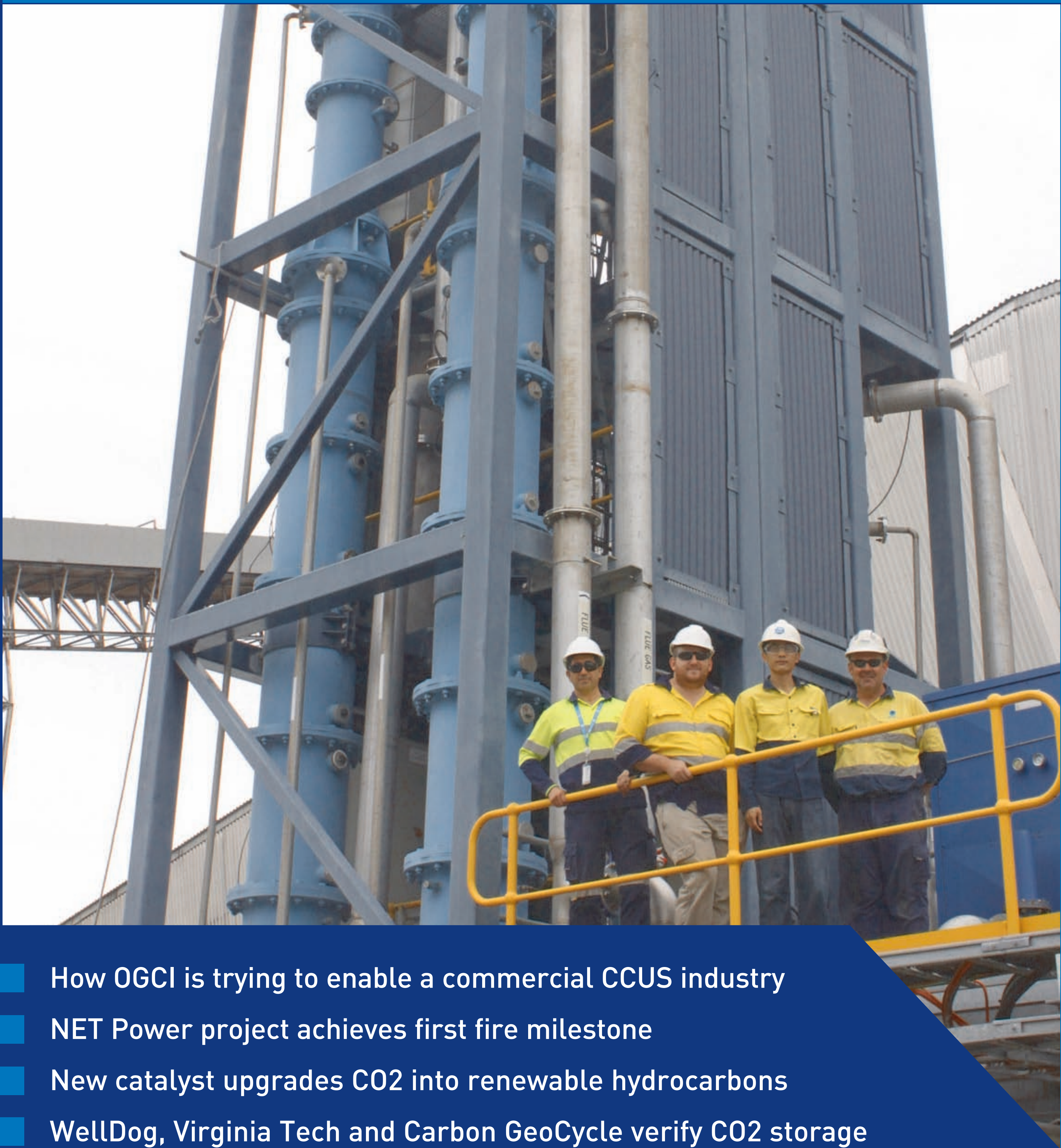
Carbon Capture Journal

CCS in Australia

CS-Cap: Development of an SO2 tolerant post combustion CO2 capture process

CSIRO pilot plant demo of aqueous ammonia CO2 capture

July / Aug 2018 Issue 64



- How OGCI is trying to enable a commercial CCUS industry
- NET Power project achieves first fire milestone
- New catalyst upgrades CO2 into renewable hydrocarbons
- WellDog, Virginia Tech and Carbon GeoCycle verify CO2 storage

Norway Industrial CCS – Budget 2018. Research to continue, Government to proceed with at least one facility but investment decision deferred

On Tuesday 15th May the Norwegian Government presented its revised Budget proposal to Parliament. The proposal sees new funding announced for the Full Scale CCS project and allows detailed engineering work to continue on CO2 capture facilities at the Norcem cement factory in Brevik and on the Europe's first CO2 transport and storage terminal.
By Bellona Europa

The Norwegian budget will allocate €29.2 million to continued development to industrial CO_2 capture, transport and offshore geologic storage.

Minister of Petroleum and Energy, Terje Søviknes, aims to have at least one project fully prepared for a final investment decision by 2020 – 2021, a postponement of two years over the initial timeline.

Industrial emissions

Norcem, Norway's only cement production company, will receive €8 million to continue development, with work on engineering and design of a capture facility in Brevik. The cement plant is still in line to be the first of its kind in the world. The production and use of cement is responsible for approximately 5% of global greenhouse gas emissions, with some calculating the total to be closer to 8% of total emissions. This is greater than the climate impact of air travel. At present CO_2 capture is the only known way of deeply reducing emissions from traditional cement production.

Klemetsrud, a district heating and waste management plant on the outskirts of Oslo, is also in the running to proceed to the engineering and design phase. The Norwegian government has requested some time to quality assure numbers and calculations of costs for the plant before deciding. District heating and waste management plants have a significant climate footprint, Klemetsrud alone makes up 15% of Oslo carbon footprint. However, with the addition of CO_2 capture and storage these facilities have the potential to permanently remove greenhouse gasses from the atmosphere.

Yara Porsgrunn, a large Norwegian fertiliser factory, will not continue development of a CO_2 capture project. Ammonia fertiliser production contributes about 1% to global emissions.

CO2 Transport and Storage

A central CO_2 shipping terminal, subsea pipeline and offshore geologic storage will continue with engineering and design. Three oil companies Statoil, Shell and Total will collaborate to in the development of Europe's first CO_2 storage terminal on the west coast of Norway.

Bellona's view on delay of Industrial CCS

It has been 5 years since Norway announced to the world that it world it would peruse a new industrial CCS strategy, avoiding the mistakes of a previous attempt. The previous attempt, managed by Statoil at the Monostand refinery was beset by mismanagement, a lack of cost control and year upon year of delays without ever proceeding past the study stage.

Olav Øye, Senior CCS Advisor "The Government has already delayed a decision on CCS and its new proposal will delay it even further, potentially deferring a final decision until after elections in 2021.

"Thanks to this proposal, we may have to wait until 2024, or even later, before industrial CCS is up-and-running in Norway. The industries involved in this process have so far done a great job of adapting to the inconsistencies and uncertainties thrown up by Government, but they won't do this forever. It's incredibly risky behaviour from Government and smacks of politicians trying to abdicate responsibility."

"This is a project for Norway, Europe and the rest of the world. It is vital that Government starts to step-up and turn its strong words on CCS into firm commitments. If it doesn't, it's not just Norwegians that will suffer, it will be the whole world."

In review, some things seem mostly stay the same, year on year the concentration of green house gases in the atmosphere increase another notch. In return, the prospect of preventing our planetary climate system from tipping over into inhospitable becomes dimmer.

The Norwegian governments new delay and lack of urgency in providing climate solutions for its own industries will again ratchet up our global climate crisis. At this rate, we may just about have low carbon cement and industrial products in time to build dams to hold back rising sea levels.

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Front cover:

The pilot plant at Vales Point Power Station in Australia will demonstrate the efficient removal of SO2 and CO2 using an advanced aqueous ammonia solution (pg. 4)

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Leaders - CCS in Australia

Projects and policy

Capture and utilisation

Transport and storage

CS-Cap: Development of an SO2 tolerant post combustion CO2 capture process

Combining the removal of SO2 and CO2 from flue gas streams into a single process step could significantly lower the cost of post combustion emissions reduction.

By removing the need for separate flue gas desulfurisation (FGD), which is typically required prior to the CO2 capture step, there is potential to save $100-200m [1] per post combustion CO2 capture installation. This is of particular importance in countries such as Australia that do not currently utilise FGD technologies. In Australia FGD would be required before any standard CO2 capture technology could be added, significantly adding to the cost of CO2 capture processes here. To address this challenge, the Commonwealth Scientific and Industrial Research Organisation (CSIRO) have developed the CS-Cap process.

Other combined capture processes

Combined capture of SO2 and CO2 from flue gas streams is a promising new approach for lower cost emissions reduction, and is already receiving attention from a number of commercial and research organisations. The Shell-Cansolv process, currently employed at Saskpower's Boundary Dam power station, is an example of one such technology. There, SO2 is removed from the flue gas in an initial amine absorption step, followed by CO2 removal in a separate downstream amine absorption unit. The SO2 loaded absorbent is thermally regenerated, releasing SO2 that is used in the production of sulfuric acid. This unit is heat-integrated with the CO2 loaded absorbent regeneration unit, which produces compressed CO2 for storage and enhanced oil recovery.

The Siemens PostCap process utilises an amino-acid absorbent to remove both the SO2 and CO2 from combustion flue gases in a single absorption unit. CO2 is removed from the absorbent via thermal regeneration, whereas chilling and crystallisation are used to remove the absorbed SO2, producing a K2SO4 by-product. Siemen's have evaluated their process at a 1 tonne CO2/day pilot plant treating a coal flue gas.

The CASPER process, developed by the Netherlands Organisation for Applied Scientific Research (TNO), has been evaluated in collaboration with the CSIRO at the AGL Loy Yang CO2 capture pilot plant in Victoria, Australia. Here, an amino-acid absorbent was used to capture CO2 and SO2 from the flue gas. Absorbed CO2 was removed from the absorbent via thermal stripping in the pilot plant stripping column. An off-line crystallisation set-up was used to remove absorbed SO2, and regenerate the absorbent. A techno-economic analysis for a 500 MW power station based in Australia was completed under the same project and identified a reduction in the cost of CO2 avoided of over 10% for the CASPER process when compared to a standard CO2 capture process (30 wt% monoethanolamine) combined with FGD.

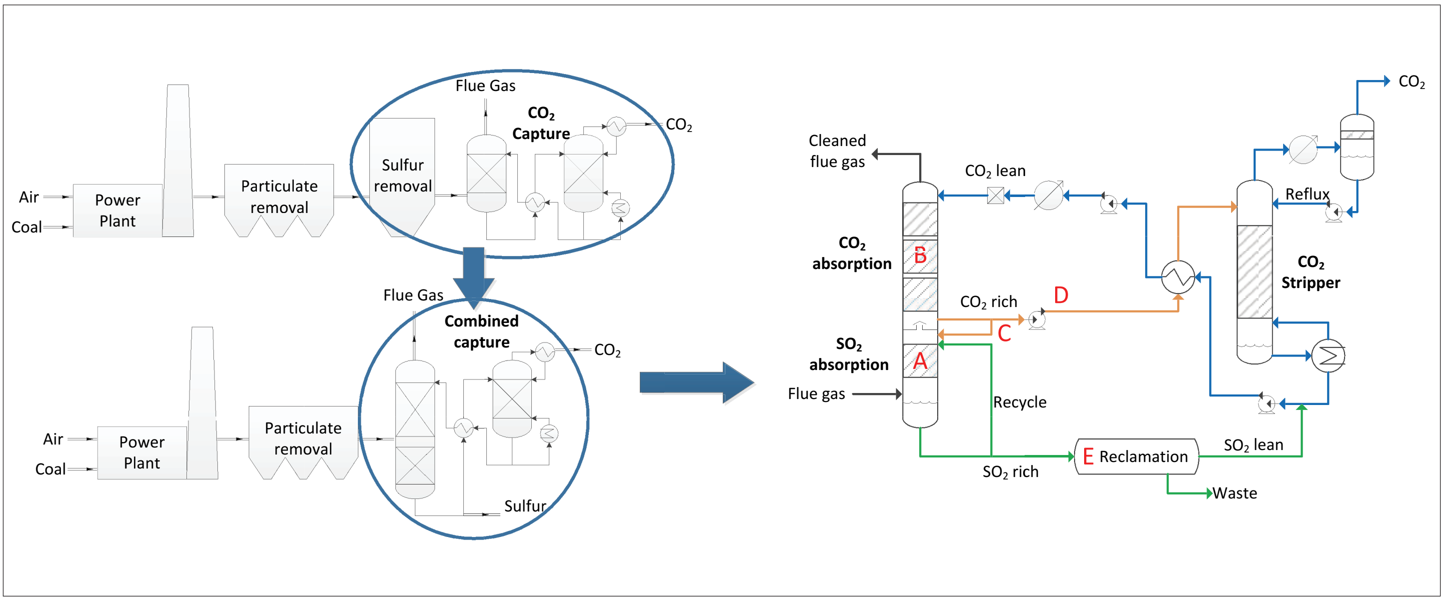

Figure 1: Diagram of power station showing concept of combined capture, and the CSIRO's CS-Cap process. A: SO2 is removed from the flue gas at the base of the column; B: CO2 is removed from the flue gas in upper stages of the column; C: a slip stream of the CO2 loaded absorbent is used in the base of the column for SO2 removal resulting in a small absorbent volume highly concentrated in sulfur; D: the remainder of the SO2 free CO2 loaded absorbent can be regenerated via a standard stripping column; E: the SO2 loaded absorbent will require separate regeneration

CSIRO's CS-Cap process

The CSIRO have been developing the CS-Cap process since 2012 [2]. The CS-Cap process is a low cost, multi-component removal process. It takes advantage of the high solubility of SO2 into aqueous amines, despite being at much lower concentration than CO2 in the flue gas. Experimental evaluation has confirmed the high affinity for SO2 absorption into aqueous amine absorbents, even when that amine is already saturated with CO2 [3]. This understanding allows the unique use of a single amine absorbent to capture both the SO2 and CO2 from flue gas streams, as outlined in Figure 1.

Proof-of-concept operation of the CS-Cap process was completed at CSIRO's CO2 capture pilot plant located at the AGL Loy Yang Power station, in Victoria, Australia. Here, a CO2 rich amine absorbent was used in the pre-treatment section to simulate the SO2 removal in the bottom of the absorber column (section A in Figure 1). The absorbent was observed to readily absorb SO2 from the flue gas until it became saturated. At that point the pH of the solution was noted to drop rapidly, and break-through of SO2 into the flue gas exiting the column was observed (Figure 2). SO2 captured in the absorbent was noted to quickly oxidise to sulfate, with sulfate concentrations up to 115g/1000g measured [4].

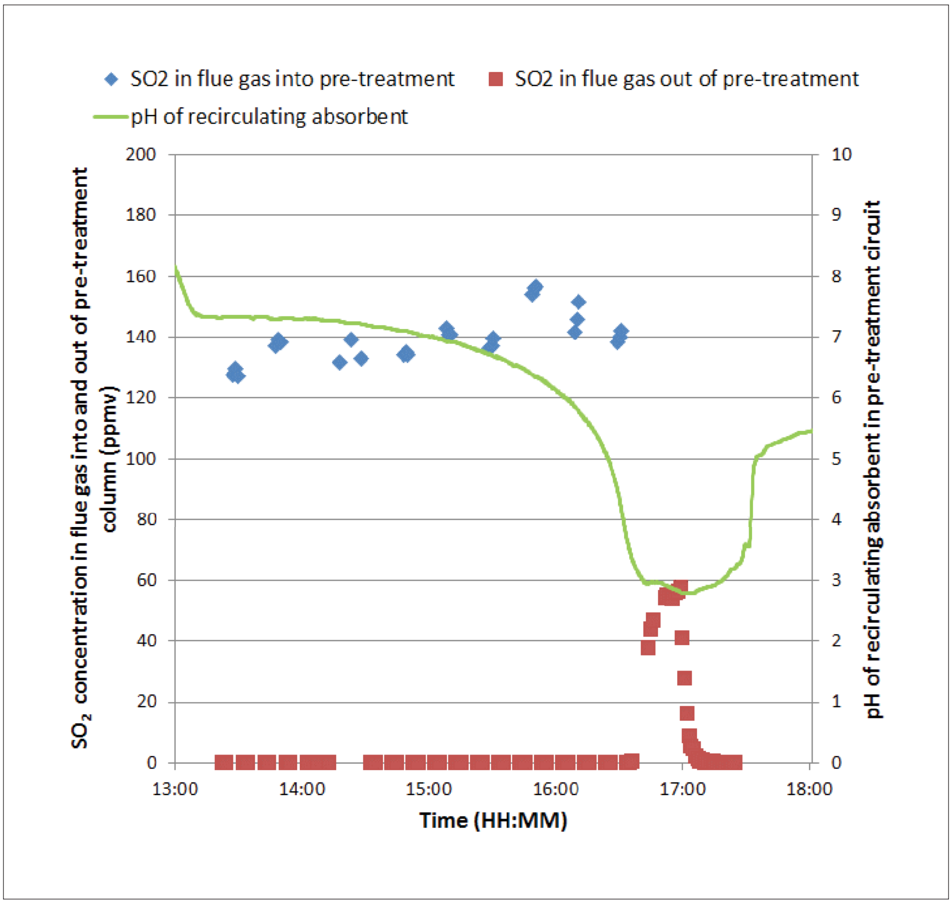

Figure 2: SO2 concentration in flue gas into and out of pilot plant pre-treatment column. pH of CO2 rich amine solution in pre-treatment system

Reclamation of the absorbent (removal of sulfur) is required for continued use. Traditionally this is achieved via thermal reclamation in standard liquid absorbent plant. The unique nature of the absorbent generated during the CS-Cap process may be more amenable to other reclamation technologies, such as precipitation, electrodialysis, or nanofiltration. CSIRO, in collaboration with Federation University, AGL Loy Yang, Energy Australia and Brown Coal Innovation Australia, are continuing the development of this process, with a focus on identifying and optimising the most promising technology for the regeneration of the sulfur-rich absorbent.

Summary

Combined capture concepts are a promising new emissions reduction strategy with the potential to significantly reduce the cost of post combustion CO2 removal. CSIRO is continuing the development of the CS-Cap process, which combines the removal of CO2 and SO2 from combustion flue gas streams. This concept is particularly attractive in countries such as Australia, which do not currently utilise flue gas desulfurisation on coal-fired power plant. As a result, combined capture concepts such as CS-Cap have the potential to significantly reduce the cost of post combustion capture of CO2 from flue gas streams in this country.

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More information

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CSIRO pilot plant demonstration of aqueous ammonia CO2 capture

CSIRO is trialling an advanced aqueous ammonia (NH3)-based post-combustion capture technology in a pilot plant at Vales Point Power Station, New South Wales (NSW) Australia.

As a result of a contested grants application process, the New South Wales Government's Coal Innovation NSW (CINSW) Fund awarded CSIRO a two year project (2017-2018) aimed to demonstrate an advanced aqueous ammonia (NH3)-based post-combustion carbon dioxide (CO2) capture (PCC) process and its benefits using a CO2 capture pilot plant located at Vales Point Power Station, New South Wales (NSW). CINSW will contribute up to AUD$ 2 million to the project.

Aqueous NH3 based PCC is a promising technology for its application in NSW power sectors. Compared to other amines, NH3 is produced locally (by Orica) and is the cheapest and most stable solvent. It does not degrade to generate hazardous waste. The environmental and health effects of NH3 are well studied and much less than that of amines. NH3 has a high CO2 removal capacity and a relatively low regeneration energy demand. It also has the ability to capture multiple components (NOx, SOx, CO2 and Hg) and produce value added products such as ammonium sulphate and ammonium nitrate.

CSIRO has been developing the NH3-based PCC process for application under Australian conditions since 2008. The CSIRO process shares similarities with GE Power's chilled ammonia process (CAP) which is more suited to the cooler climate of the Northern Hemisphere. The Australian-based process is being tailored to enable CO2 absorption at ambient temperatures (20-30 °C instead of ≤10 °C for CAP) thereby reducing the refrigeration energy required to cool the incoming flue gas and absorbent.

In collaboration with Delta Electricity, CSIRO completed pilot-plant trials of a generic aqueous NH3-based PCC technology under real flue gas conditions at Delta's Munmorah Power Station between 2008 and 2010. The pilot-plant trials confirmed the benefits and technical feasibility of the process and its potential for application in the

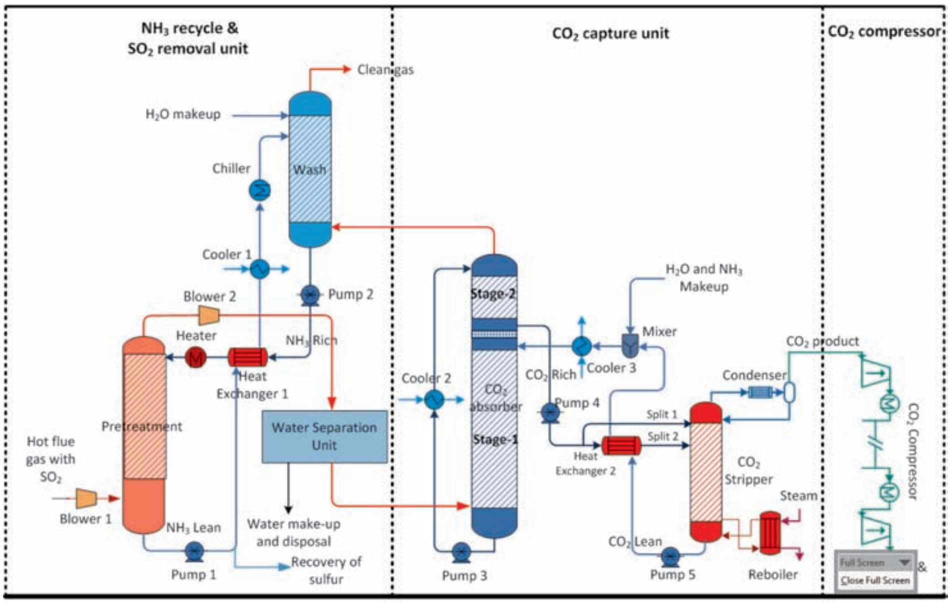

Figure 1 Schematic flow sheet of the advanced NH3 PCC process

Australian power sector [1,2]. The pilot plant evaluation also identified some issues at the specific conditions investigated which limit the economic feasibility of the technologies. These include: (1) high NH3 loss during the absorption process resulting in a high consumption of cooling water and additional refrigeration energy to recover NH3; (2) relatively low CO2 absorption rate which translates to the need for larger columns at higher capital cost; and (3) solid precipitation, a practical issue which can lead to blockages and unintentional shut down of the plant.

With support from the Australian Government and ANLEC R&D, CSIRO worked with Newcastle University and Curtin University in Australia and Tsinghua University, Zhejiang University, and China University of Mining and Technology (Beijing) in China to address these issues. A combined process modelling and bench-scale testing approach was employed to develop and evaluate innovative ideas to improve the economic viability of the technology. The joint efforts have led to the development of an advanced, aqueous NH3-based PCC technology [3].

Figure 1 shows the schematic flow sheet of the advanced NH3 PCC process developed by CSIRO. The process consists of a SO2 removal and NH3 recycle unit, and a CO2 absorption and desorption unit. It builds on the process tested previously at Munmorah Power Station and incorporates the following innovative features.

CSIRO's advanced aqueous NH3-based CO2 capture technology

1) Integrated flue gas cooling, SO2 removal and NH3 recovery

The integrated process can cool flue gas, remove SO2 and recover NH3 simultaneously. It consists of a wash column, in which the vaporised NH3 is recovered by wash water; a pretreatment column, in which the heat contained in the high-temperature flue gas is used to regenerate NH3 in the wash water and recycle it to the CO2 absorber via the flue gas; and a water separation unit for maintaining water balance. SO2 is removed in the pretreatment column. Its presence in the wash water helps to recover NH3 from the wash column, producing ammonium sulfite that can be used to make ammonium sulfate fertiliser.

2) Process improvements for CO2 absorption and regeneration

(i) Two-staged absorption: the lean solvent, rich in free NH3, is introduced to the middle of the absorber to achieve fast CO2 absorption (Stage 1 absorption), and then enters the top of the column for recovery of NH3 from the gas (Stage 2 absorption). This configuration can significantly reduce NH3 slip in the absorption process by more than 50% compared to single-stage absorption.

(ii) Elevating CO2 absorption temperature to ambient conditions (20–30 oC) and using relatively high NH3 concentrations (6–10 wt%). This can avoid both solid precipitation and the substantial energy input for solvent chilling (as required in the Chilled NH3 Process), as well as improve the CO2 absorption rate. Although NH3 volatility increases with an increase in temperature and NH3 concentration, NH3 loss can be resolved by the NH3 recycle unit and staged absorption introduced above.

(iii) Stripper rich split. One portion of the cold rich solvent is split and pumped to the top of the stripper, while the rest of the rich solvent is heated and introduced to the middle of the stripper. This configuration uses the cold, CO2-rich solution to cool the uprising hot gas vapour and recover the NH3 from the vapour. No external stream is involved in the modification. The process can help eliminate solid precipitation in the stripper overhead condenser and reduce reboiler duty and cooling water consumption.

A preliminary techno-economic analysis has been performed on the integration of the advanced NH3 based process and a reference monoethanolamine (MEA) based process retrofitted to a 650-MW, supercritical, pulverised black-coal power station to achieve 85% CO2 removal efficiency. The analysis has shown a significant cost reduction of using the advanced NH3 based process compared to the reference process and demonstrated a positive benefit for Australia in pursuing the development of NH3 over other PCC technologies [4].

Aims and objectives of the project:

• demonstrate the advanced NH3-based PCC technology at the Vales Point Power Station and confirm its benefits

• validate and optimise the process model with the pilot plant results

• complete a technical and economic assessment of the advanced NH3 PCC process integrated with a coal-fired power station in NSW

• train students from Australian and Chinese universities and generate publications in conferences and journals

• through the network of participating universities and research organisations, increase the exposure of the technology and research facility to the public, which in turn will help promote the technology and increase public awareness and acceptance

Figure 2 Pilot plant at Vales Point Power Station

Methodology/Experimental design

The pilot plant research will involve the following steps.

• Use the existing process model to guide pilot plant modifications and develop baseline operation conditions

• Implement the new process modifications, and conduct preliminary tests to achieve stable operation of the pilot plant under the baseline operation conditions

• Carry out pilot plant campaigns to assess the innovative features of the advanced aqueous NH3-based CO2 capture technology

• Using the information obtained from the above step and process modelling, establish the optimum experimental conditions, and validate the expected performances under these conditions

• Based on the results from the pilot plant trials and process modelling, perform a techno-economic assessment of the process including its integration with a power station

Figure 2 shows a photo of the pilot plant at Vales Point Power Station.

Pilot plant work involves collaboration with a number of universities and research organisations including Newcastle University in Australia, and North China Electric Power University, Zhejiang University, Tsinghua University and Chinese Research Academy of Environmental Sciences in China. Postdocs and research students will participate in the project.

Expected outcomes

The pilot plant trials are expected to demonstrate:

• Removal of SO2 and CO2 at efficiencies of more than 95% and 85% respectively at a CO2 capture rate of more than 80 kg/h and production of high purity CO2 (99-100 vol%) at elevated pressure

• Reduction of NH_3 slip in the exiting flue gas to acceptable levels which can match those achieved in the reference Chilled NH_3 Process assuming the pilot plant can be operated under designed conditions

• The new stripper configurations can eliminate solid precipitation and reduce regeneration energy compared to the base line operation

• The advanced NH_3 process can reduce the thermal efficiency loss by 20% compared to the reference MEA based processes

Progress of the project

Major pilot plant modification has been completed and the pilot plant is operational. Results from the initial tests have been positive and the systematic parametric investigation is under way.

In collaboration with Newcastle University, a novel analytical method which combines Fourier transform infra-red spectroscopy with a Partial Least-Square Regression model has been successfully developed and applied to obtain the liquid phase composition of mixed NH_3, CO_2, SO_3^{2-} and SO_4^{2-} solutions [5]. The new method allows rapid and reliable measurement of the concentration of NH_3, CO_2, SO_3^{2-} and SO_4^{2-}.

In collaboration with the North China Electric Power University in China, we have studied the integration of an NH_3 based CO_2 capture process with the 660MW supercritical steam cycle and assessed three different integration methods [6]. It has been found that the integration involving steam extraction from the Intermediate Pressure/Low Pressure crossover, addition of a new letdown turbine and returning the condensate to the deaerator has the lowest energy consumption for the integrated system. A general correlation between the energy penalty on the integrated 660MW supercritical power plant and the NH_3 based CO_2 capture process has been obtained based on the simulation results, which can serve as a quick and simple guide to calculate the energy penalty in the 660 MW supercritical power plant.

Parallel to the pilot plant trials, lab based research activities have been carried out to develop proof of concept and prototyping of an entirely new process, dubbed the "Trimonia Process", that utilises high concentration NH_3 for the capture of CO_2 from coal fired power stations and endeavors to recover NH_3 from the exit gas streams in a more efficient manner than is currently practiced.

The research outcomes and lessons learnt from both the pilot plant and lab based research will be reported in this journal following project completion.

We have developed a roadmap for further technology development towards its commercialisation. The roadmap is comprised of four stages with different research objectives, research activities, performance targets and increasing CO_2 capture scales, and is designed to reduce investment risks and increase the commerciality of the technology development. This research project is the first stage in the roadmap. The successful completion of this project will lay a solid foundation for the second stage which aims to demonstrate the integration of the NH_3 process with a power station and treatment of the SO_2 captured at a CO_2 capture capacity of between 3,000 and 10,000 tonnes/year and to decrease the CO_2 capture costs to US$40-50 /ton CO_2. In Stage 3, support will be sought to demonstrate the developed technology at large scale up to 100,000 tonnes/year in a PCC demonstration plant. Stage 4 will focus on determination of the feasibility of the advanced NH_3 process at commercial scale (1 million tonnes CO_2/year) in Australia.

Figure 3 Pilot plant work involves collaboration with a number of universities and research organisations

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More information

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Defining opportunity – how OGCI is trying to enable a commercial CCUS industry

Collaborating with a wide range of stakeholders, and supported by ten major oil and gas companies, the Oil and Gas Climate Initiative (OGCI) aims to be a catalyst for a commercial CCUS industry.

When the ten CEOs behind the Oil and Gas Climate Initiative[1] (OGCI) announced in 2016 that they were setting up the billion-dollar Climate Investments fund and prioritising investments to support carbon capture, utilization and storage (CCUS), many were surprised. True, critics had said for years that CCUS was a "get out of jail free card" for the fossil fuel industry, but in reality oil and gas companies had struggled to align around the technology. Stop-and-go government policies, high capture costs and the fear that their support might serve only to prop up the coal industry kept many companies on the sidelines.

This report explores why OGCI member companies are now putting their weight behind CCUS and how the organisation aims to be a catalyst for a commercial CCUS industry.

OGCI's commitment to the development of CCUS is part of a growing recognition among governments and industry that it could facilitate a simpler, smoother and less damaging transition to a zero carbon economy in the second half of this century. That insight is not new. Scenarios from the IPCC and IEA have consistently shown lower costs for energy transition pathways that include CCUS. What has changed is a sense of urgency and focus as governments develop mid-century climate strategies that go beyond power and focus on how to best decarbonise heavy industry and other hard to abate sectors.

In particular, there is a growing awareness of the need to ensure that measures designed to drive decarbonisation in one country don't backfire by pushing companies to close down or relocate to laxer jurisdictions. CCUS could be a way to preserve value and jobs alongside decarbonisation, by encouraging a regeneration of industrial areas as they embrace clean technologies enabled by capture and storage infrastructure.

For oil and gas companies, the value and urgency of CCUS is even clearer. It could contribute substantially to their own decarbonisation and that of their customers and consumers. It could also help the industry to develop new zero carbon business models – from providing carbon transport and storage services, to developing a comprehensive hydrogen business or negative emission technologies.

Realising that vision requires a functioning CCUS industry – something that OGCI is actively trying to enable and underpin. Over the past two years, OGCI has focused on tackling key obstacles to deploying CCUS at scale. One of its first initiatives was to work with the Society of Petroleum Engineers to develop a consistent methodology to report and classify available carbon storage capacity on a global basis. Global deployment of CCUS will require high levels of confidence in the availability of suitable storage resources in the locations needed. OGCI has deployed the reporting methodology – the Storage Resource Management System (SRMS)[2] – to assess existing storage resource estimates and is exploring what work is needed to support large-scale CCUS development in key regions.

Other work has focused on promoting clarity around potential policy mechanisms that governments can use to make CCUS investable.[3] Leveraging OGCI's global reach, smaller teams have now started engaging with governments, industry and other stakeholders in a number of countries to accelerate progress on the ground. OGCI is also participating in an innovative multi-stakeholder project to rethink the narrative around CCUS and activate support at many levels.

Getting a commercial CCUS industry going, however, will ultimately require many more projects to get off the ground. There are currently only 17 large-scale projects under operation. There are five more in construction and four in an advanced stage of development, but around 100 CCUS projects need to be in operation by 2030 to stay on track, according to the International Energy Agency.

Developing potential projects, to catalyse the development of CCUS on a material scale, is one of the priorities of OGCI Climate In-

1. OGCI is a CEO-led initiative which aims to lead the oil and gas industry response to climate change, focusing on CCUS, reduction of methane emissions, energy and transport efficiency and low emission opportunities. Launched in 2014, OGCI is currently made up of ten oil and gas companies that collaborate to increase the ambition, speed and scale of initiatives they can undertake to reduce greenhouse gas emissions. Its billion-dollar fund, OGCI Climate Investments, supports the development, deployment and scale-up of low emissions technology and business models. It has the ambitious target of delivering one gigatonne of greenhouse reduction on an annual basis within ten years. OGCI's members are BP, CNPC, ENI, Equinor, PEMEX, Petrobras, Repsol, Saudi Aramco, Shell and Total.

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vestments. CCUS projects tend to be large and complex. They usually involve multi-billion dollars of investments, multiple different parties and sets of expertise along their value chains. Development and build schedules can be as long as a decade.

Even the early-stage development of these projects is resource-intensive, requiring the deployment of teams with expertise across multiple commercial and technical disciplines, early interaction with stakeholders and sophisticated engineering design. It is often challenging for such complex and large scale projects to find the capital and resources to complete their initial development. As a result, investments at this stage tend to be too risky and speculative for any one company to undertake alone.

OGCI Climate Investments has the advantage of being able to draw on significant experience and resources among the member companies, while keeping the agility to move rapidly. It is building on the experience of its first early-stage CCUS project, a UK concept that aims to build the world's first commercial gas power plant using CCUS and provide carbon transport and storage infrastructure for a surrounding industrial hub. The fund's role has been to work with the project team to develop a commercially viable concept and basic engineering design. This would demonstrate the project's technical and commercial viability, helping the government to support it and the private sector to invest with confidence.

OGCI Climate Investments is now scanning dozens of early-stage CCUS projects globally. Its aim is to invest risk capital and deploy resources into a handful of projects that have the potential to reduce costs, create shared infrastructure and enable future progress globally and in specific regions. As with the UK project, once the viability of these projects has been demonstrated, OGCI will seek co-investment for the FEED and build phase from third parties.

Alongside these project investments, OGCI Climate Investments is investing in a broad range of novel carbon capture technologies for applicability on power and industrial flue gas sectors, as well as technologies that demonstrate the value of carbon utilisation in a range of industry sectors. Utilisation is unlikely to be able to absorb the enormous amounts of carbon that must be captured, but it helps to develop an understanding of the value of carbon dioxide as a molecule, and may play an important role in helping to unlock business models for a commercial CCUS industry.

At present, however, the utilisation industry is in its infancy and therefore faces many of the challenges that other emerging technologies and markets face. These include the limited availability of investment capital, and more specifically, the high cost and volatility of carbon dioxide supply. These problems will only be resolved as more and more innovators demonstrate the potential of their technologies.

Two of OGCI's first investments have been in companies which utilise carbon dioxide. Solidia Technologies is a US-based cement and concrete technology company which has developed patented systems for producing lower-emissions cement and concrete cured with carbon dioxide rather than water. Together, Solidia's systems lower the carbon footprint of cement and concrete by 70% and water usage by 80% throughout the concrete production process.

Econic Technologies is a UK-based company that has developed pioneering catalyst technologies that create value from carbon dioxide by incorporating it as a raw material into the manufacture of polyols, the base of all polyurethanes.

In the two years since OGCI announced it would be making CCUS a priority focus, it has stepped into several interlinked areas – early-stage projects, utilisation technologies, storage availability, policy mechanisms – where progress is needed to build the foundations of a commercial industry. Building on this experience, OGCI is starting to collaborate with a wide range of stakeholders to help get commercial-scale CCUS moving.

More information

www.oilandgasclimateinitiative.com

Expansion of the 45Q Tax Credit

The Energy Futures Initiative has compiled a comprehensive overview of the opportunities for application of the expanded federal tax incentives for carbon capture utilization and storage (CCUS), as well as the additional implementation challenges facing CCUS project developers and policymakers.

The Bipartisan Budget Act (BBA) passed by Congress on February 8, 2018 included expanded provisions for carbon dioxide (CO2) capture, utilization, and storage (CCUS). These provisions, based on Senate Bill S. 1535 (FUTURE Act) and its companion legislation in the House, expand and reform the Section 45Q tax credits originally enacted in 2008. They include an increase in the credit value for qualifying projects, a longer time horizon for developers to claim the credit, a more expansive definition of qualifying utilization projects beyond enhanced oil recovery (EOR), and eligibility of direct air capture. The provisions act like a production tax credit and are designed to encourage innovation in and adoption of low-carbon technologies related to CCUS, including direct air capture (DAC) of CO2 and conversion of CO2 into useable products.

The new 45Q provisions have the potential to significantly enhance the development and market diffusion of CCUS technologies and processes in both industrial and power applications, creating commercial opportunities both in the U.S. and abroad. The provisions provide greater market and financing certainty to help attract additional follow-on investment from the private sector. They will also likely help accelerate the pace of innovation in CCUS technologies and processes, and could mitigate asset risk for fossil fuel producers by enabling continued use of fossil fuels in a carbon-constrained world.

While the 45Q provisions represent a major step forward for emissions reductions, the size and duration of the credits may be insufficient to incentivize retrofits for the variety of facilities that are eligible, including many coal and natural gas plants. Also, the long-term post-injection monitoring, reporting and verification requirements could become an impediment for some operators, possibly limiting the universe of those that might otherwise take advantage of the credits.

To address these and other issues, a more comprehensive policy framework may be needed to maximize the value of the credits.

Key recommendations from the report

- The IRS should quickly issue the necessary implementation guidance, including clarification for qualifying projects regarding the commencement of construction.
- Because of the January 2024 timeline to commence construction, companies, states, and investors should act quickly to determine both how to best take advantage of these credits and what actions to take to maximize their utility.
- Tax credit exchange markets should begin to incorporate 45Q credit exchange mechanisms into their business plans.
- Congress should consider additional measures to facilitate and accelerate CCUS deployment, including addressing uncertainties regarding long-term post-injection carbon management, including monitoring, reporting and verification.
- Stakeholders should consider the adoption of a universal registry specifically designed to facilitate transactions between suppliers and buyers of CO2, with transparent and verifiable data, possibly through use of blockchain technology.
- DOE should significantly increase the level of federal R&D invesment in CCUS and largescale carbon removal technologies to accelerate the pace of innovation. Given the trajectory of capacity additions in the electric power sector, R&D investments should reflect a larger focus on natural gas generation.

Nonetheless, the new provisions are a critical step forward and will enable substantial emissions reductions for many facilities, especially industrial sites.

Given the short time to begin construction on projects, developers, states, and investors must act expeditiously to maximize the commercial and financial opportunities enabled by the expanded 45Q provisions and thereby kick-start larger scale deployment of CCUS.

Key findings

Numerous industrial CCUS projects could become commercially viable, especially ethanol, ammonia, and hydrogen plants, where the value of the credit may exceed the cost of capture.

Opportunities for CCUS deployment in the power generation sector (at both coal or natural gas generation facilities) may be more limited, primarily because the value of the credits over the 12 years of eligibility for each qualifying project is likely to be less than the costs for many potential new or retrofit CCUS projects. Other market factors, such as facility age, configuration and performance, as well as market structures for cost recovery, also will limit applicability.

In total, an estimated ~50-100M tons CO2 per year may be captured and stored through expanded 45Q-related deployment. This number will be sensitive to many factors, including public acceptance, the ability to transfer tax credits, the availability of CO2 pipeline infrastructure, and the readiness of storage sites.

More information

Download the full report:

energyfuturesinitiative.org

Element Energy / Vivid Economics report says CCS won't work without public-private collaboration

A new report shows that improving the dialogue and collaboration between public and private stakeholders would be crucial in supporting the deployment of CCS.

The report was prepared by Element Energy and Vivid Economics on request by the Oil and Gas Climate Initiative (OGCI) .

A common finding across technical and modelling studies such as IPCC AR5 and the IEA CCS scenarios is that CCS is vital to reducing emissions at lowest cost. However, both public and private sector stakeholders are hesitant to commit the resources necessary to scale-up and roll-out deployment of the technology.

"By recognising that CCS deployment is a shared beneficial endeavour, public and private sectors can collaborate to achieve scale-up, sais Emrah Durusut, of Element Energy. "Unfortunately, momentum in CCS deployment is currently low. A principal cause is that the dialogue between stakeholders has articulated the costs of CCS, without sufficiently articulating its value."

The report suggests that CCS technology is technically available but all market participants must become familiar with the technology and the contractual arrangements supporting its deployment. The scale-up phase proposed in the report comprises a limited number of full-scale projects, focussed on improving cost certainty and proving deliverability globally in key application sectors.

"The scale-up phase reduces costs but still carries significant risks that make it challenging to finance," said Alex Kazaglis, of Vivid Economics. "Once multiple projects have been successful, the roll-out phase focuses on standardisation. The different purposes of these two phases, risk reduction followed by efficiency, demand distinct policy treatments, with a greater role for governments earlier on."

The study also provides a timeline and comprehensive policy roadmap for the successful scale up and deployment of CCS, detailing the roles of government and business, and how policies may differ across regions. Policy options with a potential of achieving successful outcomes include:

• Obligation with CCS certificates: Emitters or fuel suppliers are obligated by law to ensure a certain amount of CO_2 is captured and stored. Certificates are awarded for storage and can be used to meet the obligation and traded freely.

• Emission performance standards (EPS) with CCS certificates: An EPS sets minimum emission standards by which emitters must abide. The tradeable certificates function similarly to the obligation scheme and can be used to meet the standard.

• Public procurement, including contract for difference (CFD), entails the government directly procuring CCS. It does not imply the government necessarily funds CCS.

• Tax credits are reductions in the tax liability of firms if they perform CCS. Credits can be provided for stored carbon but also for capital investment.

• Other options, such as carbon price (with the exception of Norway) have been insufficient to deliver CCS commercially to date.

Policy instruments should be tailored according to global regions where the specific political, legal and cultural contexts are considered. Secondly, a policy instrument should not be solely focussed on providing revenue for stored carbon but also needs to incentivise efficient investment in CO_2 network infrastructure. Finally, all parties will have to contribute to the scale-up costs of CCS: governments in terms of tax breaks or investment, the private sector via investment measures or certificates and end users via levies (e.g. fuel consumers).

The timing of action

A scale-up phase of deployment is required to counter a prevailing view that CCS initiatives are risky and the technology is not available in the near term. It is not enough for the technology to be technically available. Market participants must become familiar with a new technology and the contractual arrangements supporting its deployment.

The scale-up phase proposed in the report comprises a limited number of full-scale projects, focussed on improving cost certainty and proving deliverability globally in key application sectors, such as flexible gas-fired power (in regions with high and increasing renewable energy penetration), coal-fired power in baseload applications, iron and steel, cement, and chemicals.

A successful track record in the scale-up phase builds trust and reduces risk. Scale-up projects are templates for generic CCS applications with significant cost elements typical of subsequent projects. The roll-out phase which follows has a focus on standardisation and cost effectiveness. The different purposes of these two phases, risk reduction followed by efficiency, demand distinct policy treatments.

The viable policy instruments to deliver CCS in the scale-up and roll-out phases

A CCS obligation could be a policy instrument for delivering efficiency in the roll-out phase for specific regions and market structures. The assessment of the CCS obligation shows that the obligation ensures a target for CO2 stored can be met and the market element creates efficiency by allowing obligated parties with high CCS costs to fund lower cost CCS opportunities at other sites. However, these strengths do not imply a CCS obligation is the appropriate policy solution in all regions as the weaknesses of the obligation scheme, such as its administrative complexity, may outweigh its strengths in some locations.

Public procurement is another leading option. The two can also work together at the scale-up phase, to build trust, using the obligation as a means of tuning the allocation of the costs of procurement. Indeed, market mechanisms cannot work alone in the scale-up phase, because they depend on sufficient market scale. Nevertheless, from the start it is valuable to have a clear future, sustained policy commitment, pathway and set of instruments.

Public procurement could offer strong incentives for CCS projects in the scale-up phase. The inefficiency that may be expected from public procurement, that might be acceptable in the early stages of CCS deployment, could be addressed during the roll-out phase through transition away from public procurement to a market based mechanism. Not all jurisdictions will wish to make this transition and some may not possess the scale or capabilities to do it.

Tax credits show promise in mitigating first-of-a-kind costs and could have wider use. An example is their use in conjunction with a tradeable obligation scheme, when CCS costs are expected to fall over time. Tax credits for initial capital expenditure can make the initial capital outlay more manageable, with the obligation and certificate revenue covering operating costs. Without tax credits that begin generously and taper down over time, the certificate price might fall steeply over time, making financing difficult. Tax credits could have a wider, longer-term role to play in enhancing the commercial returns to investment along the CCS chain even after the first generation of plant have been built.

Care has to be taken in the design of policy instruments to avoid unintended consequences. A poorly-designed instrument could encourage carbon-intensive emitters to increase their share of production, to the detriment of the total quantity of emissions released, when a well-designed scheme would not. This problem is easily avoided by paying only for the CO2 that is stored below the emissions of a benchmark carbon-efficient production technology.

Design features such as price floors and ceilings as well as complementary instruments such as advance market commitments may mitigate policy risk and provide initial liquidity. Following the well-established economic principle of using one policy per market failure, a package of measures emerges in which several instruments each addresses one aspect in which the market or another policy might fail.

There is no one-size-fits-all package. Jurisdictions may choose policy mixes based on several considerations. Jurisdictions will have their own preferences, considering: policy culture; market size; market structure; endowment of institutional capability, technical skills and pore (storage) space. These regional circumstances are illustrated in four places. In India, public procurement suits the state-owned enterprises and absence of market mechanisms. The same is true in China, although China is actively testing carbon pricing market mechanisms. Saudi Arabia's high market concentration and state ownership makes public procurement seem most feasible. In contrast, the culture and practice of North America and Europe suit market mechanisms, suggesting a CCS obligation with tradeable certificates, supplemented by tax credits.

Government can support investment by taking on long term CO2 storage liabilities which are highly challenging to privately adopt or insure. Certainly the long-term post-closure liabilities could be transferred to government, and the geological leakage risks during the filling of the store could perhaps be managed through a limited liability mechanism. It may be more equitable for CO2 storage post-closure costs to be covered by an independently managed fund into which storage site operators and government pay over time, rather than accumulating costs for future taxpayers.

The conditions for collaboration

Successful cooperation relies on the expectation of a future agreement. The conditions for a future collaboration are mutual self-interest, urgency, experience of past successful arrangements of a similar nature, and a mechanism to encourage compliance over time. The next steps for parties are to determine the key terms of such collaborations.

The debate around the value gained by developing CCS remains immature but appropriate decision making tools are available. The question is whether there is greater value from backing CCS or from not backing it. Recognising this, governments can compare future costs and policy arrangements to deliver a 2°C goal using CCS with scenarios in the absence of CCS. They can then apply an appropriate decision making analytical framework, for example, the minimum regret or maxi-min rules, which suit a cautious decision-maker by avoiding the worst outcomes. In doing so, they might have more success in informing decisions.

The cost of CCS deployment will have to be shared, and here too, agreement over principles could lay the foundation for subsequent discussion of details. The principles of distribution of costs are to seek the widest funding base (affordability), make the polluter pay, place the incentive closest to the mitigation decision, ask for contributions from beneficiaries and assign risks to those who have most control of the risks and the appetite to bear them.

Applying these principles, all parties must contribute to costs, but the burden shifts over time onto consumers. Industry and government pay more at the outset, reflecting that business is developing an option that maintains the value of its underground and overground assets and that government is acting to create an option for future consumers. Those future consumers will benefit and they will pay the majority of future costs. In practice, cost can be shifted to the private sector via a levy or, in the case of an obligation, a declining level of government certificates purchase.

Government has an important role in reducing or adopting risks from the private sector and coordinating delivery as CCS scales up, although effort can shift towards the private sector over time, achieving more efficient outcomes. By signalling the transfer of these roles to the private sector in advance, alongside overall policy direction and timelines, governments help to build confidence and strengthen the pool of projects under development.

More information

www.element-energy.com
www.vivideconomics.com

CO2 Capture Project Annual Report

The CO2 Capture Project (CCP) was formed in 2000 to advance technologies for CO2 capture and geological storage to help make CCS a viable option for CO2 mitigation. The 2017 Annual Report provides an update from the Teams that make up the CCP – Capture, Storage, Policy & Incentives, and Communications.

The CCP4 Capture program, led by Raja Jadhav, made good progress in 2017 with the initiation of several technology development projects focused on pilot scale testing of novel capture technologies. These included two pilot projects related to novel solvent development, one of which was completed in 2017. Another project, involving development of an adsorbent using a novel 3D printing technique, was also initiated.

The evaluation of novel CO2 capture technologies continued as a key part of the CCP4 Capture program in 2017. A detailed assessment of two promising options identified in earlier phases of work was carried out, while further work was initiated on a new set of novel capture technologies.

The Capture program consists of four key scenarios. Much of the work has focused on applications in refining operations, heavy oil extraction and natural gas combined cycle (NGCC) power generation. Capture from natural gas extraction is the latest scenario for CCP4.

Novel capture technology assessment

Work continued in 2017 on the evaluation of novel capture technologies as part of WP2 and WP3 scopes, following completion of WP1 in 2016, in which LEAP (Laboratorio Energia e Ambiente Piacenza, Milan) undertook a techno-economic assessment of five such technologies.

WP2 work

WP2 was completed in 2017, which included detailed analysis of two technologies from WP1 – a high-pressure solvent absorption option (Pi-CO2); and a molten carbonate fuel cell option (MCFC) for post-combustion capture from natural gas-fired processes.

The Pi-CO2 technology assessment in WP2 involved evaluation of a hybrid process scheme that included a high-pressure aqueous solvent and a membrane. This was evaluated and the avoided cost estimated to be lower than the non-hybrid configuration in WP1 but still higher than the MEA base case.

For MCFC, detailed evaluations of integrated and non-integrated (retrofit) process configurations were carried out. The integrated process scheme was found to have the lowest CO2 avoided costs at ~$50/tonne, which is 30% lower than the MEA case. For the non-integrated case, the CO2 avoided cost was estimated to be ~$76/tonne, which is slightly higher than the MEA base case.

WP3 work

A scope for WP3 was agreed during 2017 and the work is underway. The scope includes assessment of piperazine (PZ) and C-Capture solvent processes for comparison with WP1 cases; estimation of cost of CO2 capture from small gas engines using the MCFC technology; and evaluation of the PZ solvent process for CO2 capture from high-efficiency gas turbines. Work on these projects, briefly described below, is underway with results expected in March 2018.

C-Capture solvent process assessment

LEAP carried out techno-economic assessment of a novel solvent developed by C-Capture Ltd., based on the preliminary performance information available from laboratory tests. The analysis indicated that the regeneration energy of the novel solvent was about 1.5 GJ/tonne CO2, although additional electrical energy will be required in the regeneration process. The preliminary analysis indicated that the CO2 avoided cost of the C-Capture process was lower than the MEA base case.

CO2 capture from small-scale gas engines

LEAP is performing a preliminary techno-economic assessment of CO2 capture from small-scale gas engines using the MCFC technology. The combined CO2 emission rate of the gas engines is about 57 tonnes/day. The aim is to understand the cost advantages of the MCFC technology, if any, over MEA-based systems for CO2 capture from smaller combustion sources.

PZ Solvent pilot scale testing

The CCP participated in pilot-scale testing of the PZ solvent at University of Texas (UT), Austin. The testing was conducted under simulated NGCC flue gas conditions (3.5 mol % CO2) with 5m PZ solvent and the performance was evaluated under eight operating conditions. An Advanced Flash Stripper configuration was employed to achieve a lower energy requirement for the solvent regeneration.

The pilot scale tests were successful – more than 90% CO2 capture was achieved and the solvent regeneration energy was estimated to be <3 GJ/tonne, which included some heat loss from the smaller-scale pilot plant. The pilot scale results matched well with those predicted by a comprehensive simulation model prepared by UT Austin. The CCP has decided to participate in a larger-scale pilot of the PZ solvent process in 2018.

Storage Monitoring and Verification

The year saw good progress in a range of projects from the CCP Storage, Monitoring & Verification (SMV) Team, led by Scott Imbus, despite some difficulties which had previously hindered progress in some areas.

The Mont Terri well sealing experiment team has successfully tested the first sealant, while a number of other SMV projects were completed, including the FOAK/NOAK cost assessment and a study into the quantification of CCS in Enhanced Oil Recovery (EOR) as de facto storage.

EOR as de facto storage

The CCP4 SMV team sought to quantify the extent to which CO2 EOR constitutes de facto CO2 storage through a simulation study, which was completed in 2017. The study provides valuable insights into the optimization of hydrocarbon recovery vs CO2 storage, with implications for revenue and credits.

The project was conducted with the University of Texas Bureau of Economic Geology (BEG) and partially funded by the US Department of Energy (DoE). It used production and fluid analytical data from a recently operated CO2 EOR flood at Cranfield, Mississippi, USA, and reservoir simulation to predict the trapping mechanisms and storage volumes of CO2 75 years into the future (after 25 years of EOR and 50 years of post-injection).

Four injection simulation scenarios were examined:

- CGI – continuous gas (CO2) injection
- WAG – water alternating gas injection
- WCI – water curtain injection (water injection wells at the water-oil contact) with CGI
- Hybrid WAG and WCI.

The most important overall finding was that the field development strategy selected by the EOR operator has a very significant impact on the relative importance of the different CO2 trapping mechanisms for a reservoir.

In simulations, while CGI maximizes oil recovery and CO2 storage in absolute volume terms (mainly because more CO2 is injected in this scenario), WAG, the most commonly employed approach currently, appears to offer a more balanced approach. WAG can produce large amounts of oil and store large volumes of CO2 with the lowest gross utilization ratio (the amount of CO2 injected to produce one unit of oil). WAG also improves storage security by reducing the amount of mobile CO2 relative to CGI, as it is the mobile CO2 phase that has the greatest potential to move towards the surface.

Plugged and abandoned well contingencies

The CCP SMV Team has begun a new project with the aim of addressing leakage issues that can occur with older plugged and abandoned (P&A) wells. The study is jointly conducted by Lawrence Berkeley National Lab (LBNL) and Stanford University.

Vintage wells of poor or unknown construction, location or P&A method may introduce an unexpected vulnerability to CO2 storage projects. Such fluid leaks are particularly problematic given their inaccessibility to determine the location and nature of the defect/conduit and the potential for long-term, persistent leakage that could impact groundwater.

A four-phase program has been set up with Stanford-LBNL to address this, with data compilation and modelling eventually leading to the design of a slim well Modular Borehole Monitoring tool and shallow and deep site tests of intervention technologies.

To date, the joint team has developed an earth model and flow simulation and assessed how an existing monitoring system (or landowner observations) may reveal an anomaly. Also, what technology can be brought to bear to qualify that anomaly as originating from a storage reservoir and, if so, how to localize and characterize it so that it can be accessed and mitigated.

The first phase of the project will be completed in mid-2018, at which time a decision will be made on whether to launch the second phase.

Aquistore CO2 storage project collaboration

CCP4 is planning a repeat Electromagnetic Monitoring (EM) survey (over the 2013 CCP3 baseline) to better assess the viability of electromagnetics as a cost-effective monitoring technology, following injection of ~80MT of CO2 by the operators at the Aquistore site in Saskatchewan, Canada. Currently, modelling of expected resolution for placing a downhole source in the observation well is being updated using the most recent reservoir simulation data. The repeat survey is scheduled for mid-2018.

The Aquistore CO2 storage project presents an opportunity for other surveys, including testing a borehole microgravity logging tool. This is an emerging technology that would bring substantial cost savings to CO2 monitoring programs if found to be effective.

Discussions with Aquistore staff continue, with the aim of developing a common reservoir flow model as the basis to integrate results of multiple monitoring surveys (e.g. surface seismic, EM borehole microgravity and possibly others) at the site over the past several years.

Policy and Incentives

The CCP Policy & Incentives (P&I) Team, led by Arthur Lee, followed up its 2016 study on the regulatory implications of transitioning CO2 EOR sites to CO2 storage with a deep dive report on the same subject in two areas of important CCS/EOR activity Alberta and Texas.

The starting point for these studies is that oil production/EOR regulations were not originally written to cover long term underground storage of CO2 as a CCS project. The 2016 report has identified that although there are no technological barriers to be overcome, there are legal, regulatory and economic challenges across jurisdictions which must be addressed to allow EOR projects to serve as CCS projects.

The 2017 report CCP4: Review of CO2 EOR Transitioning to CCS in Texas and Alberta took this further and looked at the jurisdictions of Texas and Alberta through two lenses firstly, the existing regulatory pathway for CCS permitting without EOR; and then, what is needed for a CO2 EOR scheme to gain credit as CCS and where regulation may be a barrier to that transition. Each key project stage is covered, from planning and permitting, through to operation, decommissioning and closure, with case studies from each jurisdiction providing real life insight.

The report found that, even in two relatively advanced EOR/CCS areas like Texas and Alberta, there are still gaps and uncertainties in the regulatory frameworks that need to be addressed for CO2 EOR projects to transition successfully to CCS.

More information

The full Annual Report and the Review of CO2 EOR Transitioning to CCS in Texas and Alberta report is available at:
www.co2captureproject.org

How Total and Statoil plan the 'energy transition'

The opening debate at this year's EAGE annual event in Copenhagen in June, included senior representatives of Total and Equinor talking about how they see the role of gas in the "energy transition era", with some discussion of carbon capture.
By Karl Jeffery

The opening debate at this year's EAGE (European Association of Geoscientists and Engineers) 80th annual meeting in Copenhagen in June addressed the role of oil and gas in the "energy transition era". Senior representatives of Total and Equinor took part, along with Paul McConnell, research director Global Trends with Wood Mackenzie.

The moderator was Danish journalist Martin Breum, author of a number of books on the future of the Arctic and global warming, among other projects.

Total

Arnaud Breuillac, President Exploration and Production, Total, said that the company plans for 20 per cent of its "production" in 20 years to be renewable, with $25bn to $30bn deployed in renewables by then.

Total has added a fourth main department of the company, "gas, renewable and power," to join its three traditional divisions of exploration and production, refining and petrochemical, trading and shipping.

This new fourth department should be grown as a profitable business, he said. In other words, the company will only invest in renewables if it believes the investment will be profitable.

Mr Breuillac is one of six people on the company's executive committee, the others being the CEO, the CFO, and the presidents of Total's other three divisions.

Mr Breuillac believes that the main switch in energy we will see over the next 20 years will be from coal to gas. So one of the biggest contributions an oil company can make to the climate debate is to increase gas production, thus helping keep gas prices low, because this means that the market share for gas can increase.

Total's forecasts of future oil production over the next few decades range from 70mbpd [million barrels per day] to 120 mbpd, and the factors driving it "will depend on a lot of things we don't [yet] master," he said.

Overall, it is impossible to know where the disruption will be and where the value will be. "You can't make a lot of money with solar cells," he said.

Total believes in making it clear to all stakeholders about the need for oil and gas in today's society.

It is difficult to see how world overall energy demand will come down, with forecasts of a population of 9 billion people in 20 years, he said.

Total sees the need for "carbon neutrality" to make oil and gas production acceptable to society (so there are zero overall CO2 emissions). To do it, there is a need to develop solutions like carbon capture and storage, he said. To help get there, Total is currently spending 10 per cent of its total research and development budget on CCS, he said.

"Total is currently spending 10 per cent of its total research and development budget on CCS" - Arnaud Breuillac, President Exploration and Production, Total

Equinor

Jez Averty, senior vice president Development & Production, Equinor (formerly known as Statoil), said that the company sees future oil supply and demand as very uncertain, with estimates that range between 60 and 120m bopd by 2050.

It is possible that the world can limit CO2 emissions and global warming. But in many scenarios for the future, made by different analyst companies, that's not what happens, he said.

Today, there are mixed signals on what is happening, with carbon prices slowly increasing, booming sales of electric cars, record wind and solar generation, and decreasing renewables costs. But there is also a growing demand for coal and oil, and CO2 emissions are still going up.

Equinor has set up a new business area for renewables, and set a target for how much of its total capital expenditure will go into renewables by 2030. It means that the company becomes more "energy" than oil and gas.

To steer through the uncertain times, the company's new strategy is "high value, always safe, low carbon", he said.

"We don't have the answers, we don't really know where we're going," he said. "We need to be profitable and competitive at all times. We'll contribute to transformation of industry. We are committed to delivering energy in a low carbon future," he said.

The name Equinor is made up of Equi, meaning equilibrium and equality, and Nor for Norway, he said. "This is a name much more future orientated than "state oil".

Mr Averty said that the company believes that the emissions from its operations are "about half the global average". It helps that the company is able to power many of its offshore platforms with electricity generated from hydropower on land.

In all of its renewable investments, "every decision we make has to support us being profitable and competitive at all times," he said.

The company is looking for parts of the whole energy value chain where it can add value, or where it is best to bring in a partner – for example for floating wind it partnered with a specialist company.

The main change which needs to be made in order to reach the Paris two degree target is for "coal to disappear," he said. There also needs to be a reduction in demand for oil and gas. But there will still need to be significant investment in oil and gas.

"One challenge with CCS is working out how it could be an asset, or part of a value chain, rather than purely a cost" – Jez Avery, senior vice president Development & Production, Equinor (formerly Statoil)

Getting to a "2 degree scenario" needs a co-ordinated policy response, such as for carbon capture. "In Northwest Europe you see a lack of concessions [government allowances] not a [lack of] willingness to invest," he said.

One challenge with CCS is working out how it could be an asset, or part of a value chain, rather than purely a cost, he said.

The changes in society and industry will require people with science, technology, engineering and maths skills, Mr Averty said. They will need to be able to leverage digitisation.

But the industry will also need "smart, curious, engaged people, to solve problems," he said.

"If that looks interesting, this is an industry for you."

Paul McConnell, Wood Mackenzie

Paul McConnell, research director Global Trends, Wood Mackenzie, said he sees energy markets entering a new phase.

Among other factors, 2017 has been a big year for shareholder activism for oil and gas companies, pushing companies in a 'greener' direction, he said.

Mr McConnell also predicts a peak oil demand by 2035.

Wood Mackenzie predicts that global CO2 emissions will continue to rise, and the Paris CO2 targets will not be met, although progress will be made to reduce CO2 emissions.

Wood Mackenzie predicts that global CO2 emissions will continue to rise, and the Paris CO2 targets will not be met, although progress will be made to reduce CO2 emissions –. Paul McConnell, research director Global Trends, Wood Mackenzie, Consumption of electricity will increase twice as fast as fossil fuel consumption, and the overall power (electricity) mix will be 20 per cent renewables by 2035, the company predicts.

Wood Mackenzie is often asked whether oil and gas companies should even be in renewables (in other words, whether they should they leave it to renewables companies). "In many ways that is a valid question," he said.

The answer is not clear. Perhaps the best approach is for oil companies to be flexible and responsive and find out where the business opportunities are, he said.

The EAGE Executive Session was well attended

Last man standing strategy

Mr McConnell noted that oil companies are adopting to the uncertainty with different strategies. For example, the former Dong Energy (now Ørsted) has decided to be solely involved in renewables, which is one way to adapt to the future.

Another approach could be like ExxonMobil, to declare that you have enough low cost reserves to produce at whatever the oil price goes down to. This could be considered a "last man standing" strategy for the oil industry, he said.

Total's Mr Breuillac said that the company does indeed "hope to be one of the last standing", and does not believe in opposing any of the primary energy sources. "Even coal will continue to be used," he said.

Equinor's Jez Averty said "our ambition is to be thriving in the future, not last man standing".

Electric vehicles

With the growth of electric vehicles, the different sources of primary energy will become more intertwined than they have been in the past, with many different ways to generate electricity, rather than only one way to make gasoline, said Paul McConnell from Wood Mackenzie.

Oil companies cannot do very much to moderate oil demand, said Equinor's Jez Averty. But if electric vehicles are as cheap as normal vehicles, people will start buying them.

So the main factor which could change oil demand is the development of new technology, which is hard to predict.

Total's Mr Breuillac said that the company's analysis of the impact of replacing combustion engineers with electric vehicles showed that there could be a reduction in oil demand by 6-8m bopd (million barrels of oil per day) by 2040. This is only 6-8 per cent of the total current oil demand of 100m bopd.

So this impact would be significant, but "doesn't mean all the oil is out," he said.

Pace of change

Equinor's Jez Averty stressed that the amount of change required to get to a 2 degree scenario could be described as "revolution" in the pace of change. For example, energy efficiency currently improves 0.9 per cent a year, it will need to increase to 3 per cent a year.

Also, "the energy transition will be decided in China, India, and SE Asia," he said. "Norway is totally irrelevant. Europe is not particularly relevant."

Wood Mackenzie's Paul McConnell agreed that the change has to happen in Asia. "It is just arithmetic," he said. But China is going about the change "pretty quickly", with electric vehicles "all over the place in Beijing, cheap utilitarian vehicles," he said. China is also making big investments in batteries and solar power.

Equinor's Mr Averty noted that although the change in China is made by private companies, they are closely linked to the state, so it can be considered a policy change as well.

More information

The opening ceremony of EAGE, including this debate, is on YouTube at:

www.youtube.com/watch?v=QUW0XqDIfVc

www.eage.org

EU chief scientific advisors examine Carbon Capture and Utilisation

The European Commission's Scientific Advice Mechanism has published an opinion on the potential of CCUS and the best way to implement it.

Can "carbon capture and utilisation" technologies contribute to mitigating climate change? And if so, how should we choose in which of these various technologies to invest? These are some of the issues explored in the fourth scientific opinion of the European Commission's Group of Chief Scientific Advisors.

Carbon capture and utilisation (CCU) technologies remove CO2 from the atmosphere and use energy to convert it into various useful products such as fuel, building materials or plastics. But at present, there are no accurate methods to determine the climate mitigation potential of these technologies. This has hindered investment and thus their deployment.

The opinion draws on the best available scientific and technical evidence from across Europe. The advisors observe that for CCU technologies to contribute to climate change mitigation, the energy used in CO2 conversion must be of low carbon origin. In addition, and because the converted carbon may be held in the product for a variable amount of time and not always permanently, the assessment of the climate mitigation potential of the technologies also depends on a life cycle assessment (LCA) approach that takes into account the fate of carbon once released from the product.

The opinion was drafted at the request of Miguel Arias Can~ete, Commissioner for Climate Action and Energy. He said, "We are determined to meet our commitments to curb climate change, and for that we have to explore every possible avenue. This scientific opinion provides a roadmap for specifying how carbon capture and utilisation can be part of this effort."

The opinion concludes that:

• CCU may play a role to de-fossilise the economy and help reaching climate change mitigation targets;

• It can contribute to leaving fossil carbon in the ground, and closing the carbon loop above the ground;

• CCU can also accomplish a number of other services to society with a more efficient use of energy;

• The uptake of CCU will depend on the availability of abundant lowcarbon energy and a favourable legislative and investment environment;

• The introduction of CCU could start with high-density CO2 streams from industrial processes and progressively move towards capturing CO2 from less dense sources.

The opinion draws upon a comprehensive review of scientific literature, including the Scientific Advice to Policy by European Academies (SAPEA) Evidence Review Report, a wide-ranging consultation with the most relevant scientific experts and policy, industry and civil society stakeholders. It is published at the time of the 3rd ministerial meeting of Mission Innovation in Malmö, Sweden. Countries and organisations participating in Mission Innovation, including the European Commission on behalf of the EU, have joined forces to accelerate the clean energy revolution.

Recommendations

• The development of a rigorous cross-sectorial and systemic methodology that includes a simplified Life Cycle Assessment to enable the calculation of the climate mitigation potential of various CCU technologies. This should be rolled out beyond the EU, for example through the UN's Framework Convention on Climate Change.

• The development and agreement of funding criteria for candidate CCU projects, requiring them to be feasible and green, to be superior to existing alternatives, to demonstrate additional benefits beyond climate mitigation, and to be ready to integrate with existing systems.

• CCU novel technologies. CCU technologies are not stand-alone but part of a system. Both TRLs (Technology Readiness Levels) and IRLs (Integration Readiness Levels) should be considered to assess the readiness of and the contribution that CCU technologies can make.

• That the EC develops a regulatory and investment framework to enable CCU deployment. It is strongly recommended that European Commission develops a crosssectorial and systemic regulatory and investment framework for CCU applications comprising a set of clear rules and operational guidelines for CCU applications.

• International framework - Party to the Convention on Climate Change. It is recommended that the European Commission advocates the methodologies of the Convention on Climate Change, the Kyoto Protocol and the Paris Agreement in international arenas, in particular in the scope of the UNFCCC.

More information

ec.europa.eu/research/sam

Growing CCS - key messages of the 13th CO2GeoNet Open Forum

The theme of the 13th CO2GeoNet Open Forum was "Growing CCS for a sustainable future – linking local actions for a global solution". The title underlines the urgency to implement full-scale CO2 Capture, Use and Storage (CCUS) projects across the world, and emphasises the existing diverse CC(U)S opportunities that will enable tailored solutions for individual regions, local communities and industrial entities.

The following key messages extracted from the CO2GeoNet Open Forum presentations and panel discussions, were voiced by the forum participants which included researchers, regulators and decision makers, industrial stakeholders and CCS project operators, and journalists.

CCS is back on the agenda

Increasingly, national governments are committing themselves to challenging emission reduction targets and decarbonisation strategies. More governments now accept CCS as one of the most important mitigation options to achieve the Paris Agreement Two Degrees Scenario (2DS) than ever before. Impartial stakeholders looking for the optimal decarbonisation solution are now beginning to turn to CCS.

CCS is not just a bridging technology associated with fossil fuel phase-out. Climate models show that CCS will be even more important after 2030, when new emerging technologies (such as hydrogen production, alternative hydrocarbons, etc.) are fully deployed.

Dialogue is key to integrating the necessary climate-change mitigation technologies (CCS, renewables, hydrogen, etc.) and achieving a low emission future.

Industry says: "We need CCS!"

The industrial stakeholders clearly stated "We need CCS"! Leading industrial entities now recognise that industry needs to be sustainable. Industrial initiatives planned around emission clusters and storage hubs are already on the table.

Jan Ros, of PBL Netherlands Environmental Assessment Agency, giving the opening Keynote lecture "What our energy future will look like and the role of CCS" at the 13th CO2GeoNet Open Forum

CCS is the only large-scale option currently available for process emissions (e.g. from steel, cement, fertilizers, refineries, natural gas treatment, heavy oil, waste-to-energy, hydrogen production, other chemical industries). If the hydrogen industry grows as expected (multiplying by a factor of at least 5 by 2050), CCS is needed to ensure this is a low-carbon fuel.

Commercial stakeholders require consistent policies and political support that offers predictability (not necessarily certainty), effective and cost-efficient laws and regulations, reduced costs and increased efficiency through research and development.

No 1.5DS without CCS

Many NGOs have expressed frustration that Europe still behaves as in the pre-Paris Agreement state. The message from the Open Forum was clear: either do CCS or forget about any below 2° scenario!

CCS offers a flexible and adaptable opportunity to meet climate targets through its deployment in different regions in different modes (power, industry process emissions, supporting a hydrogen economy, etc.). Models indicate that, in order to achieve 2DS, 52 Gt of CO2 must be stored from the power sector plus a further 29 Gt of CO2 needs to be avoided by 2050 from industries with high process emissions (ETP 2017, IEA). The scale of this action is equivalent to the current oil and gas industry.

In the very short term, it is possible to reach the climate reduction targets without CCS, but from 2025 onwards, CCS is essential. Therefore, actions need to start now in order to ensure that CCS is deployed in time. Excluding CCS from the models results in an exceptionally high cost for achieving 2DS. The longer we delay, the more drastic the actions that will be required. The more ambitious we are in our climate targets, the more we need CCS.

To achieve the Below 2° Scenario (B2DS), net negative emissions of CO2 are not optional, but mandatory. A clear advantage of CCS is that it is capable of delivering negative emissions at large scale. Biomass currently accounts for 10% of global energy supply.

Attendees of the 13th CO2GeoNet Open Forum in Venice

An increasing number of BECCS projects would need to emerge globally in order to achieve net negative emissions, some of which could include adapting existing plants to use biomass plus CCS. However, the supply chain needs to be developed, consistent policies ratified and the resource limitations fully defined.

Regional actions for a global solution

Given the global variations in economic development, available natural resources and social and cultural environments, the optimal emission mitigation solution will not be the same for all regions.

The use of domestic energy resources is essential for non-OECD countries to ensure better social and economic wellbeing. A strong belief exists that energy independence is achievable on a low carbon platform. CCS as a recognised climate-change mitigation technology is suitable for all regions in the world. Regional development is strategic for the EU (and all regions of the world) – therefore a tailored local approach is in line with strategies to achieve global solutions.

Sharing facilities and research efforts through international cooperation is already underway and further encouraged. Alignment and integration of these regional developments wherever possible

will result in greater efficiency. Mechanisms such as Mission Innovation, CSLF and national initiatives can play their role here. In addition, support (in the form of dissemination, technological, financial) for non-OECD countries is essential to facilitate deployment of CCS projects globally.

Large-scale installations already in operation prove that CCS works and that the economics can be positive and manageable. More strategic projects are needed in Europe to roll out CCS and to realise commercial opportunities. Every new installation has the potential to reduce costs. Further pilot and demonstration projects are crucial and an apparent dilemma is should we go small and safe or large and challenging? The consensual answer is start simple – stay flexible – upgrade.

So how do we get there?

Sustained political support is the most important enabler. CCS should form an integral component in national climate-change mitigation strategies. EU legislation is CCS ready.

We now request a level playing field with other climate-friendly technologies – all other low carbon options that are well advanced have all been supported in some way (policy and/or financial) to get them up-and-running.

Subsidies and/or incentives and tailored financial mechanisms (Green Climate Fund, International Bank, etc.) should help governments and industry to establish their national CCS plans and to boost commercial uptake of CCS. Political and economic stability is essential as it can take around 10 years to advance from concept to a working CCS project.

Design of (international) hubs and clusters will make CCS even more technologically and economically efficient (particularly for industries with high process emissions). Cost reduction is also expected through optimisation of operations, economy of scale, and international cooperation.

Lack of public awareness is also a key barrier. What climate targets mean for people and the role for CCS need to be more clearly expressed in a relatable manner. New ways of interacting with the public are being developed (e.g. ENOS project at **www.enos-project.eu**).

Recent studies show that the major concerns of the local population on CCS focus around mismanagement and non-appropriate operating of storage facilities in their neighbourhood. The public demand clear regulations and independent verification.

Climate impacts are global, not local. Everyone (regulators, scientists, engineers, the public, journalists, etc.) has a role to play in preventing negative climate impacts, using their expertise to move towards a sustainable way of life. Fuller dialogue between different sectors will optimise the impact of regional actions for a global solution to climate change.

More information

Full details of the 13th CO2GeoNet Open Forum are available at:

conference2018.co2geonet.com

Projects and policy news

NET Power project achieves first fire milestone

www.netpower.com

NET Power has successfully achieved first fire of its supercritical carbon dioxide demonstration power plant and test facility located in La Porte, Texas.

First fire is a critical milestone for the demonstration plant, as it validates the fundamental operability and technical foundation of NET Power's new power system, which is designed to produce low-cost electricity from natural gas while generating near-zero atmospheric emissions, including full CO2 capture. The achievement also confirms the operation of Toshiba's combustor at commercial scale, as several 50MWth combustors will be used together in NET Power's 300MWe commercial facilities.

Firing of the combustor involves the integrated operation of the full NET Power process. Following rigorous testing, the combustor will be integrated with the turbine and power will be generated. NET Power is targeting the global deployment of 300MWe-class commercial-scale plants beginning as early as 2021.

The plant is designed to demonstrate NET Power's Allam Cycle technology, which uses a new turbine and combustor developed specifically for the process by Toshiba. Using carbon dioxide (CO2) as a working fluid to drive a combustion turbine, the Allam Cycle eliminates virtually all emissions from natural gas power generation without requiring expensive, efficiency-reducing carbon capture equipment.

In parallel with these demonstration plant tests, NET Power is advancing the development of commercial-scale 300MWe natural gas plants. NET Power is working on projects with power generation, oil and gas, and industrial companies in the U.S. and globally, as well as a number of governmental agencies abroad.

With the passage of 45Q carbon capture tax credit reform in the U.S. and the demand for low-cost CO2 in industrial processes that use and sequester CO2, the company sees a large demand for NET Power plants and Toshiba turbines, beginning in the very near term. Existing natural gas plants burn natural gas with air, which is a mix of oxygen and nitrogen. These technologies emit CO2, which is difficult and expensive to separate from the nitrogen and residual oxygen. Unfortunately, this has made carbon capture uneconomic for traditional power plants.

NET Power addresses the cost hurdles of older technologies with a novel process—an oxy-fuel, supercritical CO2 power cycle—that produces electricity efficiently while inherently eliminating all air emissions. The system burns natural gas with oxygen, as opposed to air. Additionally, instead of using steam, the cycle uses high-pressure CO2 to turn a turbine, in effect turning the CO2 problem into the climate solution.

NET Power produces only electricity, liquid water and pipeline-ready CO2, as well as valuable argon and nitrogen, all while operating as efficiently as most natural gas power plants in operation today. Additionally, for a small reduction in efficiency, the technology can operate without water. The technology will serve as an affordable and reliable cornerstone of the world's clean energy future.

NET Power is a collaboration between Exelon Generation, McDermott, and 8 Rivers Capital. Constructed over a 2-year period, the company's 50-megawatt thermal (25MWe) demonstration plant is the world's only industrial-scale supercritical carbon dioxide-based power plant and CO2 cycle test facility.

UK commits £21.5 million to CCUS innovation

www.gov.uk

The UK is to lead an international challenge with Saudi Arabia and Mexico to remove carbon from emissions.

It is one of 7 Mission Innovation challenges announced in 2015 at COP21 with the UK setting out £21.5 million of funding for innovative new Carbon Capture, Utilisation and Storage (CCUS) technologies.

The aim of the funding is to invest in innovation that could reduce the cost of the technology by supporting its development so that CCUS can become commercially viable at scale.

While there are currently 22 plants in operation or construction, the UK has the opportunity to become a world leader in this field.

There is a global consensus that carbon capture will be critical in meeting the aims of the Paris Agreement and supporting clean growth. This technology can capture carbon dioxide emissions from industry or power generation as well as support low carbon hydrogen production.

Energy and Clean Growth Minister, Claire Perry said, "My ambition is for the UK to become a global technology leader in carbon capture, working with international partners to reduce its costs. As the UK has led the debate globally on tackling climate change and pioneering clean growth, we are leading this global challenge with an initial £21.5 million investment in CCUS innovation - a key part of our modern Industrial Strategy."

The Clean Growth Strategy sets out the new Government approach to CCUSin the UK, highlighting the important role of innovation in supporting cost reduction. Government has committed to spend up to £162 million to improve CCUS and industrial energy efficiency.

As well as the potential to help us reduce our emissions in industries through the manufacture of concrete, chemicals, steel, there are also opportunities to maximise economic opportunities for the UK through new technologies and the supply chain.

Government is working with industry to adopt CCUS in the UK by reducing its costs and capturing the export opportunities, and a CCUS Cost Challenge Taskforce will report to government in July this year. Energy Minister Claire Perry will host an international CCUS summit with the International Energy Agency, in Edinburgh later this year.

IHI Corporation to support MIT Energy Initiative

energy.mit.edu/lcec

Tokyo-based IHI will join MITEI's Low-Carbon Energy Center for Carbon Capture, Utilization, and Storage.

"With sights set on global greenhouse gas reduction, Tokyo's IHI Corporation has joined the MIT Energy Initiative (MITEI). IHI, a global engineering, construction, and manufacturing company, recently signed a three-year membership agreement with MITEI's Low-Carbon Energy Center for Carbon Capture, Utilization, and Storage (CCUS).

The center is one of eight Low-Carbon Energy Centers that MITEI has established as part of the Institute's Plan for Action on Climate Change, which calls for strategic engagement with industry to solve the pressing challenges of decarbonizing the energy sector with advanced technologies. The centers build on MITEI's existing work with industry members, government, and foundations.

"It is a source of great pleasure for IHI to be collaborating with the MIT Energy Initiative," says Kouichi Murakami, IHI's managing executive officer. "The rapid change in the global energy business, as well as the immense need for low-carbon energy, make large-scale innovation necessary. IHI is looking forward to solving energy challenges in concert with the great minds at MIT."

IHI's membership in the CCUS center stems from the company's commitment to developing technologies to reduce global greenhouse gas emissions. The company is also interested in research projects focusing on low-carbon energy technologies, as well as on the future of the electric utility.

MITEI's CCUS center draws upon a wide range of expertise, from chemistry to biology to engineering, to scale up affordable carbon capture, utilization, and storage technologies. CCUS encompasses an array of technologies that seek to reduce carbon dioxide emissions into the atmosphere by capturing it from sources such as thermal power plants and converting it into valuable products, or compressing and storing it indefinitely in the Earth's crust.

Faculty from various MIT departments are conducting research that includes new approaches to the efficient capture of carbon dioxide from a wide range of sources in the power and manufacturing industries and in the transport sector; the conversion of carbon dioxide into fuels and specialty and commodity chemicals using molecular-level engineering; and the prevention of seismicity and fault leakage during geologic carbon dioxide storage.

In addition to funding research, IHI's membership will support MIT's technoeconomic assessment program, which analyzes the technical and economic potential of various CCUS technologies with a particular focus on scalability and system integration. The program, led by MITEI Director of Research Francis O'Sullivan, also explores carbon mitigation scenarios, consolidating policy perspectives with technological viewpoints. The current focus is on helping chart a CCUS development program that will help make the technology more cost-effective, and support its more rapid scaling and deployment.

Carbon Capture Coalition expands with new Leadership Council

www.uky.edu

The Carbon Capture Coalition has formed a new group of private sector CEOs, labour, NGO and philanthropic leaders, and former state and federal officials committed to carbon capture technology development.

The Council's inaugural members formally announced its formation at the CO2NNECT 2018 carbon capture conference in Jackson Hole, Wyoming. They are:

• Jason Grumet, President, Bipartisan Policy Center;

• Don Gaston, President and CEO, Prairie State Generating Company;

• Vicki Hollub, President and CEO, Occidental Petroleum Corporation;

• Mike Langford, President, Utility Workers Union of America;

• Colin Marshall, President and CEO, Cloud Peak Energy;

• Bob Perciasepe, President, Center for Climate & Energy Solutions; and

• Jonathan Pershing, Environment Program Director, William and Flora Hewlett Foundation.

The Council will be coordinated and staffed through the Carbon Capture Coalition, a diverse, non-partisan group of energy, industrial and technology companies, labor unions, and environmental, clean energy and agricultural organizations dedicated to fostering the deployment and adoption of carbon capture technology. The Council will focus on leveraging the voices of participating leaders to expand support for policies and initiatives aimed at carbon capture technology development and deployment.

"The National Carbon Capture Leadership Council is the next logical step in the development of the Carbon Capture Coalition," explained Brad Crabtree, co-director of the Carbon Capture Coalition and vice president for fossil energy at Great Plains Institute.

"The ability to marshal leadership support and engage peer-to-peer with top government, private sector and opinion leaders will enhance the Coalition's already demonstrated effectiveness in advancing carbon capture going forward."

The Council's objectives include the following:

• Position carbon capture as an essential and equal component of our nation's broader portfolio of low and zero-carbon energy options;

• Cultivate support among peer private and public leaders for a robust national carbon capture policy and deployment agenda;

• Support priority policies through personal engagement and outreach to federal and state elected officials and policymakers; and

• Encourage and support state officials and stakeholders in their efforts to deploy carbon capture and CO2 pipeline infrastructure projects.

"Carbon capture has entered a new era in which strong, bipartisan leadership by state and federal policymakers has boosted the prospects for deploying new capture projects that will be critical to meeting the country's carbon management goals," said Jeff Bobeck, co-director of the Coalition and energy policy director at the Center for Climate and Energy Solutions. "The formation of the Council represents a commitment from top business and NGO leaders to work together to ensure that this recent progress moves into high gear, and leads to further technology advancements, new applications, and the construction of a new generation of capture projects in the ground."

The Council will host an annual meeting and quarterly conference calls to address priorities and consider opportunities. Members will also be asked to engage individually, consistent with Council priorities and members' interests and relationships. Initial funding for the Council is provided through private sector contributions and through grants from the William and Flora Hewlett Foundation, John D. and Catherine T. MacArthur Foundation, Bernard and Anne Spitzer Charitable Trust and the Energy Foundation.

New catalyst upgrades CO2 into renewable hydrocarbons

The process developed at the University of Toronto converts CO2 into ethylene using sunlight as an energy source.

Today, non-renewable fossil fuels not only provide the raw material from which plastics are made, they are also the fuel burned to power the manufacturing process, producing climate-warming carbon dioxide.

A team led by University Professor Ted Sargent of the Edward S. Rogers Sr. department of electrical and computer engineering, is turning this process on its head. They envision capturing CO2 produced by other industrial processes and using renewable electricity – such as solar power – to transform it into ethylene.

The system addresses a key challenge associated with carbon capture. While technology exists to filter and extract CO2 from flue gases, the substance currently has little economic value that can offset the cost of capturing it. By transforming this carbon into a commercially valuable product like ethylene, the team aims to increase the incentives for companies to invest in carbon capture technology.

Cao-Thang Dinh (left) and Md Golam Kibria of the Faculty of Applied Science & Engineering demonstrate their new catalyst (photo by Laura Pedersen)

At the core of the team's solution are two innovations: using a counterintuitively thin copper-based catalyst and a reimagined experimental strategy.

"When we performed the CO2 conversion to ethylene in very basic media, we found that our catalyst improved both the energy efficiency and selectivity of the conversion to the highest levels ever recorded," said post-doctoral researcher Cao-Thang Dinh. In this context, efficiency means that less electricity is required to accomplish the conversion. The authors then used this knowledge to further improve the catalyst and push the reaction to favour the formation of ethylene, as opposed to other substances.

Next, the team addressed stability, which has long been a challenge with this type of copper-based catalyst. Theoretical modelling shows that basic conditions – that is, high pH levels – are ideal for catalyzing CO2 to ethylene. But under these conditions, most catalysts, and their supports, break down after less than 10 hours.

The team overcame this challenge by altering their experimental setup. Essentially, they deposited their catalyst on a porous support layer made of polytetrafluoroethylene (PTFE, better known as Teflon) and sandwiched their catalyst with carbon on the other side. This new setup protects the support and catalyst from degrading due to the basic solution, and enables it to last 15 times longer than previous catalysts. As an added bonus, this setup also improved efficiency and selectivity further.

"Over the last few decades, we've known that operating this reaction under basic conditions would help, but no one knew how to take advantage of that knowledge and transfer it into a practical system," said Dinh. "We've shown how to overcome that challenge."

Currently their system is capable of performing the conversion on a laboratory scale, producing several grams of ethylene at a time. The team's long-term goal is to scale the technology up to the point where they are able to convert the multiple tonnes of chemicals needed for commercial application.

"We made three simultaneous advances in this work: selectivity, energy-efficiency and stability," said Sargent, who is also U of T's vice-president international. "As a group, we are strongly motivated to develop technologies that help us realize the global challenge of a carbon-neutral future."

"Upgrading CO2 to value is the next frontier in renewable energy storage and renewable chemicals," said Shaffiq Jaffer of TOTAL, a French major energy operator sponsoring this research. "The Toronto breakthrough proves that electricity and waste CO2 can be transformed into valuable chemicals for the petrochemicals sector. The possibility to close the carbon loop in a manner analogous to nature's photosynthesis is closer to industrial reality today thanks to this advance."

More information

www.utoronto.ca

Capture and utilisation news

ArcelorMittal and LanzaTech break ground on blast furnace CO2 capture project

www.arcelormittal.com

www.lanzatech.com

ArcelorMittal has begun construction of new premises at its site in Ghent, Belgium, to house a pioneering new installation which will convert carbon-containing gas from its blast furnaces into bioethanol.

The technology in the gas conversion process was pioneered by Chicago-based company, LanzaTech, with whom ArcelorMittal has entered a long-term partnership. The technology licensed by LanzaTech uses microbes that feed on carbon monoxide to produce bioethanol. The bioethanol will be used as transport fuel or potentially in the production of plastics.

This is the first installation of its kind on an industrial scale in Europe and once complete, annual production of bioethanol at Ghent is expected to reach around 80 million litres, which will yield an annual CO2 saving equivalent to putting 100,000 electrical cars on the road. The new installation will create up to 500 construction jobs over the next two years and 20 to 30 new permanent direct jobs. Commissioning and first production is expected by mid-2020.

The application of this microbial gas conversion system significantly advances ArcelorMittal's carbon capture and storage (CCS) and carbon capture and utilisation (CCU) capabilities and enhances steel's role in the circular economy. ArcelorMittal's long-term aspiration is to become a zero-waste business, with all materials used or generated during steel production recuperated, treated and reused in the production chain or becoming the raw materials for other industries.

"We are excited that after several years of research and engineering, we are now progressing with the largest project of its kind within the ArcelorMittal group. This is the first application of a viable new business case where re-use of carbon is possible at large scale. We will achieve significant carbon reduction and we hope that this will lead us to a lower carbon economy," says Carl De Maré, vice president of Technology Strategy at ArcelorMittal.

"This new Carbon Smart technology illustrates ArcelorMittal's commitment to transforming steel production and it will also further strengthen steel's standing in the circular economy, particularly compared to other higher carbon metals like aluminium."

ArcelorMittal will work with specialized partners to roll out this bioethanol technology. Funding was obtained from various sources, including the European Union's Horizon 2020 program, to carry out further research and development and scale up the project.

'Electrogeochemistry' captures carbon, produces hydrogen

www.ucsc.edu

Researchers analyze global potential for 'negative emissions energy' using electricity from renewable sources to generate hydrogen fuel and capture carbon dioxide.

A study published in Nature Climate Change evaluates the potential for recently described methods that capture carbon dioxide from the atmosphere through an "electrogeochemical" process that also generates hydrogen gas for use as fuel and creates by-products that can help counteract ocean acidification.

First author Greg Rau, a researcher in the Institute of Marine Sciences at UC Santa Cruz and visiting scientist at Lawrence Livermore National Laboratory, said this technology significantly expands the options for negative emissions energy production.

The process uses electricity from a renewable energy source for electrolysis of saline water to generate hydrogen and oxygen, coupled with reactions involving globally abundant minerals to produce a solution that strongly absorbs and retains carbon dioxide from the atmosphere. Rau and other researchers have developed several related methods, all of which involve electrochemistry, saline water, and carbonate or silicate minerals.

"It not only reduces atmospheric carbon dioxide, it also adds alkalinity to the ocean, so it's a two-pronged benefit," Rau said. "The process simply converts carbon dioxide into a dissolved mineral bicarbonate, which is already abundant in the ocean and helps counter acidification."

The negative emissions approach that has received the most attention so far is known as "biomass energy plus carbon capture and storage" (BECCS). This involves growing trees or other bioenergy crops (which absorb carbon dioxide as they grow), burning the biomass as fuel for power plants, capturing the emissions, and burying the concentrated carbon dioxide underground.

"BECCS is expensive and energetically costly. We think this electrochemical process of hydrogen generation provides a more efficient and higher capacity way of generating energy with negative emissions," Rau said.

He and his coauthors estimated that electrogeochemical methods could, on average, increase energy generation and carbon removal by more than 50 times relative to BECCS, at equivalent or lower cost. He acknowledged that BECCS is farther along in terms of implementation, with some biomass energy plants already in operation. Also, BECCS produces electricity rather than less widely used hydrogen.

"The issues are how to supply enough biomass and the cost and risk associated with putting concentrated carbon dioxide in the ground and hoping it stays there," Rau said.

The electrogeochemical methods have been demonstrated in the laboratory, but more research is needed to scale them up. The technology would probably be limited to sites on the coast or offshore with access to saltwater, abundant renewable energy, and minerals. Coauthor Heather Willauer at the U.S. Naval Research Laboratory leads the most advanced project of this type, an electrolytic-cation exchange module designed to produce hydrogen and remove CO2 through electrolysis of seawater. Instead of then combining the CO2 and hydrogen to make hydrocarbon fuels (the Navy's primary interest), the process could be modified to transform and store the CO2 as ocean bicarbonate, thus achieving negative emissions.

"It's early days in negative emissions technology, and we need to keep an open mind about what options might emerge," Rau said. "We also need policies that will foster the emergence of these technologies."

In addition to Rau and Willauer, coauthor Zhiyong Jason Ren at the University of Colorado in Boulder (now at Princeton University) also contributed to the paper.

WellDog, Virginia Tech and Carbon GeoCycle jointly verify CO2 geological storage

First direct verification of geologic sequestration of CO2 opens door for carbon sequestration efforts to proceed with greater confidence.

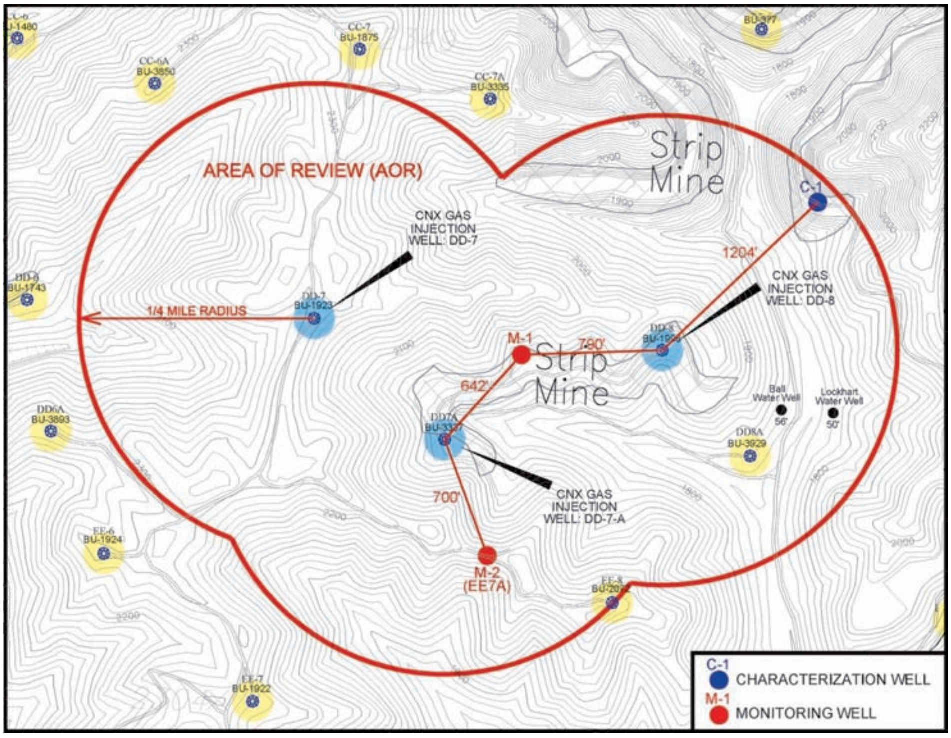
The verification, made using WellDog's proprietary Reservoir Raman System, reveals that carbon dioxide injected over the last two years successfully flowed into all of the targeted coal seams. The US$15.5MM sequestration project is located in Buchanan County, Virginia. The project is funded by the US Department of Energy, Virginia Tech, and private industry.

The test involves injecting over 13,000 tons of carbon dioxide into stacked unmineable coal seams at depths of 900 to 2,000 feet with the goal of storing carbon dioxide while simultaneously enhancing natural gas recovery.

"Carbon sequestration in geologic formations is our best way to slow and reverse climate change," said John M. Pope, Ph.D., chief executive officer of WellDog. "But understanding how, where and for how long sequestration occurs in rocks thousands of feet below ground is difficult."

"In this project the carbon dioxide flowed into the wellbore, but until we took direct downhole measurements in each coal seam, significant uncertainty persisted regarding which coal seams the carbon dioxide had sequestered," explained Pope. "We are pleased that WellDog's technical services and Carbon GeoCycle's sequestration expertise were able to help Virginia Tech's experts confirm that all of the coal seams took up carbon dioxide. This result represents an important step for sequestration efforts worldwide."

"Results from the test are very promising," said Nino Ripepi, Ph.D., associate professor of mining and minerals engineering at Virginia Tech and a manager of the project. "We have shown that coal seams can safely store carbon dioxide while at the same time enhancing gas. This is one of the first steps toward commercialization of these technologies."



Researchers from Virginia Tech are injecting CO2 into coal seams in three locations in Buchanan County, Virginia, as part of an NETL-sponsored CO2 storage research project associated with enhanced gas recovery

Research partners in the project included Virginia Center for Coal and Energy Research, Virginia Tech; Virginia Department of Mines, Minerals and Energy; DOE's National Energy Technology Laboratory; Marshall Miller & Associates; Southern States Energy Board; CONSOL Energy; Geological Survey of Alabama; Sandia Technologies; Det Norske Veritas; WellDog; and Carbon GeoCycle.

The verification methods used by the partners included WellDog's unique downhole geochemical Reservoir Raman System, in which a full spectrum chemical analyzer and other sensors are lowered into a wellbore and used to identify directly and unambiguously the types and amounts of liquids and gases it contains. By watching those liquids and gases flow over time and at various depths, the system enabled direct confirmation of carbon dioxide flows into and out of rock formations.

More information

energy.vt.edu
www.welldog.com
energy.gov/fe

Transport and storage news

Occidental and White Energy to study feasibility of CO_2 capture for EOR

www.oxy.com

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The project would capture carbon dioxide at White Energy's ethanol facilities in Hereford and Plainview, Texas, and transport it to the Permian Basin for use in enhanced oil recovery by Occidental.

"The collaboration between Occidental and White Energy is a direct result of the passage of the FUTURE Act," said Occidental Petroleum President and CEO Vicki Hollub. "Carbon capture technologies have the potential to play a critical role in reducing global emissions, and this project is an important first step in cross-industry collaboration to make these efforts economic, practicable and scalable."

The engineering study, expected to last six months, will examine the costs of building a carbon capture facility. If Occidental and White Energy determine the project is economically feasible, operations could begin as soon as 2021.

The carbon capture project would be designed to be eligible for 45Q tax credits and California's Low Carbon Fuel Standard Carbon Capture and Storage protocol, both currently in development, demonstrating that these important incentives result in near-term investment, reduced CO_2 emissions and jobs.

Occidental is an industry leader in applying CO_2 EOR technology. This technology can increase oil recovery by 10 to 25 percent in the fields where it is employed, while at the same time permanently sequestering the CO_2 in the reservoir. The U.S. Environmental Protection Agency (EPA) approved Occidental's two Monitoring, Reporting and Verification (MRV) plans for CO_2 EOR fields in its Permian Basin operations.

These plans, which were the first-ever approved by EPA, demonstrate that the captured CO_2 is safely and permanently stored and establish a framework to quantify the amount of CO_2 sequestered.

The FUTURE Act supports the conversion of CO_2 emissions from industrial sources, including ethanol and coal- or gas-fired power plants, to a commodity product that can be stored in a secure geological formation through EOR.

Cellula Robotics awarded National Oceanography Center STEM-CCS Contract

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The contract covers the design, build, testing and offshore support of a tool to place a seven meter curved pipe into the seabed to inject CO_2.

The tool will be used to enable the controlled injection of CO_2 at an instrumented test site as part of the European Union H2020 programme "Strategies for the environmental monitoring of marine carbon capture and storage" (STEMM-CCS).

This contract will leverage Cellula's experience with seafloor geotechnical drills and remotely operated subsea equipment to provide a bespoke solution to NOC. The project is expected to be completed in Q1 2019, with a deployment in the North Sea following in early Q2.

Cellula Robotics Ltd., based in Burnaby, Canada, is a world-leading engineering solutions company that specializes in the turnkey design and production of seafloor intervention and subsea robotic systems.

Cellula is a world leading supplier for seafloor drills, including the field proven CRD100. Cellula has also developed a range of autonomous underwater vehicles, including Imotus-1, a hovering vehicle capable of SLAM navigation in confined spaces and residence operation from a dock in open water.

STEMM-CCS is an ambitious multi-disciplinary project that will deliver new approaches, methodologies and tools for the safe operation of offshore carbon dioxide capture and storage (CCS) sites. CCS is a powerful mitigation strategy for addressing the increasing levels of carbon dioxide (CO_2) in the atmosphere.

The storage of CO_2 in underground reservoirs, for example in depleted oil and gas fields or aquifers, is a demonstrated technology on land and – to a more limited extent – in marine systems.

STEMM-CCS will develop approaches to help ensure we select appropriate marine storage sites and can monitor them effectively, thus further increasing confidence in CCS as a viable option for reducing atmospheric CO_2.

Scottish researchers show safety of CO_2 storage

www.sccs.org.uk

The research shows that captured carbon dioxide can be stored safely for thousands of years by injecting the liquefied gas deep underground into the microscopic pore spaces of common rocks.

In the study published in Nature Communications, researchers from SCCS's partner institutes, the Universities of Aberdeen and Edinburgh, compiled a worldwide database of information from natural carbon dioxide and methane accumulations and hydrocarbon industry experience – including engineered gas storage, decades of borehole injection, and laboratory experiments.

Computer simulations were used to combine all these factors and model storage of carbon dioxide for 10,000 years into the future. Previous research in this area had not fully accounted for the natural trapping of carbon dioxide in rock as microscopic bubbles, or the dissolving of carbon dioxide into the salty water already in the rocks.

The UN Paris agreement has committed the world to limiting climate warming to well below 2°C from pre-industrial levels. This requires huge reductions in the amount of the greenhouse gas, carbon dioxide, which is released to the atmosphere from industry, electricity generation, heating and transport.

Capturing these emissions and ensuring that carbon dioxide can be safely trapped underground is crucial for the successful protection of the atmosphere.

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