen without CCS and associated CO2 removal technologies. The BD3 CCS facility and other early iterations of CCS technology, such as the Quest and Alberta Carbon Trunk Line projects, have laid the groundwork for the massive expansion of CCS that is required to undertake the transition to cleaner energy sources in a socially and economically responsible manner.

The Government of Saskatchewan and SaskPower need to be given credit for investing in this ground-breaking project, and, along with BHP, for their strong commitment to sharing the knowledge and lessons learned with the world. Through the Knowledge Centre, the expertise and visionary leadership that brought BD3 to reality is now helping to advance the next generation of CCS projects around the globe, and is proving that the value of an internationally focused organization dedicated to the curation and sharing of this knowledge is profound.

Based in London, U.K., Niall Mac Dowell is the International CCS Knowledge Centre's Acting Vice-President of Strategy and Stakeholder Relations. Niall represents the Knowledge Centre amongst global decision makers and financiers to accelerate the deployment of CCS. He is also a professor in Energy Systems Engineering at Imperial College London.

More information

ccsknowledge.com

Progress Towards Operating a Viable Business in CO2

The report from the Carbon Dioxide Capture and Conversion (CO2CC) Program explores how to operate a viable business in CO2, from capturing at point sources or directly from air, to converting into a marketable commodity of value or storing it safely underground. It discusses the economic and environmental implications of a carbon management system, regional variability in carbon management components and how to optimize system builds to maximize economic benefit.

The report, "Progress Towards Operating a Viable Business in CO2" presents, considers and explores each element in the full CO2 supply chain and places major focus on developing a sensible methodology for selecting components in the carbon management value chain that connect in order to minimize costs and maximize revenue.

This report examines the question: with billions of tonnes of CO2 standing ready to exchange hands, how will this be achieved, and can it be done profitably? The pathways described in the report fall under the umbrella of carbon management, a catch-all term to describe, generally, engineered approaches to move CO2 between Earth's subsystems, with the ultimate goal of lowering the atmospheric stock of CO2.

The goal of the report is to equip the reader with enough detail about the various options in the CO2 supply chain to construct sensible options for starting and/or operating a business in CO2 management. The report discusses:

• Goals for the carbon management projects in terms of achieving emission reductions, net removals of carbon dioxide, or both

• Options for procuring CO2, e.g., capture or removal and storing CO2

Converting CO2 into a marketable commodity

How the procurement, storage and/or utilization components fit within corporate climate goals on a collective basis

The report explores how to operate a viable business in CO2, from capturing at point sources or directly from air, to converting into a marketable commodity of value or storing it safely underground. It also profiles several existing and promising new technical approaches and the report ends with a pair of case studies to illustrate how one might approach the formation of carbon management value chain using the tools provided in the report, and in two different contexts.

After an overview aimed at equipping the reader with a foundational knowledge in carbon management practices and technologies, key areas of concern, and metrics for evaluation, the reader is invited to explore the various areas of value in a carbon management chain. The final three chapters discuss progress in capture, utilization, and the entire value chain.

The most impactful method for decarbonisation of all value chains is summarised by sources with a range of boundary conditions in the respective life-cycle analyses. Different routes to a range of different substances are covered including, as appropriate, routes from bio-based, CO2-based and waste-polymer based feedstocks.

Key takeaways from the report

• Enhanced oil recovery is the dominant mechanism for support in CCS projects worldwide. Of the 21 active CCS projects, 16 are tied to EOR. This illustrates the importance of establishing a secure and stable off taker and consistent form of revenue.

• The most important attributes in successful CCS projects are low capital cost, high technical readiness, and credible project revenues. Projects with these traits have a higher chance of success. The EOR trend outlined above plays into these characteristics. High TRL (technical readiness level) projects have much lower risk but are often beset by incumbent competition.

• Carbon utilization remains expensive and will struggle to reach cost parity with incumbent routes. Elevated feedstock costs plus operational costs associated with conversion of CO2 are major cost drivers that place many utilization routes at a disadvantage so long as demand is market driven. It is difficult to quantify the impact of low carbon premiums, though this could help lower the barrier to entry for CO2-derived products.

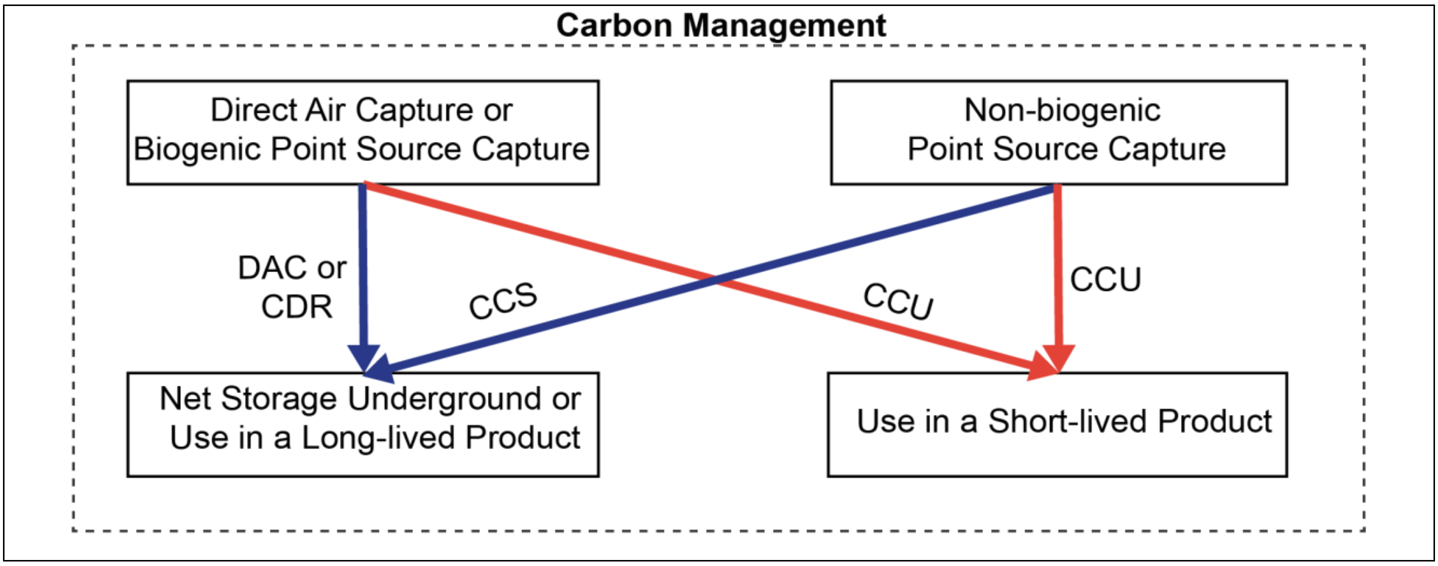
• CO2 storage remains less popular due to economic and political barriers. The lack of financial incentive to store CO2 underground is a major contributor to the lack of CCS projects that terminate in secure, geological storage. Political barriers, such as Class VI permitting in the US contribute to the disproportionate number of projects associated with EOR.

Scope of the report

It is important to understand whether a company is directly involved in the capturing of carbon or whether it is in the supply chain of using the carbon (companies that are involved in both are modeled using sum-of-the-parts).

Attributes that can impact CCS project success include:

• Engineering economics (plant siting and capital costs)



\figure 1 - Schematic representation of the terminology used in the report. Source: Authors

• Financial Credibility revenues and incentives)

• Local Political Features (population and institutional setting)

• Broader Political Features (regulatory challenges and public opposition)

Carbon capture is most practical and energy-efficient at large point sources, such as fossil fuel or biomass energy facilities, natural gas electric power generation plants, industries with major CO2 emissions, natural gas processing, synthetic fuel plants, fossil fuel-based hydrogen production plants, cement plants, and steel making facilities.

It is important to distinguish between CCS or avoiding/reducing the amount of CO2 that is released to the atmosphere, and carbon dioxide removal (CDR), where CO2 is physically removed from the atmosphere resulting in a net lowering of the atmospheric stock of carbon dioxide.

Carbon utilization is a solution proposed to address the issue of local CO2 storage while potentially generating useful revenue by converting CO2 into valuable products. This approach has great potential to subsidize the costs associated with carbon management and even generate positive revenue, and can be realized through several different pathways. However, only a rigorous life-cycle analysis can reveal if the pathway results in emission reductions or net removal of carbon over a significant time period.

The report goes on to summarise CCUS supply chain economics and cost levers in CO2 utilization pathways. It then gives an overview of the current status of commercial CCS projects and commercial CDR projects followed by a review of the status of CO2 storage.

Key conclusions

The findings of the report (see box text) have led the authors to the following conclusions:

• Political support can help to create a demand pull for carbon markets. The current market for CO2 utilization is 200 MtCO2/yr, a mere fraction of global carbon output. Most of this demand is earmarked for incumbent processes. Procurement of low carbon products can assist in creating demand and driving innovation in the utilization space.

• Major storage projects can help promote local momentum for carbon management. Dedicated storage projects, like the Northern Lights storage project in Norway, can act as an incubator for CCS deployment and development. Similar projects could arise in the US, strategically located to assume captured CO2 from nearby industries.

• Utilization should continue to be the dominant mechanism of CCS support over the next decade and until storage is ready. Policy can assist in transitioning utilization products to storage projects over time. It is important to deploy CCS rapidly and set projects down technical learning and cost curves. Utilization should continue to support CCS efforts until storage logistics, including infrastructure and political support emerge.

• Government support should rise to meet the incentive gap in carbon management practices. Subsidizing carbon management is a key strategy in developing these approaches, lowering costs across the space, and creating momentum in the market for CO2-derived goods.

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: 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/

Methanol and synthetic fuels rely on CO2 utilisation

The challenge to substitute refined products that are derived from crude oil with suitably convenient and cost-effective alternatives that have a sustainable environmental impact is reliant on CO2 utilisation. By Stephen B. Harrison, Managing Director, sbh4 consulting.

Liquid fuels are incredibly useful energy vectors due to their high energy density and ease of handling. Gasoline, diesel, aviation kerosene and heavy fuel oil have become the fuels of choice for cars, trucks, planes, and shipping.

Liquid fuels of a non-fossil origin can be produced using renewable electrical power to generate hydrogen which can be combined with captured CO2 to build hydrocarbon molecules and so-called e-fuels through Power to Liquid (PtL) technology. Thousands of tonnes per year of CO2 could be utilised in this way.

The Stena Germanica is the world's first ferry powered by methanol

E-fuels are built on CO2 utilisation

Use of solid oxide electrolysis (SOE) can consume steam and CO2 to yield syngas which can be converted to liquid hydrocarbons through established chemical pathways such as Fischer-Tropsch conversion. Introduction of steam to the SOE means that water molecules are delivered to the electrolyser in a highly energised state and about 25% less electrical power is required to split them than when using low temperature electrolysis, such as a PEM or alkaline electrolyser.

On refineries and thermal power plants, there is often waste heat or excess steam that can be fed to a solid oxide electrolyser to reduce the electrical power consumption of the PtL process. If no waste heat is available, it may be preferable to use a PEM or alkaline electrolyser to generate hydrogen and react that with captured CO2 using the reverse water gas shift reaction to yield carbon monoxide which can be blended with more hydrogen to from syngas which can be converted to the required liquid hydrocarbons.

In both the SOE and low temperature electrolysis pathways, the required CO2 can be captured from point source emissions or direct air capture facilities. The use of captured CO2 reduces the overall CO2 impact of SAF and introduces an element of circularity into the value chain. Production of SAF through PtL is an emerging CO2 utilisation application that could consume thousands of tonnes per year of captured CO2.

e-Kerosene for aviation

Synthetic aviation fuel (SAF) is a broad term meaning that the jet fuel has been derived from non-fossil fuel origins. The largest source of SAF today is biofuel. Plant oils are refined to yield an aviation fuel that has been proven to be suitable for high altitude operation on jet aircraft.

More than 300,000 commercial flights have used SAF in the past 5 years. It has been used by more than 40 airlines with 13 major airports able to refuel aircraft with SAF. By the end of 2023, Neste plans to produce around 1,500,000 tonnes of SAF each year. BP also has growth aspirations for SAF and already incorporates used frying oils into their aviation fuel production at their refinery in Lingen, Germany.

SAF is made from waste frying oils through a process called hydrodeoxygenation. The resultant molecules are then isomerised to achieve the required property of the fuel. During this process, the hydrocarbon structure is branched. Distillation follows the isomerization to ensure the SAF meets international standards, such as ASTM D756609 which specifies the requirements of aviation turbine fuel.

Whilst biofuels dominate SAF production today, the next generation of SAF will be based on technology known as power to liquids, or PtL. Hydrogen or syngas will be produced on electrolysers fed with renewable electrical power.

e-Methanol for shipping

Grey methanol is produced on about 100 plants worldwide with an annual capacity of around 140 million tonnes. About 100 ports worldwide have methanol storage. Despite the existence of some methanol bunkering facilities, extensive use of e-methanol as a maritime fuel in the future would require a significant ramp up in bunkering infrastructure.

E-methanol using captured CO2 will be produced in the HyNL project in Eemshaven, northeast NL. CO2 will be captured from the flue gas of the local waste to energy plant operated by EEW at Delfzijl. The CO2 will be utilised to make e-methanol by OCI BioMCN in combination with green hydrogen from electrolysers fed with renewable windpower. The resultant e-methanol will be used as a bunker fuel for shipping.

e-Methanol for trucks

Diesel has been the default fuel for trucks and buses for decades. Similarly, heavy fuel oil has been the maritime fuel of choice. Methanol, like diesel and heavy fuel oil, does produce CO2 emissions during combustion. However, since e-methanol is made from captured CO2 the emissions are carbon neutral: e-methanol is not a fossil fuel.

Diesel can begin to freeze at around -10 to -15 °C. Heavy fuel oil must be heated to ensure that it remains pourable. Methanol exhibits much better low temperature pour properties than diesel and heavy fuel oil and it remains usable in the harshest of winter conditions down -40 °C and below. It is therefore an ideal fuel for use on trucks operating all year round in northern Europe and Canada, or for emerging arctic shipping routes.

The wide temperature range over which methanol is a liquid makes it ideal for storage at ambient temperature and pressure since there is no need to use refrigerated storage to maintain methanol as a liquid. Neither must the storage vessel be capable of withstanding high pressure.

More information

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sbh4.de

ExxonMobil signs 'biggest CCS contract'

CF Industries has entered into a commercial agreement with ExxonMobil to capture and permanently store up to 2 million metric tons of CO2 emissions annually from its Louisiana manufacturing complex.

Start-up for the project is scheduled for early 2025 and supports Louisiana's objective of net zero CO2 emissions by 2050.

As previously announced, CF Industries is investing $200 million to build a CO2 dehydration and compression unit at its Donaldsonville, Louisiana, facility to enable captured CO2 to be transported and stored. ExxonMobil will then transport and permanently store the captured CO2 in secure geologic storage it owns in Vermilion Parish.

As part of the project, ExxonMobil has signed an agreement with EnLink Midstream to use EnLink's transportation network to deliver CO2 to permanent geologic storage. The 2 million metric tons of emissions captured annually will be equivalent to replacing approximately 700,000 gasoline-powered cars with electric vehicles.

"This landmark project represents large-scale, real-world progress on the journey to decarbonize the global economy," said Dan Ammann, president of ExxonMobil Low Carbon Solutions. "ExxonMobil is providing a critical and scalable solution to reduce CO2 emissions, and we're ready to offer the same service to other large industrial customers in the state of Louisiana and around the world. We're encouraged by the momentum we see building for projects of this kind, thanks to supportive policies such as the Inflation Reduction Act."

CF Industries' Donaldsonville, Louisiana, facility (Image: CF Industries)

CF Industries expects to market up to 1.7 million metric tons of blue ammonia annually. A chemical process is considered "blue" when CO2 emissions are captured before their release into the air, making the process more carbon-neutral. Demand for blue ammonia is expected to grow significantly as a decarbonized energy source for hard-to-abate industries, both for its hydrogen content and as a fuel itself, because ammonia's components – nitrogen and hydrogen – do not emit carbon when combusted.

"EnLink has a system of over 4,000 miles of pipeline already in the ground in Louisiana," said Jesse Arenivas, Chief Executive Officer of EnLink. "Utilizing this extensive network enables us to provide the most timely and cost-effective solution to CO2 transportation, with a significantly lower environmental impact. Because of this, EnLink is uniquely positioned to be the CO2 transportation provider of choice in Louisiana's Mississippi River corridor, which is a hub of industrial activity that is important to our economy. We look forward to working with ExxonMobil to help CF Industries and the State of Louisiana reach their decarbonization goals."

More information

www.cfindustries.com

North Sea Transition Deal and reduced costs can help spur UK CCS industry

The UK can secure a vital role in decarbonisation efforts at home and abroad by capitalising on new technology to reduce costs and developing a robust CO2 transport and storage network.
By Carlo Procaccini, co-chair of the Technology Leadership Board, and Head of Technology at the North Sea Transition Authority

To achieve net zero by 2050, the UK must roll out carbon capture and storage quickly and at scale. This is not only recognised by influential advisory bodies, such as the Climate Change Committee, it is also reflected in government policy, importantly.

The North Sea Transition Deal (NSTD), signed by the UK government and upstream oil and gas industry in 2021, committed the sector to invest £2-3 billion to support the development of four carbon capture and storage (CCS) clusters by 2030.

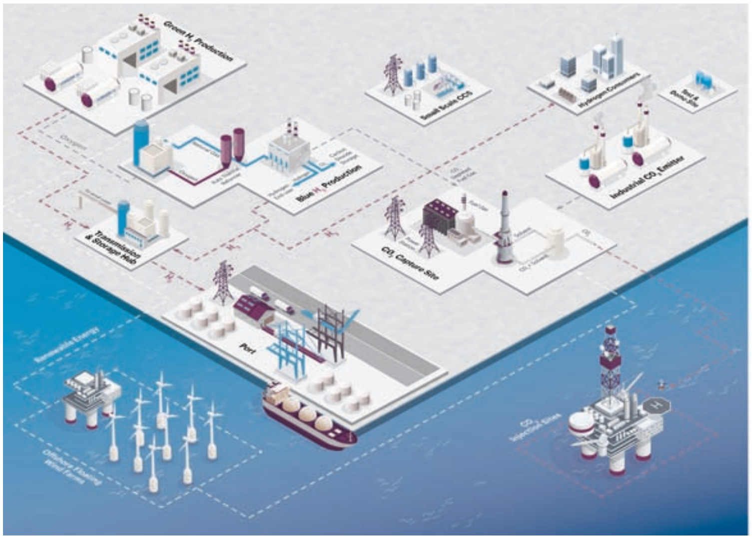
These industrial decarbonisation schemes will store 20 to 30 megatonnes of CO2 per year by 2030, the equivalent of taking 12 million cars off the UK roads, and support up to 50,000 jobs. With some adaptation, technologies used by the UK oil and gas sector's supply chain should have an important part to play.

CCS technologies are still relatively new and expensive, potentially limiting their growth potential. This must be addressed quickly.

A new report by the industry Technology Leadership Board, Net Zero Technology Centre and Accenture highlights the need to accelerate innovation, enhance existing technologies and develop new solutions to achieve the NSTD goals for CCS, hydrogen and platform electrification.

The study, Technology Driving Green Energy Growth, found that the cost of capturing CO2 could be cut by 40% through lower power requirements. However, this does require disruptive technologies, such as capture methods based on amine blends or non-amine solvents, which do not require energy intensive steam generation.

Alternative adsorbent materials with high adsorption and desorption rates and higher durability can also contribute to greater energy efficiency. And, of course, using renewable power for the CCS process can further reduce energy intensity and emissions.



The deployment of the first CCS clusters by 2025 could be accelerated by employing small-scale, modular CCS solutions, such as the cement industry's advanced zero-carbon kilns and power plants based on the Allam cycle. These systems do not require separate equipment for the CO2 capture process – they can be integrated into the main units, reducing total capital expenditure by as much as 50%.

CCS equipment design and specifications will also need to be standardised across industry to avoid supply chain bottlenecks and further reduce costs. Doing so would also help to anchor the CCS supply chain in the UK, creating and safeguarding employment, and helping companies to grow.

Beyond CO2 capture, an additional 30% of overall CCS capex and operating expenditure will come from CO2 compression. Developing low-cost compressors and liquefaction designs will be essential to reduce power demand and the cost of transport and storage.

Monitoring, measurement and verification (MMV) is another critical area – it ensures CO2 is safely sequestered underground without accidental releases.

CCS project developers can leverage the UK oil and gas supply chain for MMV technologies, including CO2 metering, well surveillance and 4D seismic, but these will need to be improved and adapted for use in carbon storage schemes.

A combination of advanced metering, downhole monitoring, autonomous underwater vehicles, and seismic technologies can improve storage monitoring and take 50% off the cost of MMV.

If the UK can seize these opportunities and develop a robust and efficient CCS transport and storage network, it will also be able to use its surplus storage capacity to store CO2 shipped in from overseas.

This would give the UK a vital role in the decarbonisation efforts of sectors in other countries and regions. It is an ambitious and exciting vision and one that the UK should pursue with serious intent and sharp focus.

More information

www.nstauthority.co.uk

Read the study:

www.netzerotc.com

Global Carbon Capture capacity to rise sixfold by 2030

The global capacity for carbon capture in 2030 is set to increase sixfold from today's level, to 279 million tons of CO2 captured per year, according to research company BloombergNEF's 2022 CCUS Market Outlook.

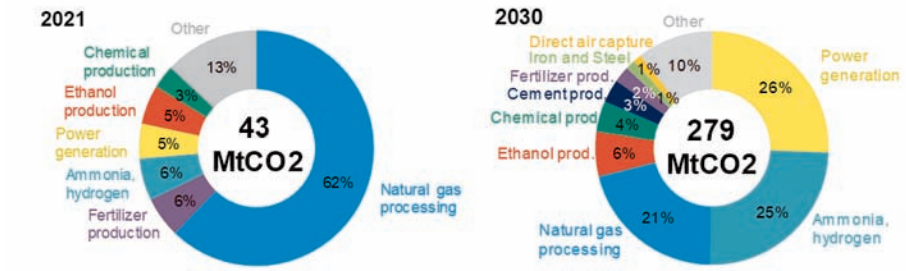
Drastic growth in the market has led to a 44% increase in expected 2030 capacity compared to last year's outlook.

Carbon capture, utilization and storage (CCUS) is a key technology needed to decarbonize hard-to-abate sectors such as petrochemicals and cement, and to provide 24/7 clean power through gas plants fitted with capture equipment.

Still, despite significant acceleration in the sector in the past two years, the world's capacity for carbon capture is not being deployed fast enough to meet climate goals at the end of the decade, according to BNEF research.

Today, most capture capacity is used to collect carbon dioxide (CO2) from natural gas processing plants and used for enhanced oil recovery. By 2030, most capture capacity will be used for the power sector, for the manufacture of low-carbon hydrogen and ammonia, or to abate emissions from industrial sources (Figure 1).

Figure 1: Global carbon capture capacity by source, 2021 and 2030



Source: BloombergNEF.

The amount of CO2 being captured today is 43 million tons, or 0.1% of global emissions. If all the likely projects that have been announced come online, there would be 279 million tons of CO2 captured every year by 2030, accounting for 0.6% of today's emissions.

The destination for captured CO2 is also due to change significantly from the status quo. In 2021, some 73% of captured CO2 went to enhanced oil recovery operations. By 2030, storing CO2 deep underground will overtake oil recovery as the primary destination for CO2, with 66% of it going to dedicated storage sites (Figure 2).

This change is being driven by legislation that incentivizes storage over CO2 utilization, and by projects that aim to use carbon capture and storage (CCS) as a decarbonization route and must store the CO2 to meet their goals.

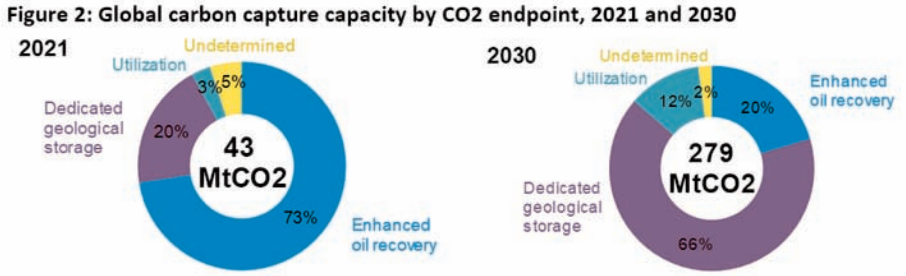
"CCS is starting to overcome its bad reputation," said David Lluis Madrid, CCUS analyst at BNEF and lead author of the report. "It is now being deployed as a decarbonization tool, which means the CO2 needs to be stored. A lack of CO2 transport and storage sites near industrial or power generation point sources could be a major bottleneck to CCS development. But we are already seeing a big increase in these projects to serve that need."

Despite rapid growth in capture project announcements, the industry is still far from making a dent in global emissions. In order to be on track for net-zero and less than 2 degrees Celsius of warming by 2050, between one and two billion tons of CO2 would need to be captured in 2030, an order of magnitude higher than current plans. Legislators have recognized this mismatch and are ramping up their support for the industry.

The Inflation Reduction Act passed in the US increased tax credits for CCUS by 70%, making a viable business case for the technology in petrochemicals, steel, cement, and in some regions, power. Incentives like these mean that countries, such as the US, will remain global leaders for CCUS.

The US tax credits are now very generous, and the law is set to supercharge project announcements in the ethanol and petrochemicals sectors, as well as in direct air capture (DAC), to provide high-quality carbon offsets for the voluntary market.

Figure 2: Global carbon capture capacity by CO2 endpoint, 2021 and 2030



Source: BloombergNEF.

"This 279 million tons of capacity in 2030 is just the tip of the iceberg," said Julia Attwood, head of sustainable materials at BNEF. "We haven't seen the full impact of these credits yet, making this outlook a fairly conservative view of the future of carbon capture and storage."

"We expect to see another jump in announcements in 2022, especially in the US as developers there rush to make sure they meet the 2032 deadline for credits."

Even before this legislation, direct air capture was booming. Venture capitalists have poured more than $1 billion into the technology this year – more than the total amount invested in DAC up to this point.

Companies are already becoming more ambitious in their projects. Soon after the US passed its Inflation Reduction Act, a project to build five million tons of carbon removal capacity in Wyoming was announced.

"In many industries, CCS is a sunset option to get high emissions assets to the end of their life," said Madrid. "But removals are present in every long-term net-zero model. They are here to stay."

More information

Read the full report at:

www.bnef.com

World's first commercial scale CO2-to-methanol plant starts production

Based in Anyang, Henan Province, China, the facility is the first of its type in the world to produce methanol at this scale from captured waste carbon dioxide and hydrogen gases.

The plant's production process is based on the Emissions-to-Liquids (ETL) technology developed by Carbon Recycling International (CRI) and first demonstrated in Iceland. The new facility can capture 160,000 tonnes of carbon dioxide emissions a year, which is equivalent to taking more than 60,000 cars off the road. The captured carbon dioxide is then reacted with the recovered hydrogen in CRI's proprietary ETL reactor system with the capacity to produce 110,000 tonnes of methanol per year.

The successful start-up marks the end of a two-year project and months-long commissioning phase. Following sign-off by the CRI's technical service team, the plant operations are now in the hands of Shunli, the project company (majority-owned by the Henan Shuncheng Group).

This flagship plant represents the achievement of an important milestone in the ongoing development of carbon capture and utilization (CCU) technology as well as the progression in industry towards a circular carbon economy.

At the heart of the process is CRI's bespoke reactor that uses specialised catalysts to convert the carbon and hydrogen feed gases into low carbon-intensity methanol. The entire unit weighs around 84 tonnes or the weight of a fully-loaded Boeing 737. The reactor is mounted in a dedicated steel frame and connected to a specialised gas compressor and a distillation column that is just under 70-meters-tall.

The Emissions-to-Liquids technology is being used to convert 160,000 tonnes of CO2 into methanol each year (Image: CRI)

The ETL process uses emissions that would have otherwise been released into the atmosphere, producing liquid methanol — from carbon dioxide that is recovered from existing lime production emissions and hydrogen that is recovered from coke-oven gas. Methanol production and use has grown rapidly in China in recent years and this new production method offers an alternative to the traditional coal-based methanol currently manufactured in China, reducing greenhouse gas emissions and improving air quality.

Björk Kristjánsdóttir, CEO of CRI, emphasizes the importance of the plant's start-up, "We are proud to have successfully realized this important project and to bring our environmentally friendly, ETL technology into the global market. We take great pleasure in being able to offer our proven technical solution to produce a valuable product directly from waste streams. This can support large scale reduction of CO2 emissions and help facilitate the energy transition. With increased demand for such solutions, we look forward to continuing to make meaningful impact by deploying the technology with our current and future partners."

CRI's second project in China was announced last year and is already well on its way. It is expected to come online in the second half of 2023.

More information

www.carbonrecycling.is

Projects and policy news

£28m carbon capture generation scheme underway in UK

www.smithbrothersltd.co.uk
lmph-uk.com

The £28 million carbon capture and power generation plant – a joint venture between Landmark Power Holdings and Victory Hill Capital Advisors LLC – represents a commitment to power generation projects in the UK, with the first located in Rhodesia, Nottinghamshire

Specialist contracting firm Smith Brothers, has 'broken ground' on a UK-first carbon capture power generation project designed to support the country's transition towards more sustainable energy sources.

The Rhodesia plant is the first to be developed under Landmark Power Holdings' FlexPower Plus concept for flexible power generation with natural gas-powered engines and waste heat recovery, for increased energy efficiency and carbon capture technology.

The project brings together some of the world's leading industrial technology companies as part of the delivery, including Rolls Royce/Yellow Power, Swedish industrial group Climeon, Mitsubishi Heavy Industries Group subsidiary Turboden based in Italy, and privately-held Swiss Carbon Capture technology manufacturer, ASCO Carbon Dioxide Ltd.

"There are over 40,000 people in Worksop, and once operational, this site will have the capacity to provide power for approximately 25% of those living in the area," explained Mick Avison, founder and managing director of Landmark Power Holdings.

"Household energy will be created using natural gas, while the plant will capture and turn waste into food-grade carbon dioxide, sold through a food-grade CO2 offtake agreement with BUSE Gas Solutions – one of the global leading suppliers in the industrial and speciality gas markets."

The project is expected to go into commercial operation in Q2 2023 and will produce highly efficient flexible power, which will help secure the supply within the UK electricity grid and contribute to the growth in renewable generation capacity.

Capable of powering 9% of the properties in Bassetlaw, chairman of Bassetlaw District Council, Madelaine Richardson said, "Having the first decarbonisation power plant is a great asset for us. Partnerships and investments such as these are important for sustainable outcomes, plus making the most of the waste products is of particular interest to me, as I continue to explore how we better tackle the challenges of all forms of waste, in our area."

John Smith co-founder and joint chairman of Smith Brothers concluded: "This carbon capture project is the first of its kind in the UK and represents the future of power generation – if we're to achieve our nation's sustainability ambitions. This week's breaking ground is a milestone moment, and we're proud to be part of the powerhouse of organisations which are committed to delivering on this vital scheme."

'CCUS 2022: Time to Deliver' showcases huge appetite for CCUS

www.ccsassociation.org

The conference was sponsored by 13 companies from across the CCUS value chain, including platinum sponsors SSE Thermal, GE and Equinor as well as Carbon Clean sponsoring the conference drinks reception.

The Carbon Capture & Storage Association (CCSA) held its annual two-day conference 'CCUS 2022: Time to Deliver'. This year's conference saw leaders of the Carbon Capture, Utilisation and Storage (CCUS) industry – technology developers, end-users, governments and regulators, research, legal and financial sectors – address over 400 delegates about latest developments in this rapidly evolving sector.

Ruth Herbert, Chief Executive at the CCSA, said, "It was a great pleasure to see so many industry experts, NGOs and policy leaders at our conference, discussing key actions that are needed in the UK, EU and internationally to enable CCUS to play its vital role in tackling climate change and driving economic growth, through transitioning our industrial regions to Net Zero."

"I would like to thank all our delegates, speakers, and conference sponsors for helping to not only make this event possible but for championing CCUS on a daily basis by moving forward with their plans. Industry leaders are investing millions of pounds of capital to ensure we are on track to decarbonise our economy in line with the Paris Agreement goal to limit global warming to 1.5°c. We now need to see decisive action from the new Prime Minister to maintain the UK's lead in this area by putting in place the legislation and funding the cluster sequencing programme to make this industry a reality."

The conference heard from Graham Stuart, Minister of State for Climate, who spoke about the important role CCUS has to play in delivering the government's Net Zero strategy, saying "Deploying CCUS technology is not only an intelligent way of reaching Net Zero, it is vital."

"By transforming sectors like cement and chemicals, we'll create low carbon, super place clusters up and down the country and our important heavy industries won't wither on the vine and die but find new life in a decarbonised world. That's why deploying CCUS and hydrogen technology at scale formed an important part of the growth plan we announced in September."

Aramco announces $1.5bn Sustainability Fund

www.aramco.com

The fund plans to invest in technologies that support the Company's announced net-zero 2050 ambition as well as development of new lower-carbon fuels.

The fund's initial focus areas will include carbon capture and storage, greenhouse gas emissions, energy efficiency, nature-based climate solutions, digital sustainability, hydrogen, ammonia and synthetic fuels. The fund will target investments globally.

Aramco Chairman, H.E. Yasir O. Al-Rumayyan, said, "Climate change is a critical issue, which is why sustainability is well-integrated in Aramco's strategy and investment decisions."

"The Company is harnessing innovation and collaboration as it seeks long-term solutions to global energy challenges. By driving large-scale investments and building key domestic, regional and international partnerships, Aramco aims to enable a stable and inclusive energy transition that meets the world's need for energy with lower emissions."

Leilac announces global licence agreement with Heidelberg Materials

Cement and lime decarbonisation technology company, Leilac,has signed a licence agreement for the use of its decarbonisation technology with Heidelberg Materials, one of the world's largest cement producers and building materials companies.

The licence agreement applies to any Heidelberg Materials facility where the Leilac decarbonisation technology is installed. Heidelberg Materials operates 149 cement plants globally.

Leilac CEO, Daniel Rennie described the agreement with Heidelberg Materials as a key milestone in the development and commercialisation of the Leilac technology. "Together, Leilac and Heidelberg Materials continue to de-risk, prove and scale Leilac's decarbonisation technology."

"The agreement is an important step in our journey towards providing cement and lime producers with access to a low cost carbon abatement solution, allowing them to take urgent action against climate change and protect their industries' jobs and prosperity."

The operational Leilac-1 pilot plant at Heidelberg Materials facility in Lixhe, Belgium

Leilac's technology

Leilac, a 93% owned Calix subsidiary with 7% owned by Carbon Direct, is a collaborative technology partner enabling sustainable decarbonisation of cement and lime.

Leilac's unique technology is being developed to efficiently separate and capture unavoidable CO2 process emissions in cement and lime production, with no additional chemicals or processes.

Leilac's modular, scalable and retrofittable technology is designed to be energy agnostic and electrification ready, providing viable, flexible and economical pathways to carbon free cement and lime.

Leilac CEO, Daniel Rennie said, "Scalable and low cost decarbonisation technology solutions for cement and lime are essential to ensuring a just transition to net zero that balances social, economic and environmental sustainability.

Heidelberg Materials is a founding and key member of a consortium of companies and institutions partnering to develop and apply the Leilac technology. The global licence agreement with Heidelberg Materials follows many years of close collaboration and partnership.

Leilac-1, located at Heidelberg Materials' plant in Lixhe, Belgium, is a pilot plant supported by EU funding, with a capacity to capture 25,000 tonnes per annum of CO2. In operation since 2019, Leilac-1 has successfully piloted separation of unavoidable process CO2 emissions from cement and lime.

Leilac-2, also supported by EU funding and due to commence construction in 2023, will be located at Heidelberg Materials' plant in Hanover, Germany. Once retrofitted to Heidelberg Materials' operational plant, Leilac-2 should have the capacity to capture 100,000 tonnes per annum of CO2 or 20% of a typical cement plant's emissions, and is aiming to have a low CO2 capture cost. The project paves the way for future deployments of the Leilac technology that scale to capture all of the unavoidable process CO2.

Cement and lime provide the foundations of our societies and economies. They are also amongst the largest industrial contributors to climate change, accounting for 8% of global CO2 emissions.

Unlike other industries, most of the CO2 produced in the manufacture of cement and lime is unavoidable. It is estimated that 1.37 billion tonnes of CO2 from cement will need to be captured and stored annually by 2050.

With no additional chemicals or processes, Leilac's technology efficiently separates CO2 process emissions for use or storage. It aims to be energy agnostic and electrification ready, providing flexible and economical pathways to net zero cement. The Leilac technology's unique, modular design is being designed to be retrofitted to cement plants with minimal operational impact.

More information

www.leilac.com

www.heidelbergmaterials.com

Breakthrough discovery in carbon conversion for ethylene production

A team of researchers at University of Illinois Chicago has discovered a way to convert 100% of CO2 captured from industrial exhaust into ethylene, a key building block for plastic products.

While researchers have been exploring the possibility of converting carbon dioxide to ethylene for more than a decade, the UIC team's approach is the first to achieve nearly 100% utilization of carbon dioxide to produce hydrocarbons.

Their system uses electrolysis to transform captured carbon dioxide gas into high purity ethylene, with other carbon-based fuels and oxygen as byproducts.

The process can convert up to 6 metric tons of carbon dioxide into 1 metric ton of ethylene, recycling almost all carbon dioxide captured. Because the system runs on electricity, the use of renewable energy can make the process carbon negative.

According to Meenesh Singh, his team's approach surpasses the net-zero carbon goal of other carbon capture and conversion technologies by actually reducing the total carbon dioxide output from industry. "It's a net negative," he said.

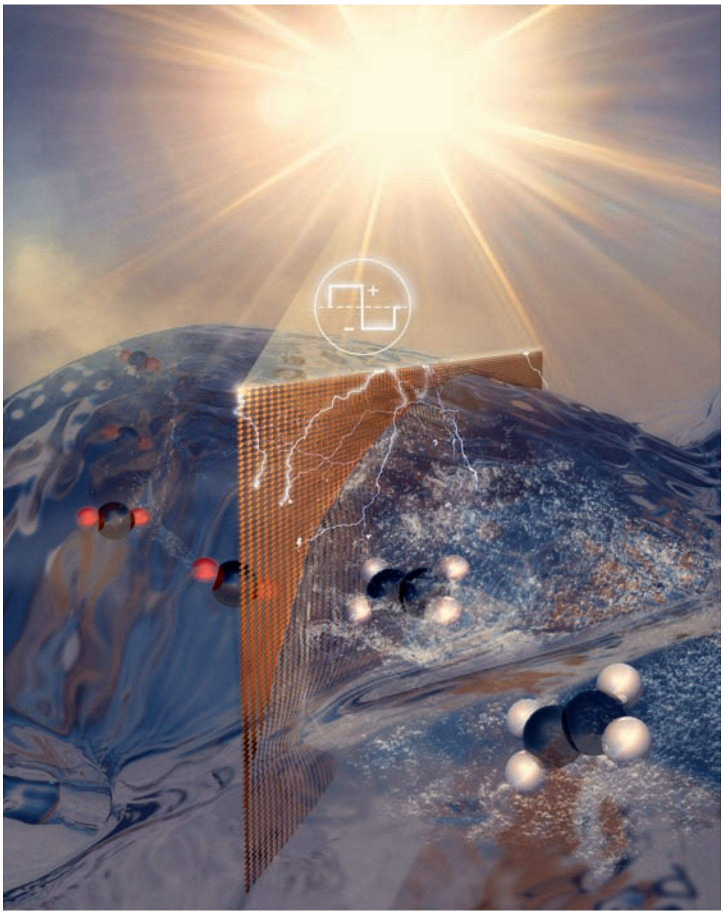
"For every 1 ton of ethylene produced, you're taking 6 tons of CO2 from point sources that otherwise would be released to the atmosphere."

Previous attempts at converting carbon dioxide into ethylene have relied on reactors that produce ethylene within the source carbon dioxide emission stream. In these cases, as little as 10% of CO2 emissions typically converts to ethylene. The ethylene must later be separated from the carbon dioxide in an energy-intensive process often involving fossil fuels.

In UIC's approach, an electric current is passed through a cell, half of which is filled with captured carbon dioxide, the other half with a water-based solution. An electrified catalyst draws charged hydrogen atoms from the water molecules into the other half of the unit separated by a membrane, where they combine with charged carbon atoms from the carbon dioxide molecules to form ethylene.

Among manufactured chemicals worldwide, ethylene ranks third for carbon emissions after ammonia and cement. Ethylene is used not only to create plastic products for the packaging, agricultural and automotive industries, but also to produce chemicals used in antifreeze, medical sterilizers and vinyl siding for houses.

Ethylene is usually made in a process called steam cracking that requires enormous amounts of heat. Cracking generates about 1.5 metric tons of carbon emissions per ton of ethylene created.



Abstract illustration of atoms passing through water and an electrified membrane under a shining sun. Illustration: Meenesh Singh

On average, manufacturers produce around 160 million tons of ethylene each year, which results in more than 260 million tons of carbon dioxide emissions worldwide.

In addition to ethylene, the UIC scientists were able to produce other carbon-rich products useful to industry with their electrolysis approach. They also achieved a very high solar energy conversion efficiency, converting 10% of energy from the solar panels directly to carbon product output.

This is well above the state-of-the-art standard of 2%. For all the ethylene they produced, the solar energy conversion efficiency was around 4%, approximately the same rate as photosynthesis.

Their findings are published in Cell Reports Physical Science.

More information

www.uic.edu

University of Wyoming, Wood and Atlas Carbon demo coal conversion

The field demonstration project, located near Gillette, Wyoming, will serve as a testing facility for sustainable coal refinery processes using Powder River Basin coal.

The University of Wyoming School of Energy Resources (SER), in partnership with Wood and Atlas Carbon, broke ground on a coal refinery field demonstration project, announced UW SER.

Groundbreaking at the test site near Gillette, Wyoming

The site, located near Gillette, Wyoming, will showcase – at pre-commercial scale – a sustainable coal refinery process, as well as product technologies using Wyoming Powder River Basin (PRB) coal.

The thermochemical process technology developed in SER's Center for Carbon Capture and Conversion (CCCC) efficiently decomposes Wyoming coal, yielding beneficial liquids and solids that are then used to create valuable, non-energy products, such as building and construction materials, asphalt products and agricultural soil amendments.

The core process technology integrates thermal coal solvent extraction and flash/thermal-pyrolysis processing and is a critical part of the carbon engineering program. CCCC researchers have worked with much success since 2016 refining the novel process and developing the coal-derived carbon products. Wyoming has invested more than $30 million to date on such projects.

Wood, a British-based leading consulting and engineering company, has completed a phase 1 engineering study for site works, as well as a corresponding feasibility study that could integrate UW's coal refinery technology to showcase a first-of-a-kind field demonstration.

"We are proud to continue and grow our presence in Wyoming," says Steve Conway, senior vice president for process and chemicals at Wood. "This collaboration aligns well with our pursuit of future-ready, innovative technology and complements our ongoing research with the university to develop additional industry solutions."

Situating the novel coal-processing technology adjacent to the existing activated carbon production facility, which is operated by Atlas Carbon, will take advantage of existing Wood expertise and coal-handling preparation capabilities at the site.

The manufacturing plant is located near the Wyoming Innovation Center and has the ability and capacity to convert carbon into products, making it an ideal location for a field demonstration.

The new pilot facility will be in "the heart of the Powder River Basin" and will enable Atlas' continued improvement of activated carbons produced from the high-quality coal as a feedstock

In the next phase of this site demonstration, the pyrolysis portion of the technology will be installed to create larger volumes of coal char that can then be used to manufacture useful products such as building materials and soil amendments.

Once fully operational as a demonstration site, the facility will showcase the possibilities of PRB coal to potential industry and commercial stakeholders. The evolution of a new carbon economy is taking shape through the three-way collaboration and with the support of the state.

More information

www.uwyo.edu/ser

Capture & utilisation news

ArcelorMittal, Mitsubishi Heavy and BHP collaborate on steel CCS

www.bhp.com
www.arcelormittal.com

They are collaborating on a multi-year trial of MHIENG's carbon capture technology with ArcelorMittal, following the signing of a funding agreement between the parties.

ArcelorMittal, Mitsubishi Heavy Industries Engineering (MHIENG), leading global resources company, BHP, along with Mitsubishi Development Pty Ltd will also conduct a feasibility and design study to support progress to full scale deployment.

The agreement, which involves a trial at ArcelorMittal's steel plant in Gent, Belgium and another site in North America, brings together the expertise of the various partners in identifying ways to enhance carbon capture and utilisation and/or storage (CCUS) technologies in the hard-to-abate steelmaking industry.

The industry is estimated to account for around seven-to-nine per cent of global greenhouse gas (GHG) emissions. CCUS has the potential to be a key technology for reducing emissions from existing global blast furnaces, which are anticipated to remain a significant portion of steel production over coming decades. The IEA estimates CCUS technology needs to apply to more than 53 per cent of primary steel production by 2050, equivalent to 700 Mtpa of CO2, for the Net Zero Emissions scenario.

There are no full scale operational CCUS facilities in blast furnace steelmaking operations at present, with only a limited number of small capacity carbon capture or utilisation pilots underway or in the planning phases globally. However, later this year ArcelorMittal Gent will commission its Steelanol project, a scale demonstration plant that will capture carbon-rich process gases from the blast furnace and convert them into ethanol.

To further understand how carbon capture technology can be incorporated into existing steel plants, ArcelorMittal is facilitating the trial at its five million-tonnes-a-year steel plant in Gent, Belgium, and at another location in North America, with MHIENG supplying its proprietary technology and supporting the engineering studies. BHP and Mitsubishi Development, as key suppliers of high-quality steelmaking raw materials to ArcelorMittal's European operations, will fund the trial that is anticipated to run for multiple years. In Gent, the trial will have two phases.

The first phase involves separating and capturing the CO2 top gas from the blast furnace at a rate of around 300kg of CO2 a day – a technical challenge due to the differing levels of contaminants in the top gas. The second phase involves testing the separating and capture of CO2 from the offgases in the hot strip mill reheating furnace, which burns a mixture of industrial gases including coke gas, blast furnace gases and natural gas.

ArcelorMittal is facilitating a trial at its five million-tonnes-a-year steel plant in Gent, Belgium

The parties plan to install the mobile test unit in one of ArcelorMittal's North American Direct Reduced Iron (DRI) plants, to test MHIENG's technology in this steelmaking route.

ArcelorMittal Belgium's Chief Executive Officer, Manfred Van Vlierberghe, said, "The decarbonisation of the steel industry is a huge challenge that we cannot solve alone: it is through pan-industry partnerships and collaboration that we will achieve ArcelorMittal's climate goals of reducing CO2 emissions by 35 per cent by 2030 in Europe, and by 30 per cent by 2030 worldwide. Alongside our continued energy efficiency improvements, we are developing two routes to decarbonize steelmaking: Smart Carbon and Innovative-DRI. Both routes will contribute in our journey to deliver carbon-neutral steelmaking. The Smart Carbon route also allows us to integrate carbon capture and re-use (CCU) or storage (CCS) technologies, capturing carbon emitted during the steelmaking process. We are therefore proud to be working with BHP, Mitsubishi Development and Mitsubishi Heavy Industries Engineering on this pioneering Carbon Capturing pilot project, in ArcelorMittal Gent."

Carbon capture activities are the largest cost component of the CCUS value chain and represent roughly two-thirds of the total capital cost and are the greatest consumer of additional energy. Improved understanding of carbon capture technology performance, cost, risk and sustainability outcomes are essential to determine its role in efforts to decarbonise the steel industry.

This latest collaboration marks a milestone in BHP's strategy to support decarbonisation efforts in steelmaking, which aims to achieve coverage of geographically diverse customer markets and potential technology pathways and follows partnerships in recent years with other global majors POSCO, China Baowu, JFE Steel, HBIS Group and TATA Steel. Collectively with ArcelorMittal, these companies account for more than 17 per cent of reported global steel production.

BHP's Chief Commercial Officer, Vandita Pant, said, "There is currently no certain or single pathway to net zero for steelmaking. CCUS is one of the key abatement technologies with potential to support development of some of those pathways, so working with industry leaders like ArcelorMittal, Mitsubishi Development and MHIENG, we hope to arrive at scalable solutions more quickly to help reduce carbon emissions in steelmaking."

"Steel is a critical product for the world to develop and decarbonise, and we must work hard, together, to enable lower GHG emissions steel, support the reduction of carbon intensity in the blast furnace and test new technologies for steel production," she added.

Converting CO_2 to solid minerals underground for more stable storage

A new scientific review article from Pacific Northwest National Laboratory discusses how carbon dioxide converts from a gas to a solid in ultrathin films of water on underground rock surfaces.

These solid minerals, known as carbonates, are both stable and common.

"As global temperatures increase, so does the urgency to find ways to store carbon," said Pacific Northwest National Laboratory (PNNL) Lab Fellow and co-author Kevin Rosso. "By taking a critical look at our current understanding of carbon mineralization processes, we can find the essential-to-solve gaps for the next decade of work."

Mineralization underground represents one way to keep CO_2 locked away, unable to escape back into the air. But researchers first need to know how it happens before they can predict and control carbonate formation in realistic systems.

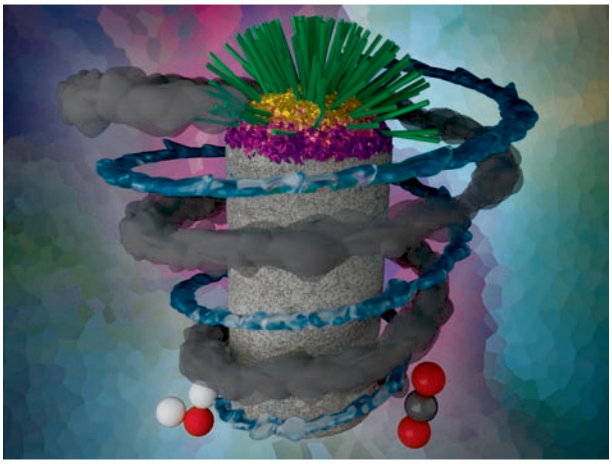
"Mitigating human emissions requires fundamentally understanding how to store carbon," said PNNL chemist Quin Miller, co-lead author of the scientific review featured on the journal cover. "There is a pressing need to integrate simulations, theory, and experiments to explore mineral carbonation problems."

Instead of emitting CO_2 into the air, one option is to pump it into the ground. Putting CO_2 deep underground theoretically sequesters the carbon away. However, gas leaks remain a concern. But if that CO_2 gas can be pumped into rocks rich in metals like magnesium and iron, the CO_2 can be transformed into stable and common carbonate minerals. PNNL's Basalt Pilot Project at Wallula is a field site dedicated to studying CO_2 storage in carbonates.

Although these subsurface environments are generally dominated by water, the conversion of gaseous carbon dioxide to solid carbonate can also occur when injected CO_2 displaces that water, creating extremely thin films of residual water in contact with rocks. But these highly confined systems behave differently than CO_2 in contact with a pool of water.

In thin films, the ratio of water and CO_2 controls the reaction. Small amounts of metal leach out from the rocks, reacting both in the film and on the rock surface. This leads to the creation of new carbonate materials.

Previous work led by Miller, summarized in the review, showed that magnesium behaves similarly to calcium in thin water films. The nature of the water film plays a central role in how the system reacts.



Mineralizing carbon dioxide underground is a potential carbon storage method. Credit: Cortland Johnson / Pacific Northwest National Laboratory

Understanding how and when these carbonates form requires a combination of laboratory experiments and theoretical modeling studies. Laboratory work allows researchers to tune the ratio of water to CO_2 and watch carbonates form in real time. Teams can see which specific chemicals are present at different points in time, providing essential information about reaction pathways.

However, laboratory-based work has its limits. Researchers cannot observe individual molecules or see how they interact. Chemistry models can fill in that gap by predicting how molecules move in exquisite detail, giving conceptual backbone to experiments. They also allow researchers to study mineralization in hard to experimentally access conditions.

"There are important synergies between models and laboratory or field studies," said MJ Qomi, a professor at the University of California, Irvine and co-lead author of the article. "Experimental data grounds models in reality, while models provide a deeper level of insight into experiments." Qomi has collaborated with the PNNL team for three years, and plans to study carbonate mineralization in adsorbed water films.

The team outlined key questions that need answering to make this form of carbon storage practical. Researchers must develop knowledge of how minerals react under different conditions, particularly in conditions that mimic real storage sites, including in ultrathin water films. This should all be done through an integrated combination of modeling and laboratory experiments.

Mineralization has the potential to keep carbon safely stored underground. Knowing how CO_2 will react with different minerals can help make sure that what gets pumped underneath the surface stays there. The fundamental science insights from mineralization work can lead to practical CO_2 storage systems. The Basalt Pilot Project represents an important study site that bridges small-scale basic science and large-scale research applications.

"This work combines a focus on fundamental geochemical insights with a goal of solving crucial problems," said Miller. "Without prioritizing decarbonization technologies, the world will continue warming to a degree humanity cannot afford."

More information

www.pnnl.gov

Offshore carbon storage needs to scale up for UK Net Zero goals

The UK will need to step up research and deployment of new offshore carbon storage wells if it is to achieve the capacity required to deliver its net zero emissions plans, a new report says.

Published by the Royal Society and led by University of Cambridge researchers, Locked Away – Geological Carbon Storage explores the latest evidence and technical considerations for permanently storing CO2 by pumping it into deep saline aquifers or depleted oil and gas fields offshore.

Alongside sustained reductions in carbon emissions, international bodies and the UK's Committee on Climate Change identified carbon capture and storage (CCS) as a critical technology in most possible routes to achieving net zero.

However, the levels of CCS deployment globally have been slow and, globally, are 'well below those anticipated to be needed to limit global warming to 1.5°C, or 2°C', the report warns.

"Geological carbon storage will be an essential part of our long-term energy transition, both in storing emissions from hard-to-decarbonise industries, and for longer-term removal of CO2 through direct air capture," said Professor Andy Woods from Cambridge's Institute for Energy and Environmental Flows (IEEF), chair of the report's working group.

"The UK's access to potential storage sites in its offshore waters, along with a strong industrial base and regulatory and assurance environment, mean this could be an important industry.

"But thousands of wells are likely to be needed globally, and each new subsurface reservoir can take years to develop to ensure its suitability."

Scaling up

The policy briefing considers the latest geoscience evidence and lessons from current and planned CCS projects that could inform policymakers if they pursue geological carbon storage.

It also looks at the challenges of scaling up CCS, including outstanding research and policy questions relating to transport, storage, monitoring, sustainable business models and incentives.

The IPCC special report on global warming of 1.5°C and research by the International Energy Agency suggest that 7-8 gigatonnes of CO2 will need to be stored globally each year by 2050 to keep warming below 1.5°C: this represents over 20% of present global annual fossil fuel and industrial emissions (roughly 34 gigatonnes of CO2 per year).

By 2100, cumulative storage of between 350-1200 gigatonnes of CO2 is likely to be needed to avoid the worst effects of climate change.

For the UK to deliver on its net zero carbon emissions pledge, it needs to develop new wells – and the associated injection, transport and storage infrastructure – capable of storing about 75-175 megatonnes of CO2 every year by 2050, according to the UK North Sea Transition Authority.

With CO2 injection rates currently constrained by pressurisation limits, and a 5-7 year timeframe to deploy a new reservoir, the report's expert working group estimates this will require the equivalent of around one new carbon storage system, capable of injecting 4-5 megatonnes of CO2 per year, being added each year to 2050.

Sustained investment

To date, the upfront capital costs, lack of sufficient and predictable incentives to support operating costs, and concerns over the social acceptability in many jurisdictions have contributed to a global under-deployment of CCS.

The Global CCS Institute's 2021 survey lists 27 CCS projects as being operational, capturing 36.6 megatonnes of CO2 per year, with a further 62 projects listed as either in construction or advanced development. If successfully deployed, the combined capture potential would be 86.4 megatonnes of CO2 per year.

A UK target of delivering CCS in four industrial clusters, set under the previous government, aims to capture and store around 20-30 megatonnes of CO2 each year. With Phase 1 sites, in the East Coast Cluster (Teesside plus Humber) and HyNet in the Northwest, targeting delivery in the middle of this decade.

Scaling up required capacity, the report says, demands an enormous and continued global investment each year to 2050 to build the injection wells, transport networks, monitoring technologies, and a skilled workforce, to install hundreds of new wells each year.

"We have technology to store and monitor carbon in this way," said Woods.

"But as deployment of these technologies rolls out, there will likely be many new challenges, especially since each storage reservoir has its own unique geological structure and setting.

"So we need to continue to invest in research, and the policy and regulatory frameworks that are required to scale up safely and at pace."

In particular, the report highlights the need to understand the storage capacity and properties of different geological formations; the critical pressures which might cause seal rocks to fail and leak; different monitoring strategies for detecting CO2 leaks, new understanding of some of the geochemical processes; and the potential to increase capacity in old wells.

There is also a need to for ongoing effective public dialogue to highlight the importance of carbon storage in mitigating climate change, and to understand and address the concerns of communities and citizens.

More information

www.ieef.cam.ac.uk

Transport and storage news

Stena Bulk launches end-to-end CO2 capture onboard

www.stenabulk.com

The company has begun a two-year, three phase project aimed at demonstrating shipboard carbon capture, together with the Global Centre for Maritime Decarbonisation (GCMD) and the Oil and Gas Climate Initiative (OGCI).

Project REMARCCABLE (Realising Maritime Carbon Capture to demonstrate the Ability to Lower Emissions) will see one of Stena Bulk's Medium Range (MR) IMOIIMAXX tankers installed with a carbon capture system, developed together with other project partners, Alfa Laval, the American Bureau of Shipping, Deltamarin, and TNO.

Targeting at least a 30% absolute capture rate for carbon dioxide during normal vessel operations and on deep-sea voyages, and by working with organisations to offload and sequester or reuse the CO2, the project is the world's first initiative demonstrating end-to-end shipboard carbon capture at such a large scale and across the full value chain.

The project will use non-proprietary equipment and processes, so results can be shared broadly and publicly to maximise learning and encourage further development. It also aims to establish a pathway to reduce the cost of onboard CO2 capture to €150 per tonne of CO2 or lower, to allow the technology to be commercially deployed in the near future.

Stena Bulk's participation in the consortium of the seven organisations will help guide the technical design and integration of the system onboard, as well as help evaluate the operational and commercial opportunities and challenges when capturing CO2 at sea.

The project will see one of Stena Bulk's Medium Range IMOIIMAXX tankers installed with a carbon capture system

Chart Industries and CarbonCure collaborate on liquid CO2 transport, storage

www.chartindustries.com
www.carboncure.com

Chart Industries and CarbonCure Technologies have announced an agreement to further advance collaboration on equipment for the storage and transport of liquid carbon dioxide.

They will also use Sustainable Energy Solutions' (SES), a division of Chart Industries, Cryogenic Carbon Capture™ technology for deployment at concrete facilities globally.

"We are excited to continue our work with CarbonCure and their cutting-edge solutions to transform the concrete industry by reducing the sector's carbon footprint without sacrificing performance," said Jill Evanko, President and CEO of Chart Industries.

"This agreement formalizes the collaboration that began years ago as we supported CarbonCure in its successful XPRIZE campaign and we look forward to continuing to work with CarbonCure's talented team."

The two companies will support opportunities for the use of Chart's cryogenic CO2 microbulk storage tanks to support CarbonCure's suite of carbon removal technologies for the concrete industry. Additionally, Chart's cryogenic trailers may be used to transport liquid CO2 to the concrete plants of CarbonCure's concrete producer partners.

During the concrete manufacturing process, CarbonCure systems inject captured carbon dioxide into fresh concrete, reclaimed plant water and recycled concrete aggregate where the CO2 immediately mineralizes and becomes permanently embedded. The CO2 will never return to the atmosphere even if the concrete is later demolished.

eDrilling receives £840,000 to develop well control software for CCS

www.edrilling.no
www.climit.no

eDrilling has been awarded 10 MNOK in funding from Gassnova CLIMIT to support the research and development of well control software for Carbon Capture and Storage.

Full-scale CO2 storage demands comprehensive analysis and knowledge of reservoir and formation to eliminate risks for leakage underground. Well control technology for CCS addresses these risks for safe, efficient, and controlled in-fill drilling in mature CO2 storage.

There is no tool available in today's market to provide well control for drilling into CO2 storage reservoirs. Th2 technology will be crucial to assist the transformation of the energy industry and meeting the goals of the Paris Agreement.

eDrilling said its years of experience with well control of petroleum wells will reduce the time and resources needed to launch reliable software for well control in CO2 wells at the required technology readiness level efficiently. It also enables easy integration with existing systems without the need to replace.

The CLIMIT Programme is Norway's national programme for research, development, and demonstration of CCS technology.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