Carbon Capture Journal

CCS in Australia

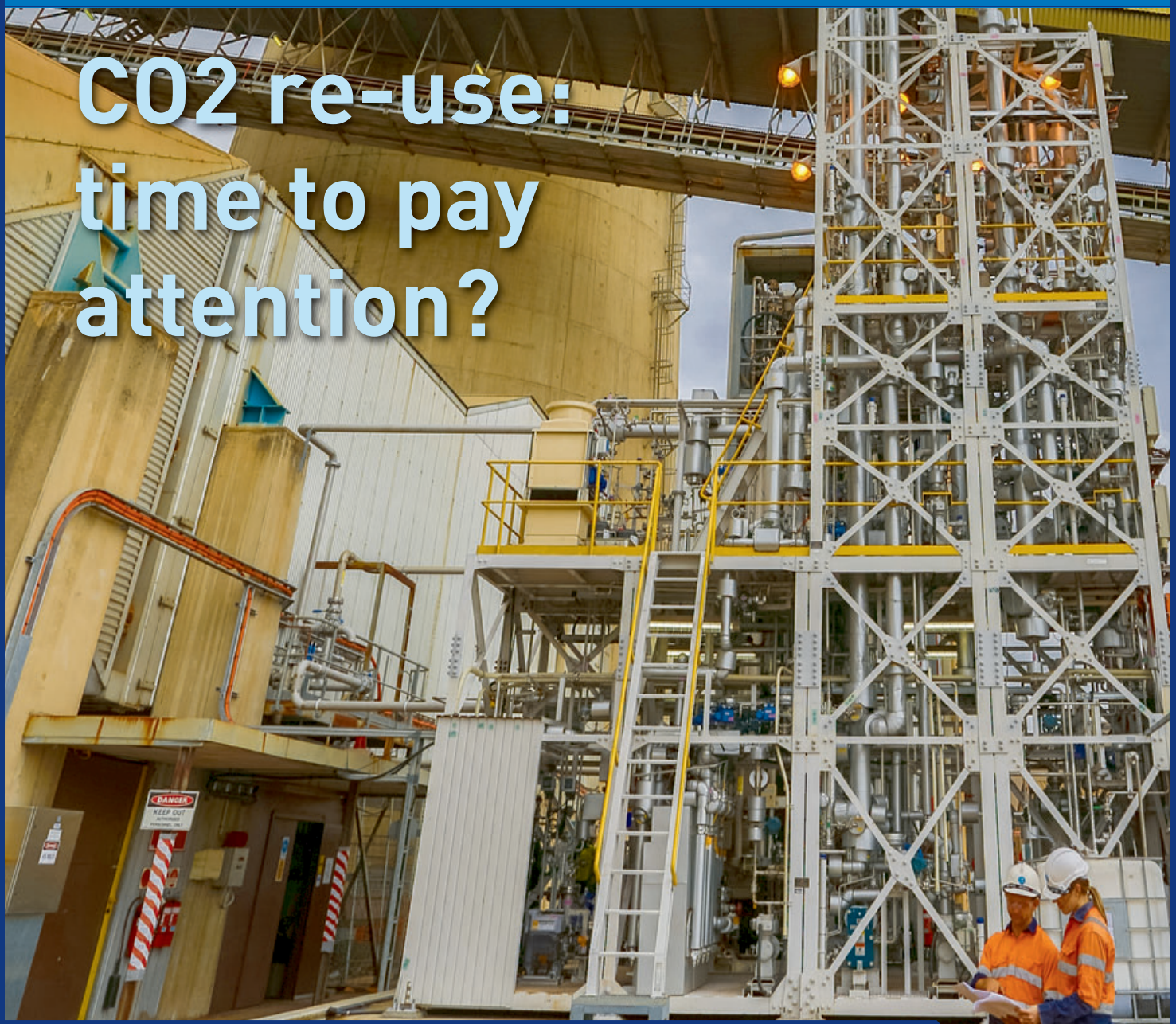
PICA project to improve CO2 capture efficiency for power and industry

GipNet – Applied research in marine MMV for CarbonNet

Uni of Queensland looks at rock reactivity

July / Aug 2016 Issue 52

CO2 re-use: time to pay attention?



Energy Technologies Institute: no technical barriers to UK CCS

University of Calgary system for early CO2 leak detection

Covestro opens production plant for plastics made from CO2

Columbia Engineers develop low-cost way to capture carbon

CCS in Australia: PICA project to improve CO2 capture efficiency

CSIRO, AGL Energy (AGL), Brown Coal Innovation Australia and Japan's IHI Corporation are partnering on the PICA post-combustion capture research project which will evaluate innovative processes using gases drawn from AGL Loy Yang brown coal-fired power station in Victoria.

While CO2 is already being captured at large scale around the world, cost and efficiency challenges remain an impediment to wide-scale commercial implementation.

This research program is targeting a 40 per cent reduction in energy use of current capture processes in order to overcome these challenges.

Throughout the two-year program, researchers will examine the energy efficiency of CO2 capture configurations, the effectiveness of two new solvents into which CO2 will be absorbed, and measure the total amount of CO2 removed.

The PICA (derived from first letters of PCC, IHI, CSIRO, AGL) research plant is 21 metres high and was built by IHI in Japan and transported to the Latrobe Valley where it will operate around the clock, capturing 150 to 200 tonnes of CO2 each year.

CSIRO Energy Director Dr Peter Mayfield said CSIRO was excited to embark on the PICA research journey as part of its support of mitigation research efforts to reduce greenhouse gas emissions and ensure Australia's energy security.

"CO2 capture can be applied to both energy generation and industrial processes," Dr Mayfield said.

"This research will complement our research in CO2 storage, and it's a great example of globally-coordinated R&D on emissions management."

AGL's Executive General Manager, Group Operations, Doug Jackson said AGL had committed to decarbonisation by 2050 and technology innovation would be critical in the transition to a lower carbon emissions energy sector.

BCIA Chief Executive Officer Dr Phil Gurney said to meet Australia's commitment to limit dangerous climate change, emissions of CO2 from the use of coal must be reduced.

CSIRO's Aaron Cottrell and IHI Corporation's Jun Arakawa work on the PICA post-combustion capture project

"BCIA has invested heavily in research and development to improve the efficiency of brown coal power generation and reduce the costs of carbon capture technologies," Dr Gurney said.

"The PICA project is a major step forward and will make a significant contribution to the broader roll-out of CCS for power generation and the manufacturing sector in the longer term."

More information

www.csiro.au

Carbon Capture Journal

July / Aug 2016 Issue 52

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Front cover:
Improving CO2 capture efficiency
PICA post-combustion capture project against AGL Loy Yang brown coal-fired power station (Image ©CSIRO)

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

Leaders - CCS in Australia

Projects and policy

CO2 re-use - SCOT project event report

Capture and utilisation

Transport and storage

GipNet – Applied research in marine MMV for CarbonNet's storage sites

The CarbonNet Project in Australia is investigating the potential for establishing a commercial-scale, multi-user carbon capture and storage network in Victoria's Gippsland region. The network could integrate multiple carbon dioxide capture projects transporting CO2 via a common-use pipeline and injecting it deep into underground storage sites in the offshore Gippsland Basin.

CarbonNet's storage sites (with capacities up to 125 million tonnes of CO2) are located in shallow waters within 20 km of the coastline, in Gippsland Australia (Figure 1).

There is a clear expectation that geological storage sites will be chosen after significant site investigation such that the risk of leakage is extremely low and this is the case for the CarbonNet project as demonstrated through multiple independent reviews and certification by Det Norske Veritas of its geoscience evaluation programme.

Storing CO2 at CarbonNet sites is considered to be low risk due to multiple proven seals, good reservoirs with excellent pressure buffering capacity and well-defined structural geometries, all proven by extensive local and regional well and seismic data. However, it is necessary to continually work to reduce and manage any residual storage risks. A critical part of risk reduction is the continuous application of a site monitoring program. Unlike other CO2 storage sites worldwide, the CarbonNet sites are neither onshore nor in deep and distant waters. Therefore, a non-standard and project-specific combination of monitoring technologies will need to be validated.

Norwegian sites at Sleipner and SnØvit have tested and implemented several aspects of marine monitoring including 3D seismic, gravity, seabed imaging, marine magnetotellurics, and seabed and water column geochemistry. Detailed conformance studies have been conducted with richly-sampled 4D timelapse datasets. However, those sites are located in deeper waters (>100m), and so the new GipNet research is aimed at shallow water sites such as exist in the nearshore parts of many basins worldwide, including Gippsland, the North Sea and the Gulf of Mexico.

A relevant reference study would be the QICS marine release experiment, where CO2 was released in the shallow subsurface below a Scottish marine loch in 10-12m of water. The QICS experiment confirmed the high detectability of migrating CO2 plumes and bubbles in the subsurface, prior to it emerging at the surface.

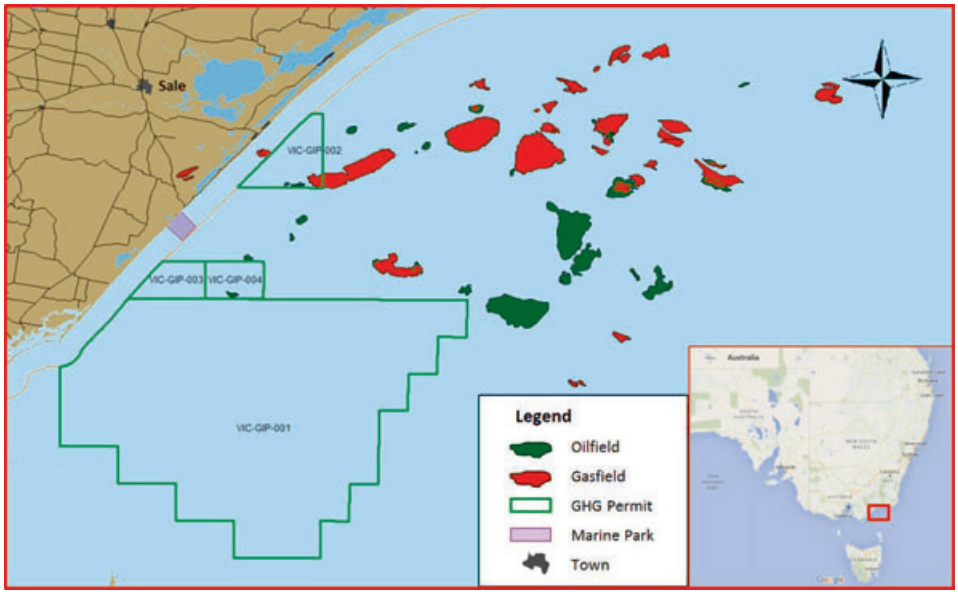


Figure 1 – CarbonNet's offshore greenhouse gas assessment permits

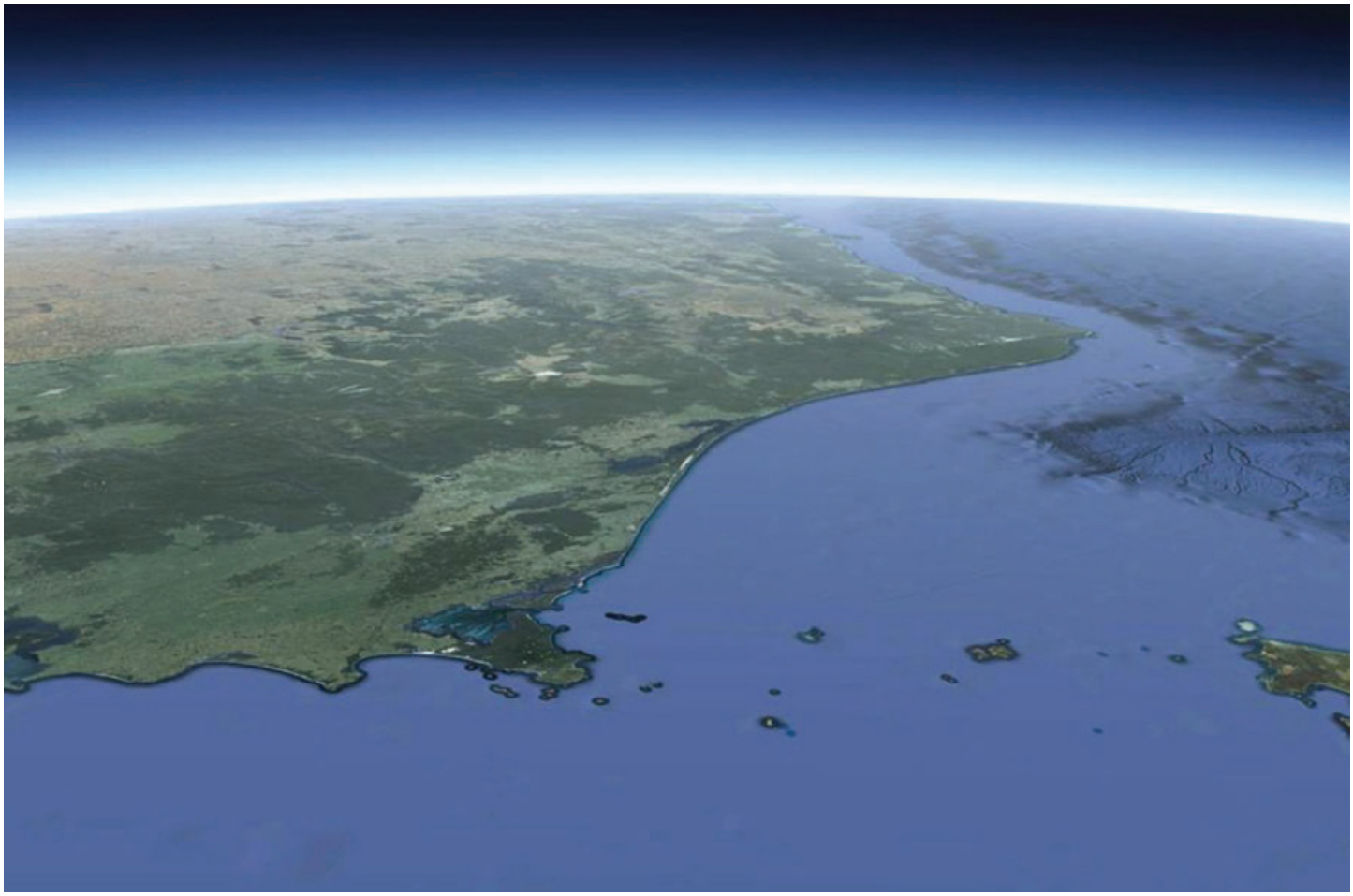
Together the QICS and Norwegian sites straddle the range of water depths anticipated in Gippsland nearshore storage sites (15-50m), and offer insights into likely successful technologies and sources of noise and data artefacts that need to be processed.

GipNet Research Assets

CarbonNet's lead research organisation CO2CRC, along with University of Melbourne and CSIRO are developing the GipNet program. The GipNet research assets are funded through the Australian Government's Education Infrastructure Fund. They will allow research programs for observations and instrument tests aimed at defining practical and relevant, shallow-marine Measurement, Monitoring and Verification (MMV). GipNet will research the levels of various types of noise and natural variation against which one seeks to detect a signal, or confirm a null signal.

In the well-understood, high quality and thick reservoirs of the Gippsland Basin, plumes are expected to be very predictable, relatively thick, and easily observable with the right techniques such as timelapse 3D seismic imaging and downhole monitoring. Provision must also be made for unexpected outcomes and technologies sought that have low detection thresholds to identify thin or diffuse plume offshoots or early warning of unexpected plume movements in order to provide assurance of storage security.

CarbonNet seeks to define at this pre-commercial stage, an appropriate, but not excessive, range of measurements to characterise



Google Earth image of the Gippsland Basin

the pre-existing environments. For each proposed technology, the physics of detection was reviewed, as well as the practicalities of deployment in the shallow-water and nearshore environment with multiple sources of 'noise', of initial research and test instruments and later detection systems appropriate for a commercial project. Most importantly, each MMV technology was assessed for its value in monitoring CO2 storage Integrity, Conformance and Assurance and adding to the proven technologies of 3D seismic and downhole monitoring.

Three key technologies were identified for trial deployments and further testing:

1. Natural Seismicity Monitoring Network

The GipNet Seismic Network will involve surface-deployable onshore seismometers and shallow water (<100m) Ocean Bottom Seismometers (OBS). The network will enable monitoring of background seismic activity and other 'noise' sources in the region of prospective storage sites and in the future will enable detection of any induced seismic events that might occur as a consequence of future injection activities.

The infrastructure will facilitate research into the state of stress, and controls on seismic energy release in the region, and a variety of associated geophysical properties such as crustal and basin velocity structure, and attenuation properties. An important research objective is to determine protocols for seismic monitoring of CCS in complex, noisy settings such as the nearshore Gippsland Basin.

Practicalities

Nearshore measurements will be strongly affected by surf noise and the ground conditions of soft dune sands. It will be important to characterise that noise and its variability in time and space so that noise floors can be established for different locations and weather conditions. It is also important to investigate methods for equipment installation that minimise noise (e.g. cemented into shallow boreholes, local noise-cancelling arrays, etc.).

Shallow marine seismometers will also be subject to weather and tide/current noise and will have limited time deployments. It is not yet clear whether they will allow a significant catalogue of events to be recorded, and modelling of the probability of useful detection is underway.

2. Atmospheric Monitoring

An open-path measurement system will be established for atmospheric trace gases and isotopic composition of CO2. The research program will monitor sources and sinks of CO2 in the region, characterise the natural variability in atmospheric concentration and isotopic ratios, and characterise the baseline CO2 fluxes for the region.

In the future, project MMV can then attribute any changes in local sources or sinks to natural oceanic or biogenic sources or conversely identify whether they are due to the storage infrastructure.

Practicalities

The coastal region is a low-density populated region with established agricultural and local industrial uses, but hosts significant summer vacation activity on lakes, beaches, and adjacent campgrounds and holiday homes. This activity may disturb installed equipment and lines of sight.

Atmospheric impacts of open fireplaces, vehicle exhausts, and recreational activities need to be considered, as well as atmospheric drift from the nearby hydrocarbon processing plant and industrial sources further afield. The open-path network will trial measurement over both onshore and marine paths, with strategically-placed retroreflectors and establish whether shore-based marine atmospheric measurements are practicable in the presence of marine aerosols.

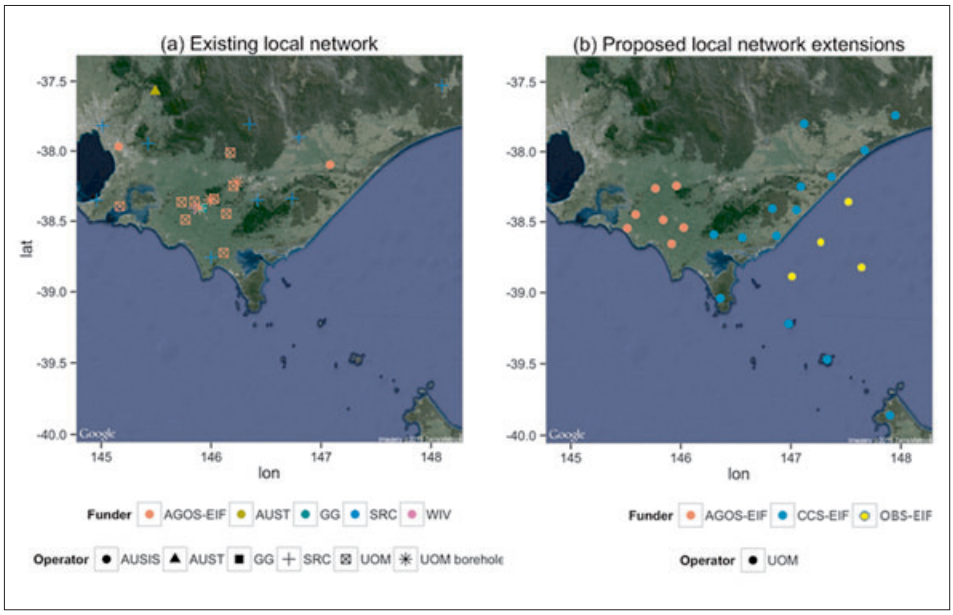


Figure 2 –Natural Seismicity Monitoring Network (LHS existing) (RHS proposed local network) (University of Melbourne)

3. Baseline Marine Monitoring

This project aims to utilise marine monitoring assets relevant to promising monitoring technologies, develop their use, test in the marine environment, and commence baseline definition activities.

The shallow coastal waters containing the GHG exploration permits are well-mixed throughout the year due to tidal stirring, thus changes in water properties near the seabed should be reflected throughout the water column which will have advantages for monitoring. Records from nearby buoys show that the current direction is oscillatory with a range of timescales. The area is also subject to seasonal intrusions of water from the Tasman Sea with quite different properties to Bass Strait waters, increasing environmental variability substantially.

Outputs will include a reference dataset from which to select appropriate measurable parameters and fixed locations or schedules for mobile measurements in the future, including reference to physical features such as wellheads and subsurface discontinuities, including faults.

Practicalities

A marine exclusion zone exists around oil and gas facilities in the basin, including subsea wellheads and pipelines. Shipping traffic can be predicted to a large extent with defined shipping channels and direct pathways between oil platforms and the service base, but non-scheduled traffic also exists, including leisure craft and fishermen.

Summary and Conclusion

The general requirements for MMV technologies in shallow water marine environments needs to be identified and the methods and application refined so that a suite of technologies can be deployed in a cost-effective and fit for purpose manner. A significant body of research exists but now must be matured through practical analysis and deployment for commercial storage sites. The GipNet program represents a key opportunity to make significant advances in MMV.

A more detailed report on the GipNet research initiative is available on the GCCSI website.

The GipNet assets are currently in procurement with detailed research plans being developed by University of Melbourne and CSIRO. Implementation is scheduled to commence in 2017 and progress in stages through to 2020.

Authors

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Acknowledgements

The CarbonNet Project is funded by the Commonwealth Department of Industry, Innovation and Science and the Victorian Department of Economic Development, Jobs, Transport and Resources. Publication and knowledge-sharing is supported by the Global CCS Institute.

The CO2CRC is supported by industry members and governments. The Education Infrastructure Fund is supported by the Commonwealth government Department of Education and Training.

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University of Queensland project looks at rock reactivity

Scientists are using laboratory and modelling experiments to determine the effect of injecting CO2 into different rocks.

A pilot project is already being conducted by the CO2CRC Ltd at Otway in Victoria, as well as overseas.

Research fellow in UQ's School of Earth Sciences Dr Julie Pearce said Australia was set to introduce capture and storage systems by 2030.

"Our project at UQ is looking at the reactivity of the storage system rocks, identifying the best geological conditions for storing CO2 underground, and also developing tools to monitor CO2 once it's injected a kilometre under the Earth," she said.

"For CO2 storage to be deployed large-scale, its viability in terms of containing the injected CO2 and the long-term safety needs to be determined at each site."

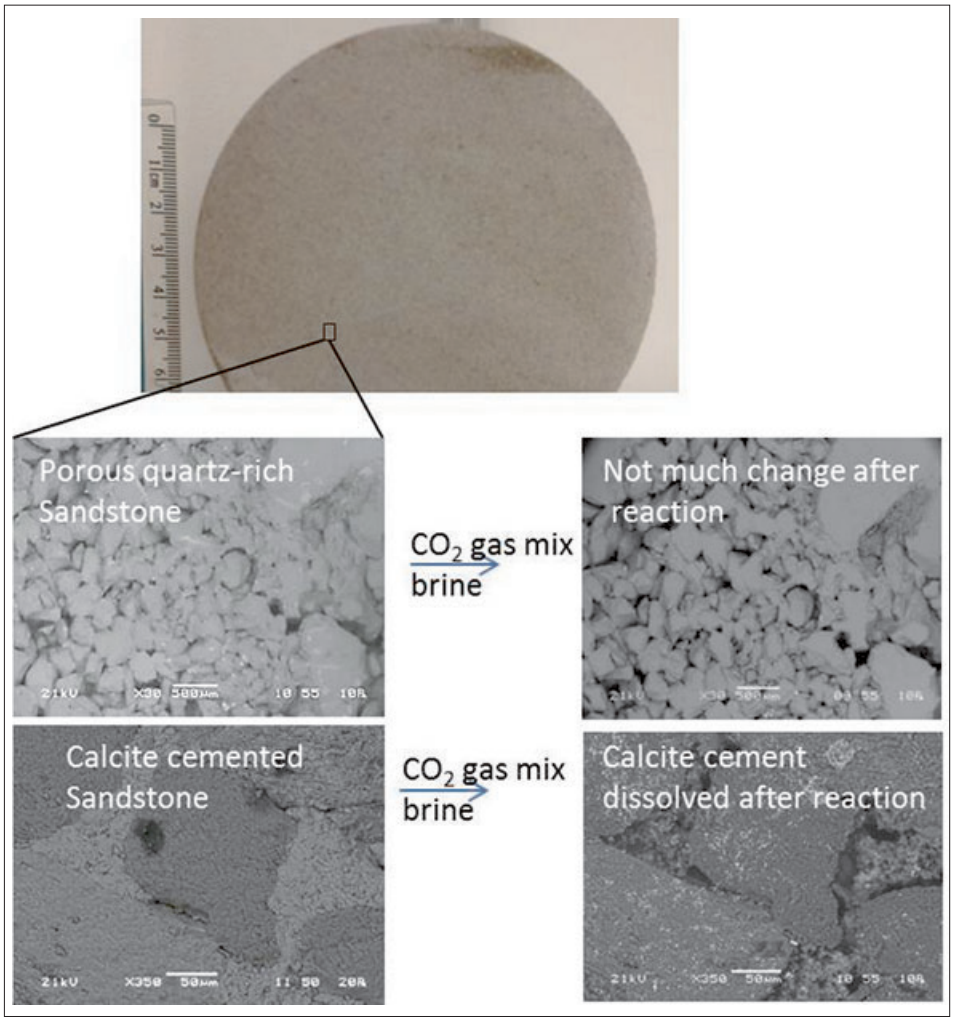
Dr Pearce said CO2 storage already occurred naturally in some types of rock formations, which had trapped fluids containing CO2 for millions of years and converted CO2 to carbonate minerals.

Research has found these formations could hold vast amounts of CO2, potentially equivalent to hundreds of years of human-made emissions.

She said the proposed new technologies captured CO2 from power plants and injected them into porous rock such as sandstone.

"We've been conducting research on underground storage for almost 10 years and have looked at the effect of injecting CO2 on different rocks containing different minerals like carbonates and clays to identify changes and optimal conditions to trap the gas," she said.

"As far as I am aware, there have been no problems with underground CO2 storage either in Australia or overseas, but that is why we conduct stringent research, to ensure we identify any potential risks and develop risk mitigation strategies.



The team is working on proposed new technologies to capture CO2 from power plants and injecte it into porous rock such as sandstone

Dr Pearce's team is using laboratory and modelling experiments in collaboration with Professor Sue Golding of UQ's School of Earth Sciences and Professor Victor Rudolph of UQ's School of Chemical Engineering.

They performs geochemical modelling in collaboration with Associate Professor Dirk Kirste of Simon Fraser University in Canada.

The research is funded by not-for-profit agency ANLEC R&D (Australian National Low Emissions Coal Research and Development).

More information

earth-sciences.uq.edu.au

www.anlecrd.com.au

No technical barriers to CCS in the UK, way forward is shared infrastructure

Despite the UK Government's decision to scrap its CCS commercialisation competition, the Energy Technologies Institute is continuing to demonstrate that CCS is technically feasible and an essential component of the lowest cost option for UK decarbonisation.
By the Energy Technologies Institute

There has been a lot of talk about CCS since the UK Government's decision last November not to proceed with their CCS Commercialisation Programme.

The ETI's internationally peer reviewed energy system (ESME) modelling, in line with analysis by the Committee on Climate Change and the UK Energy Research Centre, highlights that the cost of decarbonisation doubles when CCS is not employed in the system. This cost could increase further still should new nuclear developments be seriously delayed. The scrapping of the Commercialisation Programme does not change this.

The UK has pledged to reduce emissions by at least 80 percent of 1990 levels by the year 2050. And while solar panels and wind turbines may enjoy a positive public perception, emissions targets would be more difficult and costly to reach by using renewables alone.

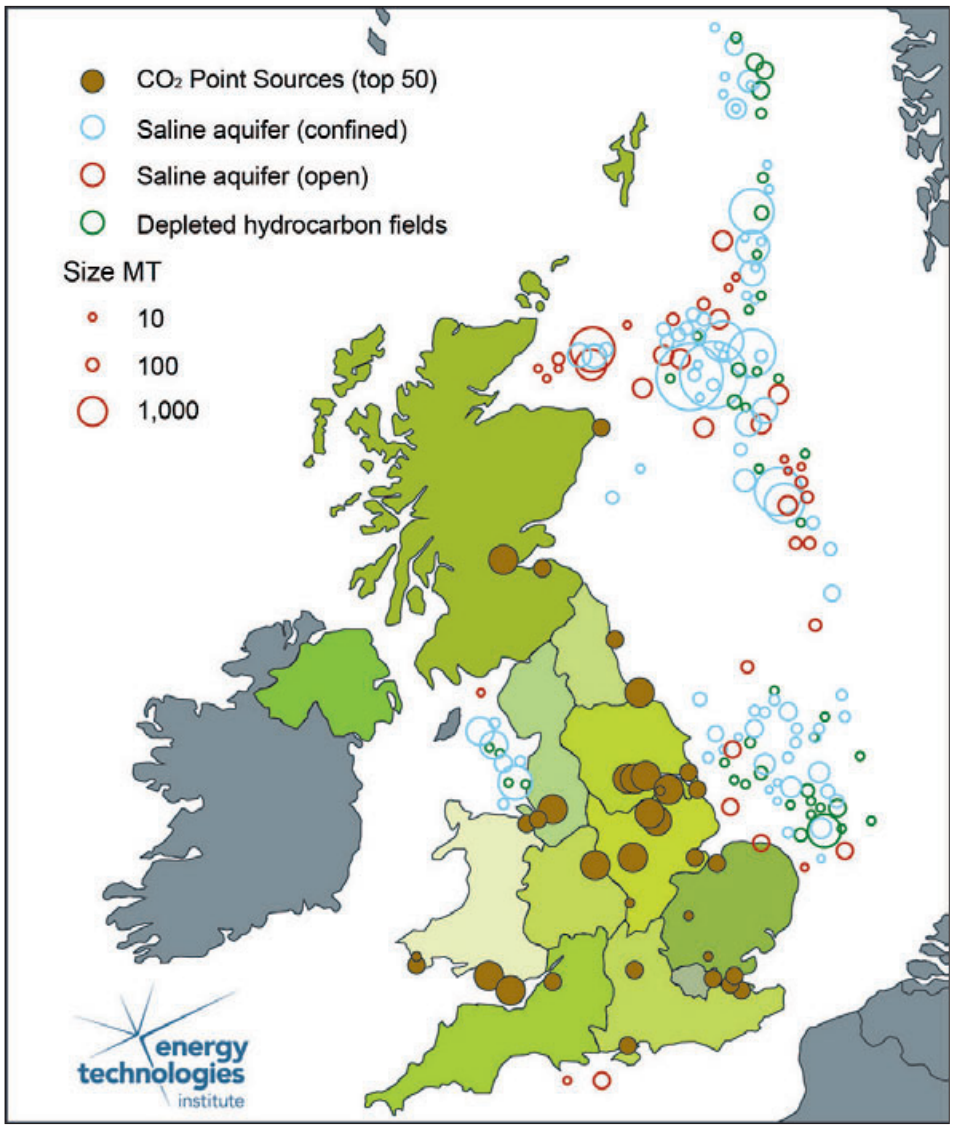
When ESME is run to achieve the UK's 2050 targets in the most cost-effective way, it has consistently shown that CCS is the single-most valuable technology in the country's carbon reduction arsenal. Renewable energy has a sizeable part to play in reducing greenhouse gas emissions, but fossil fuels will likely remain a practical, and integral, part of our energy mix in decades to come – not least as they can provide power when we need it and not just when the wind blows.

ETI has built up in depth knowledge of the UK's CO2 storage potential[1]. It shows that there are no technical barriers to UK offshore CO2 storage, and that this could be available for use from the early 2020s, with plenty of options to service short and long term UK requirements.

There is broad consensus that the UK power system needs to be largely decarbonised by the early 2030s to enable any material decarbonisation of heat and transport to be viable thereafter. Economic transition pathways require more electrification of heating and more electric vehicles, increasing the need for low carbon power generation further. This is a huge challenge, given the intermittency of low carbon generation presently.

CCS has a key role to play in decarbonising the power sector. And with a strong history in oil, gas and power skills, the UK is well placed to lead the world in the development of CCS.

Despite the UK Government's decision to scrap its CCS commercialisation competition, ETI analysis confirms that the way forward for CCS in the UK is to keep options open and look at co-location and shared infrastruc-



CO2 sources and storage sites in the UK

1. ww.eti.co.uk/eti-project-identifies-cost-effective-ccs-storage-sites-off-the-uk-coast

ture to reduce costs. Although new CCS technology may reduce costs in the long-run, this will only be possible when then industry is established. Until then, existing technology will be cheaper as it reduces project risk and financing costs, by 45% compared to 'demonstration' costs according to our analysis.[2]

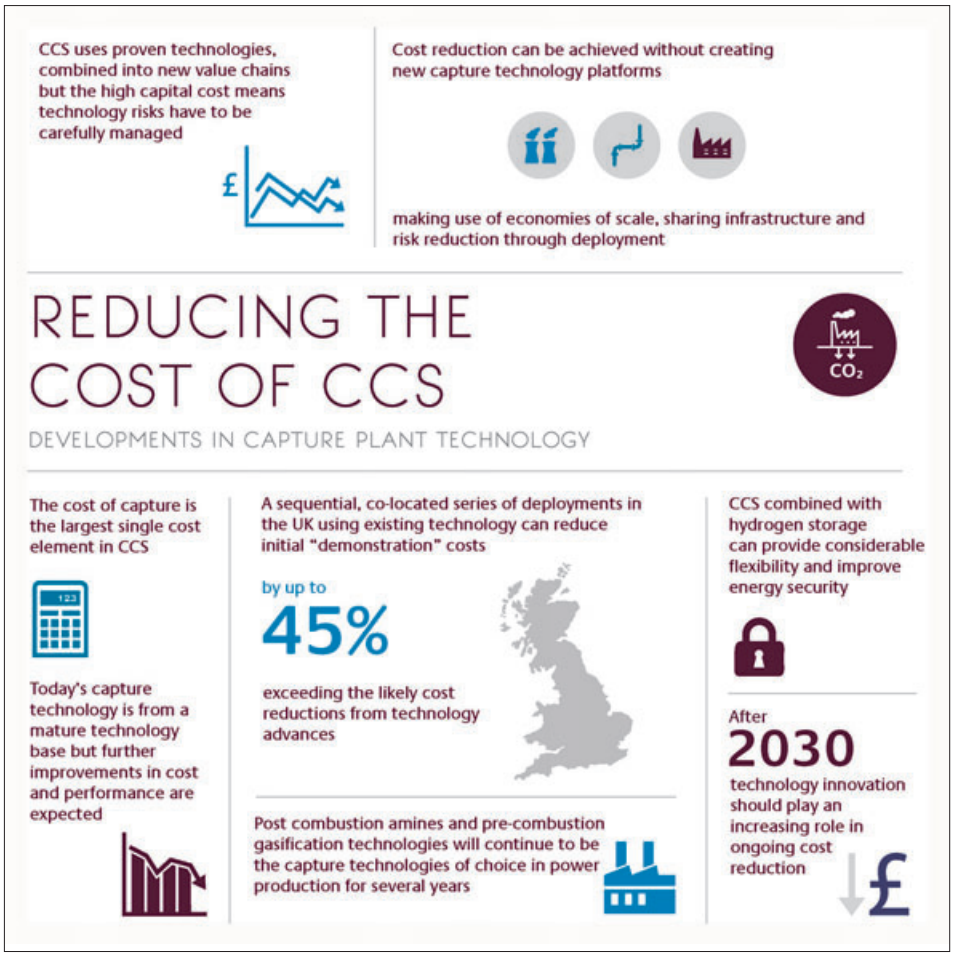
To summarise, then, all the required CCS technologies are proven and significant cost reduction is best achieved through economies of scale, by sharing infrastructure and risk reduction through a coordinated and co-located series of large deployments. The challenge is then a commercial one, with the integration risk being key. Few companies have the breadth of skills and risk appetite required, particularly to initiate the asset chain and industry.

In order to get CCS off the ground in the UK, the private sector will have to be willing to come forward and invest in the installation of the technology. This seems a remote prospect for now, but the UK power supply/demand position is such that minds will be concentrated in the coming years. We also have the benefit of the Contract for Difference and Capacity Market policy instruments that enable funding for new power developments. Clearly an abated plant will provide both capacity and low-carbon electrons and there should be a way to make a good scheme work.

Both Nuclear and Offshore Wind have received strong Government support to establish, or re-establish, the sectors, so we should expect a willingness for Government to enable wider competition, for example by enabling CCS. Government is clearly constrained in its spending and its resource, with the range of issues and loss of staff in DECC, so perhaps it is now time for industry to re-examine its role and the opportunity. Rather than Government define the policy goal and the competition process to advance the sector, maybe we should seek out a commercial, industry-led project?

Although the first plant carries most risk and is difficult to get to financial close, ETI analysis has shown once one CCS facility has been constructed, the cost of building others will inevitably and sharply decrease as subsequent plants take advantage of the knowledge gained and the shared infrastructure.

As a number of the UK's existing fossil fuel and nuclear fleet reach the end of their life, there will be a growing need for new, dispatchable power through the 2020s, with low



CO2 intensity to meet tightening carbon budgets.

The ETI is therefore keen to keep options for CCS in the UK open and, as well as sharing and exploiting its knowledge on potential future costs and storage capacity, is moving forward with a new thermal power project.

In June 2015 the ETI launched a request for proposals[3] for its Thermal Power with CCS (TPwCCS) project, which aimed to accelerate development of a low cost, low risk 'Phase 2' CCS project which could build on the proposed 'Phase 1' commercialisation competition projects.

The scope included developing a 'Generic Business Case' for projects of this type. Following the November 2015 Comprehensive Spending Review (CSR) decision and subsequent closure of the 'Phase 1' competition, the ETI has been considering how the TPwCCS project might be re-scoped to reflect the new circumstances.

As well as the whole-system benefits of CCS, the ETI's latest analysis suggests that the levelised electricity costs of a well-designed power with CCS project could be attractive against other low-carbon alternatives.

The ETI has carried out a range of different analyses around potential ways forward. They confirm that the most cost-effective and secure way to meet these needs is to move forward as soon as reasonably possible with a strategically-located, large-scale abated gas power project (i.e. CCGT + CCS).

Capturing and storing industrial emissions only becomes practically and economically feasible once infrastructure is put in place: this can only be reasonably done with large scale power with CCS projects. If it is started earlier, the unit costs are far higher and any real abatement in tonne terms is delayed.

The UK Government retains the belief that CCS could play a crucial role in the future energy system in the long term if costs can be reduced, but delay benefits no-one. In fact delays in the implementation of CCS could cost £1 – 2bn per annum in the 2020s, rising to £4 – 5bn by 2040 according to our analysis.

2. www.eti.co.uk/existing-technology-and-a-co-ordinated-co-located-series-of-deployments-can-cut-ccs-costs-new-eti-report

3. www.eti.co.uk/eti-seeks-co-venturers-to-develop-an-investable-concept-for-major-new-power-generation-capacity-with-carbon-capture-and-storage-2

However, stakeholders in CCS will need compelling evidence of the business case for a power with CCS project.

As a consequence the ETI has identified a revised programme for the TPwCCS project. We are commissioning a work package to develop an outline scheme and 'template' power plant design for a CCGT with post combustion capture, identifying potential sites and building a credible cost base for such a scheme, benchmarked as far as possible against actual project data and as-built plant. This will then inform the financial and business model that will also be developed. This later phase will be iterative in that stakeholder discussions will improve the structure of the proposal such that it may be more investable.

There are too many constraints around the problem, and the context for abated fossil generation so poor, for a solution to be quickly or easily found. The point to starting now is that it provides some time to develop and test options. It will also expose those areas where Government may still need to take a role. It will show how competitive abated gas at scale could be and provide some feedback from potential investors on its attractiveness. This will inform both Government and industry on the importance or otherwise of progressing this low-carbon power solution and the need for alternatives such as storage. As a public-private partnership the ETI should be well-placed to help guide this.

Rather than just running the project as a hypothetical desk-study, the next step is to plan around real opportunities. This has the advantage of accelerating deployment, which is part of the ETI's mission. Clearly such deployment will ultimately be by other parties, so the ETI will withdraw from the project when/if industry participants make commitments to take the scheme forward.

Early financial modelling suggests that the concept, on paper, is cheaper than many, if not most, alternatives. The project will assess these assumptions and test the business model with potential investors. If there is merit in the concept, then interested investors may seek to collaborate to examine the real costs and risks.

The proposed abated gas project would be at commercial scale and near a large storage site. This has several advantages:

- The capture process and CCGT technology are well-proven enabling lower financing costs
- UK industry knows the technology and has the skills to manage the risks in the asset chain
- Build costs and lead times compare favourably with other low carbon options
- Power output is independent of wind and solar levels and can load-follow if necessary
- Power output can remain/increase if the capture process is shut down for planned, unplanned or commercial reasons
- Economies of scale can be achieved and impact/replicability improved
- It is more attractive for large investors due to materiality and risk-sharing
- There is strong alignment with UK decarbonisation targets and the need for energy security

The ETI-funded phase of the project will develop and assess the feasibility of the concept, bring together industry and Government stakeholders and test the investment potential of the concept and related business models.

The UK is an ideal market to test such a concept. Besides having a power supply crunch, providing a strong demand driver, there remains a broadly positive policy environment with CFDs and the Capacity Market. And other fundamentals support the concept. There is an abundance of high quality storage resource. This is in easy reach of major brownfield industrial sites such as Teesside and Hull, easing consenting and grid/utilities connections. The UK has a sound regulatory framework covering the new activities.

So on the face of it and despite the decision to stop the demonstration competition there is plenty to be positive about the potential of CCS in decarbonising the UK's future energy system.

Clearly there is a challenge to move public and industry opinion but the fundamentals behind the good value and feasibility of abated gas generation in the UK warrant continued examination. We now want to move forward and help ensure the UK can take advantage of the knowledge and understanding of CCS and the opportunities of storing CO2 off the UK coast.

More information

www.eti.co.uk

Team develops novel system for early detection, analysis of potential leaks from carbon storage sites

Technology developed at the University of Calgary in Canada can distinguish between carbon dioxide that may leak from sequestration sites and other sources of CO2 in the air.
By Mark Lowey

It is crucial to detect potential leaks from carbon storage sites as soon as possible, both to fix the problem immediately and to maintain public support for carbon sequestration as a safe and reliable way to reduce greenhouse gas emissions. But it is a technological challenge to identify and analyze, in the field, relatively small leaks of carbon dioxide into the atmosphere that may arise from a geological storage facility.

A team of researchers at the University of Calgary in Calgary, Alberta, Canada has developed an air-monitoring, plume-sampling and analysis system capable of detecting carbon dioxide in atmospheric plumes in which CO2 is elevated by as little as 50 parts per million (ppm) above the normal level typically found in air (about 400 ppm). Their system's powerful and unique capability is that it can differentiate between the various origins of CO2 making up the plume, be it from biological respiration, fossil fuel combustion or a leak from a carbon storage site.

CO2 injection at the Quest site. Shell has developed a detailed measurement, monitoring and verification plan that includes atmospheric, biosphere, hydrosphere, geosphere and well-based monitoring at its Quest project (Image ©Shell)

"It is relatively easy to detect a plume of air having elevated CO2, but much more challenging to be able to identify the origin of the CO2 that has contributed to the plume, says David Layzell, one of two professors involved in the study and director of Canadian Energy Systems Analysis Research (CESAR) initiative at the University of Calgary.

"Our study has shown the feasibility of not only detecting and rapidly sampling CO2 plumes, but then analyzing those plumes to determine the origin of the CO2," Layzell says. The novel plume-analysis technique involved simultaneously measuring, relative to background air, the increase of carbon dioxide and decrease of oxygen in the plume, he notes.

The team published its work, which included a successful field test of its prototype system, in the April 22 edition of the Journal of the Air & Waste Management Association. Along with Layzell, the team included professor Ann-Lise Norman, graduate student Nasrin Mostafavi Pak and postdoctoral fellow Ofelia Rempillo.

"We're aiming to develop a technology that is capable of identifying exactly where a carbon sequestration leak would be at the surface, before it becomes a problem," says Norman, professor in the Department of Physics and Astronomy. "This is about being proactive and identifying the leak early, so it can be fixed as soon as possible."

Studies have shown that carbon dioxide leakage from geological storage sites can contaminate shallow aquifers and surface water bodies, and eventually reach the atmosphere with potential adverse impacts on ecosystems as well as animal and human health.

Large facilities, such as Shell Canada's Quest project near Edmonton, Alberta, typically use monitoring wells – drilled near the CO2-injection wells – to monitor the storage of CO2 in the geological reservoir. Shell has developed a detailed measurement, monitoring and verification plan that includes atmospheric, biosphere, hydrosphere, geosphere and well-based monitoring. The Quest facility is designed to inject and store – approximately two kilometres underground in the deep Basal Cambrian Sandstone formation – more 1 million tonnes of CO2 annually.

'Signature' provides source of CO2

Graduate student Pak, whose Master's thesis is based on the University of Calgary team's work, says: "Our study showed that in both theory and practice, the ratio of oxygen (O2) depletion to carbon dioxide enrichment in a plume provides a 'signature' reflecting the source of the CO2 emission." With natural gas, gasoline and biomass combustion, the ratios are about 1.8, 1.5 and 1.0, respectively, she explains. "However, a carbon storage leak gives a ratio of around 0.2, so it can be readily distinguished from the other, more common sources of atmospheric CO2 plumes.

By being able to analyze differential O2/CO2 ratios relative to 'bulk' ambient air, the team's system can distinguish between a leak of CO2 from a carbon storage site versus another source of carbon dioxide, such as oxidation of carbon compounds through nearby combustion or from biological respiration – of vegetation, for example, or human breath.

The technology developed and tested by the team was adapted from gas-analysis systems commonly used to study respiratory quotients in biological systems. Therefore, the team was able to use off-the-self components, but put them together in a novel way to provide a proof-of-principle for a CO2 leak-detection-and-analysis system.

"The system's uniqueness is in being able to combine the hardware and software in a way that can find a plume, sample it and then simultaneously analyze it for CO2 and O2 differentials relative to background air," Norman says.

The most challenging aspect of the technology to develop – and the system's key component – was being able to accurately measure the small changes in O2 concentration in the plume (typically 100 to 600 ppm), given the high background O2 concentration in air of 20.9 per cent (or 209,460 ppm). To accomplish this, the team used a differential oxygen analyzer (DOX) patented by Layzell and which is available commercially through Qubit Systems Inc., a spin-off company that Layzell established when he was a professor at Queen's University in Kingston, Ontario, Canada.

The DOX instrument used in the study was built for laboratory work on biological systems, and therefore is not portable. So for this study, a backpack unit was designed and used to detect and sample both background air and plumes enriched in CO2. Those samples were then taken to a laboratory where the O2 and CO2 differentials were measured.

To field test the system, researchers placed six, 23-kilogram blocks of dry ice on a raised wooden platform in a soccer field, so that all sides of the dry ice could release CO2 to the atmosphere

Field test confirmed system's capability

To field test the system, researchers placed six, 23-kilogram blocks of dry ice on a raised wooden platform in a soccer field, so that all sides of the dry ice could release CO2 to the atmosphere. Researchers walked downwind of the dry ice with a sampling wand connected to a CO2 analyzer in a backpack. Whenever a plume contained CO2 concentrations at 100 to 600 ppm above ambient levels, they used a high-volume pump to rapidly collect samples for subsequent laboratory analysis of the O2/CO2 ratio and determine the origin of the CO2 in the air sample.

Along with corroborating results obtained in the laboratory, "The field test essentially told us that we don't have to have a massive leak of CO2 in order to detect it," Norman says.

"New technologies for monitoring

A backpack unit was designed and used to detect and sample both background air and plumes enriched in CO2 as the DOX instrument was not portable

CO2 storage sites, such as the prototype instrument described here, are important steps in de-risking geological storage and advancing public confidence in this approach as a CO2 emissions-reduction strategy," says Don Lawton, director of Calgary-based CMC Research Institutes' Containment and Monitoring Institute. CMC wasn't involved in this study, but helps develop and test new technologies for monitoring CO2 storage.

"The ability of this instrument to distinguish between the different origins of CO2 is an important characteristic to ensure that the correct interpretation of CO2 measurements is made," Lawton says.

Layzell said that for future designs of the system, it should be possible to miniaturize the differential oxygen analyzer and integrate it into the backpack unit, so the plume analysis could be done in real time with a completely portable system. Then, if the plume showed the 'signature' of the CCS lead, the results could be integrated with data on GPS, wind speed and direction to provide an approximate location of the leak.

Monzurual Alam, a doctoral candidate who joined the team after Pak completed her thesis, is now working the theory and practice behind a complementary technology that can be dragged across or close to the soil surface and provide precise information on localized CCS leaks that are even smaller than those detectable in an atmospheric plume. Once the atmospheric technology has detected a CCS leak, the soil-sampling probe could be used to narrow down the spatial area and pinpoint the surface location of the leak.

The team is interested in partnering with industry to produce a commercial system. It could be applied not only for early leak detection and analysis at carbon storage sites, but also for detecting leaks from CO2 pipelines. The study was financially supported by the Institute for Sustainable Energy, Environment and Economy (University of Calgary) and the Natural Sciences and Engineering Research Council.

More information

Mark Lowey has worked as a professional journalist for more than 35 years; he is the publisher and managing editor of EnviroLine.

envirolinenews.ca

www.ucalgary.ca

CEMCAP - making existing cement production plants cleaner

The CEMCAP project addresses the challenge of making CO2 capture technologies retrofittable to cement plants. Its primary objective is to prepare the ground for large-scale implementation of CO2 capture in the European cement industry.

Cement plants typically have a lifetime as long as 30-50 years, and few if any are being newly built in Europe. Most of the existing/envisaged CO2 capture technologies have been developed for power plants, in particular coal. In CEMCAP, three post-combustion capture technologies are being developed in a direction that responds to the operating conditions of cement plants.

For instance, CO2 concentrations are higher in the cement plant exhaust, compared to coal-fired power plants (20% CO2 or more), and also the CO2 concentration may vary on a daily basis, depending on the operating mode of the plant, although the production of clinker proceeds at a constant rate. The post-combustion capture technologies are chilled ammonia (CAP technology, proprietary of GE Power), membrane-assisted CO2 liquefaction and Ca-looping).

Overall, CO2 emissions from the cement industry constitute 5% (or 1.9 Gt annually) of global anthropogenic CO2 emissions. In 2013, approximately 20% of global CO2 emissions from cement production originated from Europe (EU28).

CO2 generation is an inherent part of the cement production process, due to the calcination of the most important raw material, limestone (CaCO3 converted to CaO and CO2): about 60 % of the CO2 emissions from cement production are due to this conversion, whereas 40% come from the burning of fuels (which are to a large extent fossil) to provide heat for the clinker production. There are currently no feasible methods to produce clinker and thus cement without releasing CO2 from CaCO3.

In addition to post-combustion capture, CEMCAP is also testing and evaluating three components for oxyfuel retrofit of CO2 capture. This activity is very closely connected to the ECRA CCS project, and the experimental results will feed directly into that project.

The components tested are the oxyfuel burner (a new burner has been developed by ThyssenKrupp), the oxyfuel calciner and the oxyfuel clinker cooler (a prototype has been designed and engineered by IKN for on-site testing at the HeidelbergCement plant in Hannover).

CEMCAP will undertake process simulations and cost estimates on a consistent basis for all the capture technologies investigated in the project, in order to generate comparable results on the technology performance. This, together with a retrofitability analysis at the end of the project will generate a comprehensive decision basis for the cement industry on how what capture technology/-ies are suitable under what conditions, and thus provide guidance on how the cement industry should proceed in this area.

More information

www.sintef.no/cemcap

www.ecra-online.org/226/

www.heidelbergcement.com

Lessons learned from the UK's CCS programmes

The Carbon Capture and Storage Association has written a report looking at what can be learned from the experiences of CCS project developers and other CCS stakeholders after the cancellation of the UK's CCS commercialisation competition.

The CCSA conducted interviews between January and April 2016 seeking views on the recent UK CCS Commercialisation Programme (2012 - 2015) and more generally around experiences with developing CCS projects in the UK and Europe over the last decade and identified 36 key lessons based on evidence provided by participants.

The 36 lessons

1. Peterhead/Goldeneye: Subject to HMG's assessment of affordability and value for money, a CCS full-chain project could have been delivered by Shell at Peterhead, using the Goldeneye store, within the structure, risk allocation and terms of the Commercialisation Programme, albeit with some amendments.

2. White Rose: After lengthy and detailed exploration with the potential providers of both equity and debt finance to the project, it became clear that delivery of a CCS full-chain project developed at Drax by CPL, using the Endurance store developed by NGC would have required important adjustments to the structure of the risk allocation and to the terms of the Commercialisation Programme.

3. Given the conclusions in 1 and 2 above, the Peterhead/ Goldeneye project may best be characterised as 'the exception that proves the rule', because of the specific nature of the project and project developer. The singular circumstances of the Peterhead project, which underpinned the developer's ability to deliver the project (which were constructed based upon experience of participation in the Longannet venture3), and which would seem unlikely to recur, were:

i. A single company controlling capture, transport and storage technologies and assets;

ii. A single developer with competence and capability to develop and deliver the project across the full chain;

iii. A developer with financial capacity to deliver the full chain project based on equity without project finance;

iv. A developer with the strategic interest and drive to deliver a complete CCS project;

v. A developer with sufficient knowledge of and confidence in the CO2 store to take on substantial store performance risk;

vi. A developer with sufficient stature to attract wider industry participation both at investor level, and through the supply chains.

4. The bids for both Competition projects (had they been made) would have sought Contract for Difference (CfD) Strike Prices which were likely to have been within the range forecast by the CCS Cost Reduction Task Force (CRTF) Final Report published in May 2013.

5. The expected CfD strike prices for the Competition projects were much higher than the expected strike prices for subsequent projects. This was in large part because each full-chain project was required to carry the full costs of the entire CO2 transport and storage (T&S) infrastructure of their project, which was perforce much larger than that needed for the CO2 capture plant.

6. Future Phase 2 projects which would have used the infrastructure built by either of the Competition projects would have required CfDs with strike prices very well below those of the Competition projects; arising particularly from the economic savings accruing from sharing the T&S infrastructure developed by the Competition projects, as well as from lower risk premia and smaller contingency requirements.

7. It is believed that the 'Outcome' set out in the ITPD as the goal for the Competition could have been met in each of the new CCS clusters that would have been created if a Competition project had gone ahead in either region. It is now believed that the costs of future Phase 2 projects, which would have used theinfrastructure developed by the Competition projects in either region would have been even lower than the projections in the CRTF Final report.

8. The Goldeneye store was capable of and ready for technical development.

9. The Endurance store was (and remains) capable of and ready for development.

10. Depleted gas fields with proven storage capability and comprehensive production history may already be fully appraised for CCS service to the level of confidence that would be required to obtain a storage permit with seismic appraisal, model construction and without further appraisal wells being drilled.

11. It is possible to appraise a saline aquifer, which has not previously been involved in hydrocarbon production, to the level of confidence that it would be possible to apply with confidence for a CO2 storage permit.

12. It is now known with confidence that the Goldeneye infrastructure could have been extended at relatively low cost to provide very considerable, relatively easily accessible storage capacity in the Captain aquifer in the Central North Sea (of which the Goldeneye field is a part), capable of serving a significant number of CCS projects.

13. It is now known with confidence that the Endurance infrastructure could have been extended at low cost to provide accessible storage capacity capable of serving a very significant number of CCS projects in the Southern North Sea.

14. Under the ITPD, developers were to share some of the costs and consequences of socalled 'CCS risks' with HMG. Whilst each of the Competition projects would have ac-

cepted a share of these risks it was clear that HMG would have had to accept the majority of the financial risk arising from developing, operating, monitoring and decommissioning the new CO2 stores.

15. The Competition project developers consider that the majority of the risks associated with CO2 storage, which HMG proposed be taken by the developers, could have been adequately quantified and insured against, though any insurance would have been of limited term (probably significantly less than the life of the CfD) and capped in value. However, one of the major risks that was not considered insurable was the cost and impact of CO2 leakage (i.e. the required surrender of EU Emissions Trading System (ETS) allowances for any emissions from the site, including leakages, pursuant to the ETS Directive).

16. Guidance Document 4 of the EU CCS Directive on Financial Securities and the Financial Mechanism (GD4) risks imposing additional and onerous financial obligations on storage operators that go beyond the specific requirements of the Directive. Whilst the Guidance Documents themselves are legally non-binding, there is a risk that their literal interpretation by a Competent Authority could act as a major deterrent to CO2 storage development.

17. GD4 suggests that the level of Financial Security required to cover the surrender of ETS allowances in the event of a leakage should be based on the potential total tonnes of emissions multiplied by the market cost of purchasing an equivalent amount of allowances. In setting the level of the Financial Security for the Competition projects the OGA demonstrated a willingness to adopt a more pragmatic approach compared to the more rigid guidance laid out in GD4.

18. The Storage of Carbon Dioxide (Licensing) Regulations 2010 outline a list of five types of Financial Security that may be provided by projects to satisfy the requirements of the EU CCS Directive. There remains uncertainty as to whether OGA considered this list to be exhaustive or not, and whether or not the OGA can accept other forms of Financial Security.

19. The full-chain private sector business model as used in the Commercialisation Programme and as spelt out in the ITPD ('UK CCS ITPD full chain structure') is unlikely to work in future, for several reasons.

20. Under the 'UK CCS ITPD full chain structure' investing in early offshore CO2 storage projects is currently not, and is unlikely to become, an attractive investment proposition for the private sector.

21. Under the 'UK CCS ITPD full chain structure' the likelihood and consequence of cross-chain default by the generation operator, the capture operator, the transport operator or the storage operator in this model was a significant challenge to both debt and equity investors in all parts of the CCS chain.

22. The potential CfD strike prices for the Competition projects were perceived in November 2015 by HMG to be too high to accept.

23. The future benefits of developing CCS now, including delivering the Commercialisation Programme 'Outcome' were deemed in November 2015 by HMG to be either insufficient or too remote to justify investing in either of the Competition projects.

24. Assessment of the benefits and costs of CCS generation against other forms of low carbon energy generation suffered from lack of like-for-like comparison.

25. Whilst interest in CCS remains, there is no discernible appetite from any project developers to participate in a further UK CCS competition.

26. There is appetite from a number of CCS project developers to enter into discussions and bilateral negotiations with HMG on developing new 'bespoke' CCS projects (covering industrial CCS, hydrogen and heat, power and possibly EOR) that they believe could be attractive to HMG.

27. Over-sizing CO2 T&S infrastructure for simultaneous use by several future projects will, without doubt, generate the best value for money if a number of projects can share the same T&S infrastructure.

28. There is a mismatch between the size of cost effective offshore T&S infrastructure and the expected volume of CO2 captured from the first single Generation and Capture (G&C) projects.

29. It does seem clear that opportunities to use existing pipelines could give very good value for money.

30. The arguments for or against using existing platforms versus building new platforms or new sub-sea installations is very case-specific.

31. Public funding (UK government, the EU and other national governments) for project development and FEED costs have so far been fundamental in moving projects forward prior to there being any binding contractual commitment to provide a CfD to a project.

32. Financing of storage appraisal has, to date, necessitated some form of public funding in advance of FID. This is likely to remain the case whilst there is no clear business case for preinvestment in CO2 storage capacity.

33. CCS projects with CfDs granted under the Electricity Market Reform (EMR) regime will be deemed in receipt of State Aid, and will require State Aid approval from the EU (as will any projects receiving significant grants). Although State Aid approval is likely to be forthcoming under the existing Guidelines for Energy and Environmental Aid,17 because early projects will require individual approval, and a system of blanket approvals will not be available for some time, State Aid approval is likely to add considerable time to the project approval process.

34. CCS projects developed on the basis of CfD revenues appeared to be an attractive proposition to providers of long term Power Purchase Agreements (PPAs)

35. Securing a bankable PPA for sale of electricity from a CCS plant is crucial to providers of debt financing.

36. HMG policy changes over the last 10 years have proved to be a significant factor influencing the development of CCS projects. This has reduced the appetite of many developers, investors and the supply chain to engage in UK CCS project development.

More information

The Carbon Capture and Storage Association (CCSA) exists to represent the interests of its members in promoting the business of Carbon Capture and Storage (CCS) and to assist policy developments in the UK, EU and internationally.

Download the full report free from their website:

www.ccsassociation.org

ZEP provides input to proposed EU Innovation funding

The Zero Emissions Platform has provided input to the new EU-ETS funding proposal. ZEP believes that the Innovation Fund should be made significantly more flexible than the NER300.

In its proposal for revising the EU ETS Directive, the European Commission suggests the introduction of dedicated funds to support innovation in low carbon technologies and modernisation in the energy sector. The ZEP exists as the European Technology Platform for Carbon Capture and Storage (CCS) and sees the Commission proposals as an important step towards securing further EU support for CCS under the 2030 framework for climate and energy policies and as an integral part of the Energy Union Strategy.

The European Commission proposed in its Summer Package 2015 that the existing NER300 programme should be replaced by an Innovation Fund under Phase IV of the EU Emissions Trading System, made up of an initial endowment of 450 million allowances. This Fund, supplemented by a Modernisation Fund for eligible Member States, would support the deployment of CCS projects, innovative renewables and to deliver emissions reductions from industrial installations.

NER300 aimed to support the European Council's objective of 12 operational CCS demonstration projects by 2015. For multiple reasons, including the inadequacies of the NER300, not a single commercial scale CCS project is yet operating in the EU. In order to ensure that the Innovation Fund is fit for purpose and can deliver commercial scale CCS projects ZEP has undertaken an initial review of the NER300 Decision (2010/670/EU) and identified high level recommendations.

ZEP believes that the Innovation Fund should be made significantly more flexible than the NER300: this applies on multiple levels from the balance of funding between technologies, the process of achieving geographical balance, right through to the technology categories prescribed in Annex 1 of the Decision.

ZEP strongly recommends moving away from the full value chain approach of NER300 towards a more outcomes-focused approach that also enables part-chain projects to come forward. Projects awarded funding should be compatible with the Paris Agreement and the EU 2050 Roadmap, taking account of 2030 objectives but not losing site of longer-term energy and climate goals.

Innovation fund

The European Commission proposed the endowment of 450 million allowances under the EU ETS, to support CCS beside innovative renewable energy and energy intensive industry. ZEP welcomes the proposal, however notes that CCS and other innovative low carbon technologies will require multi-year support to get it to deployment phase. Therefore ZEP believes that a long-term mechanism should be put in place, as it would best support break-through of innovative projects.

In the impact assessment that accompanies the ETS legislative proposal, the Commission analyses different options for the outline of the fund, including the possibility to move away from the present current grant-based option for a permanent financial support provided through a financial instrument.

The Commission has decided to continue with a grant scheme. ZEP agrees that a grant scheme will be the most appropriate option for the new Funds but would also welcome a separate pot being set aside for loans and/or financial guarantees that could be made available to successful bidders to support project financing.

ZEP recommendations

In particular, for the Innovation Fund implementing decision, ZEP recommends that:

1. The Funds should be able to support the development of part-chain and CO2 transport and storage infrastructure projects, including funding for "market makers" as described in the ZEP Executable Plan.

2. That a geographical balance can best be achieved through allowing an increase in the funding rate for projects that deliver greatest EU added value and which contribute towards the decarbonisation of multiple Member States.

3. If a project is awarded funding from more than one source of EU funding, those funds should be allowed to accumulate. Under the NER300 scheme projects awarded funding would have had any additional EEPR funding deducted from its NER300 total.

4. Project selection should move away from award based on the cost of performance defined by the total eligible cost divided by the amount of CO2 stored towards a more flexible system that recognises the value in infrastructure development and the clean output of industrial processes (including electricity generation).

5. The requirement for Member State support should be revisited to make it easier for projects to apply for, and receive funding from the new Innovation Fund.

More information

The report can be downloaded here:
www.zeroemissionsplatform.eu

Identifying and Developing European CCS Hubs

The Zero Emissions Platform (ZEP) was requested, by the EU Commission, to enlarge on the potential core areas for near-term European CCS deployment that had been identified in their earlier report, An Executable Plan for enabling CCS in Europe. In a short note, ZEP expands on the contribution toward Net Zero and a sustainable Europe that deployment of CCS hubs and clusters can deliver.

Storage requires suitable geological strata, but these do not exist under every EU region therefore CO2 transport is required. This is analogous to natural gas transportation where pipelines cross the continent linking gas fields to customers.

The transport and injection of CO2, like that of natural gas, benefits from economies of scale – it is more cost effective to build one large trunk pipeline than to build three smaller pipelines. The same holds for injection infrastructure and aquifer storage monitoring technology.

Large emission sources also tend to be clustered – because they often historically grew near coal fields, ports or rivers; and because there are benefits to clustering manufacturing near to refining and power generation.

This leads logically to the development of CO2 collection clusters, trunk transmission networks, and CO2 storage hubs. Once established a hub and cluster network can significantly reduce the cost of entry to new decarbonised companies.

Industrial clusters represent a real opportunity to exploit shared infrastructure that many parties can use, therefore benefiting and reducing cost for multiple (and especially smaller) emitters. Strategically sized transport & storage infrastructure built with additional/spare capacity allows the investment decision to be de-risked for the emitter, allowing for potentially more attractive capital structures and funding approaches, which would reduce risk and cost for many potential low carbon projects. Shared infrastructure with sufficient, proved storage capacity also allows emitters to separate their investment decisions (in terms of both time and technology) from the development of the network. This is important to maximise deployment and exploitation of CCS and realise benefits of scale2.

Key messages

A low carbon EU should be inclusive with a comprehensive collection network enabling emitters large and small to connect to CO2 storage and create value in the Net Zero economy.

Developing such CO2 gathering networks & clusters linked to CO2 storage hubs via trunk pipeline networks and shipping routes is the lowest cost route to creating low carbon sustainable growth.

The EU has a number of large CO2 emission clusters, plus it benefits from world class CO2 storage formations. Connecting emissions clusters to the storage formations will often cross national boundaries – a regional collaborative approach incorporating adjacent member states is therefore needed.

A necessity for the creation of hubs and clusters, is policy supported by suitable (financial) instruments that can facilitate deployment. However, an often overlooked fact is that, in addition to policy instruments, the maturation of hubs and clusters requires dedicated people to tailor and plan deployment. Only with both dedicated people and policies can CCS be deployed to accelerate the transformation to Net Zero industrial and power generation clusters.

Efficient and effective design and delivery of optimal hubs and clusters requires regional development organisations, each drawn from relevant Member States, working with national market makers and transport & storage network developers.

Europe's advantaged global position

The EU is lucky to have a world class storage region – the North Sea basin. This basin has many tens of billions of tonnes (Gt) of CO2 storage capacity and has the advantage of being offshore thereby reducing the public acceptance barrier. Offshore development, however, has a higher capital cost than onshore and benefits even more from the cost savings delivered by economies of scale. The Baltic Sea has also been recently evaluated and significant storage resources in the multi-Gt range have been identified.

Onshore CO2 storage will also be important and is already proven in Canada and in the USA. Recent experience in the EU indicates that public acceptance is more challenging to obtain than in the USA and Canada, due substantially to population concentration and location, therefore it is likely that offshore storage will precede onshore storage. There might, however, be exceptions to this especially in Eastern Europe where there is an existing onshore CO2 EOR industry.

Many of Europe's largest carbon emitters (both power plants and industrial facilities) are already 'clustered' together around major ports such as Rotterdam, Duisburg, Hamburg, Humberside, Teesside, Grangemouth, Antwerp, Le Havre and Merseyside.

Importantly, some industrial clusters are also

close to excellent and extensive geological CO2 storage opportunities. For example on the North Sea coast of the UK, the Teesside area's industry represents 5.6 per cent of the UK's industrial emissions, while the Yorkshire and Humber region represents 10 percent of total UK CO2 emissions.

How are hubs and clusters encouraged to develop?

The challenge with CCS is scale. Full scale CCS projects can make a massive impact on the CO2 emission reductions targets of a member state – a single commercial scale project will remove between 1Mtpa and 5Mtpa. For reference 1Mtpa is equivalent to removing the emissions of about 250,000 EU cars. However, the large scale of a CCS project – which delivers a large emission reduction – means that the individual project capital cost is significant, commonly over €1Bln. In order to fund this level of investment, finance is generally sought over a period of up to 25 years – this exposes projects to significant counterparty risk as described in ZEP's T&S business model report, and also to political/policy risk. While the renewable industry, which also faces the need for significant capital investment, has overcome this challenge through the use of policy led stimuli like subsidy, feed in tariffs and loan guarantees this bridge has not evolved yet for CCS industry.

CCS is an emissions control technology, in order avoid damages and resulting cost to the environment and society. This helps explain why CCS has not managed to develop an effective funding model as it is an adjunct to existing processes (coal/gas power generation + capture; manufacturing + capture) rather than an industry in its own right (wind generation, solar generation). Another challenge is that transport infrastructure needs to be developed to link CO2 emitters to CO2 storage sites from scratch. By contrast renewable generation benefits from the Member State transmission grids. The capital risk for grid upgrades can often be borne by regulated utilities not by an individual renewable energy project. For this reason ZEP is recommending the disaggregation of the CCS chain – the separation of capture from transport and storage infrastructure development.

This separation requires the development of key transport infrastructure, sized correctly for regional requirements. Some of the infrastructure can take advantage of the flexibility of ship transport – requiring the provision of liquefaction, loading and offloading facilities rather than whole pipeline systems. It also requires the development of strategic storage hubs.

In order for a region to be ready for the development of CCS a number of critical success factors need to be in place. These are described in full in ZEP's Executable Plan, but the key ones that are being selected here in order to identify potential hubs and clusters are:

(1) Ambition to decarbonise industry and energy

(2) The presence of emissions sources and storage formations

(3) A politically supportive industrial region and member state

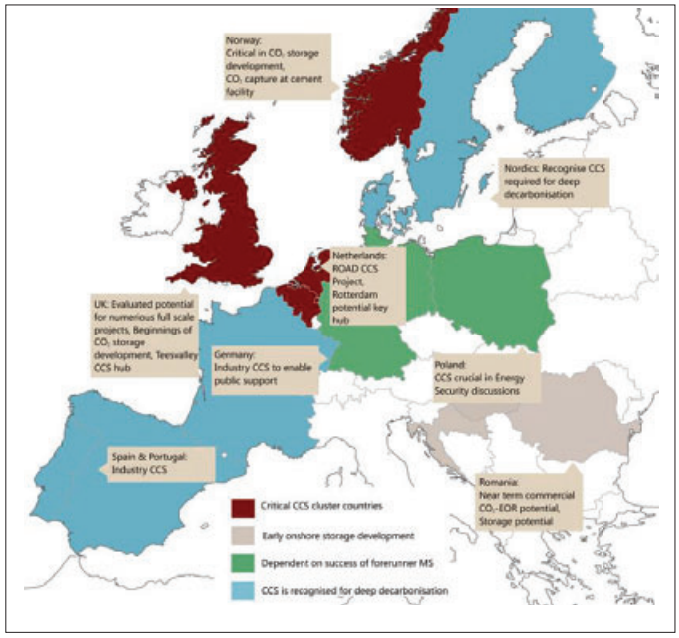
(4) The potential for EU regional funding

(5) The potential for economic value creation and retention through the development of CO2 advantaged manufacturing of products or CO2 utilisation opportunities.

A necessity for the creation of hubs and clusters is a policy supported by suitable (financial) instruments that can facilitate such development. Effective delivery requires coordination by regional development organisations, each drawn from relevant Member States, working with national market makers and T&S network developers.

In the absence of regional development organisations ZEP has drawn upon the knowledge of its members to create outline development plans for a number of candidate regions. The fact that the level of detail of the summary plans varies highlights the need for the key first step of stimulating the creation of these regional organisations. Thanks must be given to those organisations that do exist and who have helped: Gassnova; Scottish Carbon Capture & Storage (SCCS); the CCSA; the Rotterdam Climate Initiative and the GCCSI.

Potential regional groupings of emissions clusters and hubs



Candidate regions that have been identified as possessing many of the key characteristics: CO2 sources, sinks, and political awareness of the opportunity presented by CCS

The lack of identified regional development organisations or proxies thereof in Poland, Germany, Romania and Spain/Portugal means that ZEP has to date been unable to mature notional CCS development options for these key regions.

A critical recommendation is therefore to request that the Commission work with these regions to establish organisations that can effectively outline the opportunities for rapid and deep carbon reduction by CCS.

The figure outlines a potential integrated development opportunity for the countries that skirt the North Sea. It is possible to start small with demonstration scale projects (1-3 Mtpa), then develop initial commercial scale cross border connections, and finally install the full scale (mature) interconnection trunk lines. Ship transport is ever present connecting smaller sources to the established storage hubs, initially transporting CO2 between onshore hubs until offshore unloading has been developed.

The four initial components are: Rotterdam hub; the UK Southern North Sea hub; the UK Scottish hub; and the Scandinavia hub. These regions would also benefit from formal regional development organisations.

More information

www.zeroemissionsplatform.eu

Projects and policy news

Industrial emissions overlooked says Global CCS Institute report

www.globalccsinstitute.com

The Institute has released two new public information reports highlighting the long-term application of CCS technology in a variety of industrial sectors.

More than eight billion tonnes of annual carbon dioxide (CO2) emissions are being overlooked in a climate debate focused too narrowly on energy policy, according to Brad Page, Chief Executive Officer of the Global CCS Institute.

CCS was first applied to natural gas processing in 1972, a sector that now boasts nine operational large-scale CCS projects with annual capture potential of more than 20 million tonnes of CO2.

Introduction to Industrial Carbon Capture and Storage summarises 17 CCS projects across sectors including natural gas processing, fertiliser manufacturing and hydrogen production.

The report highlights that one quarter (25 percent) of the world's CO2 emissions, or 8.5 gigatonnes, result from these, and other industrial sectors such as iron and steel, cement production and petrochemicals refining.

Industrial process emissions are unavoidable regardless of the energy source used to run the facilities where they take place.

"Strong policy support is required globally, now, to help decarbonise these industries," said Mr Page.

"If we are serious about tackling climate change then we've got to reduce emissions from every possible sector of the global economy, urgently and without bias.

"Steel and cement are vital to build the essential infrastructure that drives economic progress – including the factories where low carbon energy technologies are manufactured.

"These sectors cannot simply be 'switched' out of the global economy, and transitioning to low-carbon energy sources still fails to address the billions of tonnes of emissions released through industrial processes. CCS is the only technology that can deliver deep cuts to these emissions.

"An electric car may be charged on a grid powered by renewables. But that car cannot be built without metals, plastics and polymers. It cannot be built without factories, production lines, or tools.

"In CCS we have a proven technology that is already reducing carbon emissions by millions of tonnes each year, in applications as diverse as natural gas processing, hydrogen production and fertiliser manufacturing.

The second report, Understanding Industrial CCS Hubs and Clusters explores the economic benefits of building shared infrastructure for multiple small industrial emitters to reduce emissions using CCS.

Norway's plans to realise CCS by 2022

www.regjeringen.no

The Ministry of Petroleum and Energy has released a feasibility study report on full-scale carbon capture, transport and storage in Norway.

The Government says it has chosen a step by step approach following industry best practice for maturing CCS projects in Norway. "The feasibility studies are an important part of this work and show that realising a full-scale CCS chain in Norway within 2022 is possible and at lower costs than for projects considered in Norway earlier," said Minister of Petroleum and Energy Tord Lien.

Stortinget (the Norwegian parliament) and the Government have high ambitions for succeeding with CCS. The Government has seen through on the ambition by following up on the strategy presented to Stortinget in the state budget for 2015. The strategy covers research and development, demonstration, international cooperation, support for a full-scale project through an EU research program, and assessment of full-scale CCS projects in Norway.

"Wide deployment of CCS is necessary for the world to reach its climate goals" said Minister Lien. "The most important goal of a full-scale project in Norway is to contribute with knowledge and learning so CCS can be deployed in industry across the world. The feasibility studies provide good fact-based grounds for considering how we will continue our work with full-scale CCS in Norway."

The aim of the feasibility studies is to identify at least one technically feasible CCS chain with corresponding cost estimates. Such a chain includes capture, transport and storage of CO2. The results show that it is technically feasible to realise several alternatives in Norway.

Three industrial players have completed feasibility studies of CO2 capture; Norcem AS has assessed the possibility for capturing CO2 from the flue gas at its cement factory in Brevik, Yara Norge AS has assessed CO2 capture from three different emissions points at its ammonia plant at Herøya in Porsgrunn and the Waste-to-Energy Agency in Oslo municipality has assessed CO2 capture from the waste recovery plant at Klemetsrud (Klemetsrudanlegget AS).

Gassco has carried out a study of ship transport of CO2 between locations for capture and storage for different conditions (pressure) at vapour/liquid equilibrium. Gassco considers all solutions for the studied transport conditions as technically feasible.

Statoil ASA has completed feasibility studies of CO2 storage at three different sites on the Norwegian continental shelf. Both Statoil and Gassnova consider a solution for developing a CO2 storage site with onshore facilities and a pipeline to the Smeaheia area as the best solution given the project's objective. The Smeaheia area is located east of the "Troll" field, approximately 50 km from the coast. This solution has the lowest implementation risk, large storage capacity and it is relatively easy to develop the capacity of the infrastructure.

The cost for planning and investment for such a chain is estimated at between 7.2 and 12.6 billion kroner (excluding VAT). The planning and investment cost will depend on how much CO2 will be captured, where it will be captured from and how many transport ships are needed. The cost estimates are based on the reports from the industrial players and have an uncertainty of +/- 40 percent or lower.

The Ministry of Petroleum and Energy has had overall responsibility for the feasibility

studies. Gassnova SF has been project coordinator and responsible for capture and storage, while Gassco AS has been responsible for transport.

The Government will present further plans for CCS in the state budget for 2017.

CO2CRC and Canada's Petroleum Technology Research Centre collaborate

www.co2crc.com.au

www.ptrc.ca

The two organisations will work to accelerate the uptake of carbon capture and storage technology.

Australian and Canadian carbon capture and storage research leaders have quickly moved to establish a memorandum of understanding where internationally significant projects led by CO2CRC and the Petroleum Technology Research Centre (PTRC) will collaborate on a range of technologies to drive down the costs of carbon capture and storage as an industrial scale emissions reduction tool.

CO2CRC is Australia's leading carbon capture and storage research organisation, having been the first company to have undertaken full chain CCS (capture, transportation and storage) nationally. CO2CRC research focuses on enhancing monitoring techniques for regulator and community certainty while reducing cost. The CO2CRC research teams also design, manage and partially fund projects that investigate the capture of high concentrations of CO2 in otherwise uneconomic natural gas wells.

As a leader in the field of carbon management, PTRC manages all research associated with Aquistore - the world's only integrated storage project associated with an industrial scale coal-fired power plant. Aquistore provides an exclusive 'industrial laboratory' to test and develop viable, lower cost monitoring technologies to advance commercial CCS projects internationally.

Tania Constable, CO2CRC's CEO said, "Both CO2CRC and PTRC are focused on driving the costs of carbon capture and storage down to deploy CCS more quickly. Sharing information techniques will help".

"CO2CRC will work closely with PTRC to support this goal", Ms Constable said.

Ken From, PTRC's CEO notes "The performance of Aquistore and the data generated are exceeding expectations of the PTRC team and the world's research community, and we are very pleased to collaborate with our Australian colleagues."

This agreement represents efforts to prepare and execute joint research, facilitate the exchange of scientists and technical personnel, and encourage dedicated CO2 storage on regional, national, and international scales.

Clean coal essential to meet 2 degrees targets

www.worldcoal.org

The World Coal Association (WCA) has welcomed the publication of a report by the Coal Industry Advisory Board to the International Energy Agency (CIAB) on the role of coal in energy security.

The report, "The Role of Coal for Energy Security in World Regions" concludes that in order to meet the growing global energy demand and to simultaneously reduce global greenhouse gas emissions, increasing the support for HELE coal-fired plants and CCS technologies is essential. HELE coal technologies provide a source for significant immediate CO2 emission reduction and are a key first step towards CCS.

Coal is widely used across countries and regions to ensure the security of energy supply as measured through affordable energy, broader dependable access for consumers and increased economic competitiveness.

Thue report found that there is no trade-off between the increased use of renewable energies and the use of coal; instead there is a partnership which is needed to meet global, regional and country level energy requirements now and in the future.

The widespread deployment of clean coal technologies, high efficiency low emissions (HELE) and carbon capture storage (CCS) is needed to meet a 2°C climate target, the report says.

Following the launch of the report, the WCA Chief Executive Benjamin Sporton commented: "As the Paris Agreement is formally adopted, it is vitally important that its implementation integrates environmental imperatives with the aims of universal access to energy, energy security and social and economic development. All low-carbon technologies must play a role including HELE coal technology and CCS."

Dr Hans-Wilhelm Schiffer, leader of the CIAB Energy Security Working Group and lead author of the report said: "Coal and renewables complement each other and are partners in the effort to meet present and future energy requirements. Coal-fired power plants provide dispatchable capacity due to their ability to operate flexibly and so compensate for the fluctuations of wind and solar energy supply. In addition, coal-fired power plants can also be seen as an economic balance to the higher system costs of most renewable energies."

The report considers how the use of coal contributes to affordable energy prices, and allows broader access to electricity and improved industrial competitiveness of economies in various regions. Coal is found to be a key component of a secure energy supply in all the regions/countries covered.

Applying advanced coal-based technologies, like HELE coal plants and CCS technologies, contributes to improving not only the environmental impacts but also leads to increased security of supply. HELE coal technologies provide significant immediate CO2 emission reductions and are a key step on the pathway to CCS.

$2.4m for U.S.-China CCS Centre

www.caer.uky.edu

The U.S. Department of Energy (DOE) has awarded the University of Kentucky's Center for Applied Energy Research (CAER) a five-year renewal of its United States-China Clean Energy Research Center (CERC) grant.

CERC was created in 2009 by DOE, the China Ministry of Science and Technology and the China National Energy Administration to facilitate joint research and development on clean energy by teams of scientists and engineers from the U.S. and China.

The DOE grant totals $2.4 million over five years and will support CAER efforts to develop advanced coal technologies. Kunlei Liu will serve as the University of Kentucky's principal investigator, along with his co-investigators Mark Crocker and Don Challman. Liu, an advanced combustion and pollution control expert, and Crocker, a leader in utilizing algae to mitigate CO2, will each serve as technical leads for specific research areas, while Challman serves on the U.S. Steering Committee and on the bilateral U.S.-China Intellectual Property Experts Working Group.

"CAER is a global leader in developing carbon capture and storage technologies," UK President Eli Capilouto said. "This grant will help advance promising research and development in this area, as UK CAER and its industry partners in Kentucky, across the nation and throughout the world seek sustainable energy solutions."

UK CAER is a founding member of CERC's Advanced Coal Technologies Consortium, led by West Virginia University and also including the University of Wyoming and Washington University in Saint Louis; geological surveys (Wyoming and Indiana); national laboratories (Lawrence Livermore, Los Alamos and the National Energy Technology Lab); leading non-government organizations working in China on carbon capture and storage and clean energy development (World Resource Institute and U.S.-China Clean Energy Forum); and various industrial sponsors. The consortium's purpose is to advance American and Chinese leadership and collaboration in advanced coal technologies, particularly as directed to carbon capture and utilization, advanced combustions systems and geological sequestration.

"This grant will help maintain UK CAER's international leadership in developing and advancing carbon capture technologies," said Rodney Andrews, director of the UK CAER. "The development of proven and economical clean coal technologies is crucial to sustaining economic and community development and improved quality of life in Kentucky and in communities throughout the world.

NETL launches a University coalition for fossil energy research

energy.gov/fe

The Department of Energy's (DOE) National Energy Technology Laboratory (NETL) has selected Pennsylvania State University as the lead institution to establish the University Coalition for Fossil Energy Research.

The Coalition will bring together a multidisciplinary team of researchers from participating universities to address the fundamental research challenges that impede advancement of fossil energy-based technologies.

Research performed by Coalition members will directly support the Office of Fossil Energy's Coal and Oil and Gas programs by focusing efforts in a variety of pertinent areas that include, but are not limited to, advanced energy systems, carbon dioxide capture and storage, natural gas resources and infrastructure, and onshore and offshore oil and gas technology. The Coalition will facilitate basic and applied energy research and promote multidisciplinary collaboration among the member universities and NETL.

Pennsylvania State University, the lead institution, will leverage expertise, facilities, and resources from the founding coalition member universities that include Massachusetts Institute of Technology, Princeton University, Texas A&M University, University of Kentucky, University of Southern California, University of Tulsa, University of Wyoming, and Virginia Polytechnic and State University.

The coordination structure is flexible, allowing for new university members to provide additional research capabilities and collaborations as needed throughout the research lifespan. Members of the Coalition will actively seek industry participation in research projects and promote technology transfer to the private sector.

The research completed throughout the six-year initiative is expected to accelerate the development and deployment of fossil fuel-based technologies, enabling the continued use of our nation's abundant natural resources in a cost effective and environmentally responsible manner.

Former BP Executive joins Global CO2 Initiative

www.globalco2initiative.org

Dr. Issam Dairanieh, the former head of the corporate venture capital team at BP, will lead a new initiative focused on converting carbon emissions into valuable commercial products.

Launched this January in Davos at the World Economic Forum annual meeting, The Global CO2 Initiative and its innovation arm, CO2 Sciences Inc., were created to realize the ambitious goal of capturing 10 percent of global CO2 emissions and transforming them into valuable products.

By harnessing market demand for products that capture and reuse CO2, this worldwide initiative aims to catalyze substantial economically-driven change that reuses the increased amounts of CO2. There are many products that can be made using captured CO2, including cement, aggregates, carbon fiber, plastics and fuels, among others.

"Creating bold solutions for one of the world's most pressing challenges requires innovative leadership, which is why we are thrilled to have Dr. Dairanieh join our team," said Bernard David, Chairman of the Initiative's innovative research and development platform, CO2 Sciences Inc. "Issam's extensive expertise in both research and development of emerging technologies and in commercialization make him uniquely positioned for this role."

Dr. Dairanieh brings over 30 years of experience in technology assessment, development, deployment and investment to The Initiative.

"We have a tremendous opportunity to harness the power of commercial markets to reuse global CO2," said Dr. Dairanieh. "We estimate that converting CO2 into products like construction materials, fuels, and carbon fiber has a market value of $800 billion — 1.1 trillion annually, achievable by 2030. Supporting and accelerating the variety and scale of CO2-based products turns a liability into an asset.

In my new capacity as CEO, I look forward to working to catalyze innovative research in carbon capture and reuse by granting $100 million per year for ten years to scientific research. Simultaneously, we will work with investment funds, joint ventures and corporations to invest in companies to enable them to grow market demand for CO2-based products."

Since 2006, Dr. Dairanieh has conducted strategic studies on emerging clean energy technologies providing insights and prospects on business opportunities for BP's Alternative Energy division. In 2007, Dr. Dairanieh joined BP Ventures and wrote an investment thesis on carbon conversion that lead to investing in three leading companies in this arena. Then in 2010, Dr. Dairanieh took on building and leading the U.S. venture team for BP Alternative Energy and then became the international head of the corporate venture capital team.

"The Global CO2 Initiative is taking on the grand challenge of developing real-world solutions to reduce our carbon emissions," said former U.S. Energy Secretary Dr. Steven Chu, a member of the Initiative's Global Advisory Board. "Dr. Dairanieh is well positioned to undertake this ambitious and critically important effort that will have a direct impact on climate change."

"Developing carbon capture and utilization technology will play a crucial role in the global effort to reduce the atmospheric carbon burden and tackle climate change," said Thomas Lovejoy, Senior Fellow at the United Nations Foundation and University Professor in the Environmental Science and Policy department at George Mason University. "The Global CO2 Initiative is leading the work to scale and commercialize these critical technologies. Their ability to bring together the worlds of science, business, technology and finance is unparalleled."

DOE Awards $10 Million to Small Businesses for Fossil Energy Research and Technology Transfer

science.energy.gov/sbir

The U.S. Department of Energy (DOE) has selected 10 research projects to empower small businesses to develop technologies that allow for the nation to more wisely and efficiently use our vast fossil energy resources and sustain economic growth.

The projects are funded under the Small Business Innovative Research (SBIR) and Small Business Technology Transfer (STTR) programs for the fiscal year 2016 SBIR/STTR Phase II Release 2 funding opportunity announcements through the DOE's Office of Science. The SBIR program increases private-sector commercialization of innovations derived from Federal research and development (R&D). STTR simulates and fosters scientific innovation and technology transfer through cooperative research and development carried out between small business concerns and research institutions.

The ten selected projects, under two topic areas, will receive a total of $10 million in R&D funding.

Heseltine report supports Teesside Collective

www.teessidecollective.co.uk

A report by a UK peer supports the Teesside Collective's CCS objectives.

Teesside Collective welcomed the launch of Lord Heseltine's report on economic opportunities in Tees Valley and his strong recommendations around progressing the industrial carbon capture and storage initiative.

"This is a rare instance when existing industries can harness a new technology and ensure that Britain becomes a European and world leader," said Lord Heseltine. "Without this work continuing this opportunity could be lost to other industrial areas overseas. The opportunity that industrial CCS and CCU could offer the region cannot be underestimated – in terms of both existing and future investment and employment."

Key report recommendations are:

The Teesside Collective should develop a new business case that reflects changed circumstances (i.e. the end of the Carbon Capture Storage Commercialisation Competition and closure of SSI) and clearly sets out the rationale for Industrial Carbon Capture Storage in the area.

Should any further feasibility funding be available this Parliament, the Government should continue to support the Teesside Collective subject to the Teesside Collective proposals demonstrating a strong rationale for Industrial Carbon Capture Storage in the area and value for money.

The Government to set out its new approach to Carbon Capture Storage (CCS) taking into account the findings of Lord Oxburgh's CCS Advisory Group report.

The Teesside Collective should work with existing petroleum and carbon dioxide storage licence holders, and harness the Storage Site Appraisal work to explore and identify the best potential offshore pipeline network and potential storage site for Teesside's Industrial Carbon Capture Storage emissions.

Guangdong CO2 project milestone praised in top level US-China talks

sccs.org.uk

Progress by the Guangdong offshore CO2 project has been highlighted in the latest strategic talks between the US and China as one of two "top achievements" in developing carbon capture, utilisation and storage (CCUS).

The Guangdong offshore carbon capture, utilisation and storage (GOCCUS) project, which was initiated by the UK and Chinese governments through the UK-China (Guangdong) CCUS Centre, was recognised for the progress being made on its detailed engineering design.

The project is one of six pairs of CCUS demonstration projects being supported by the US Department of Energy and the National Development and Reform Commission of China.

Ongoing CCUS activities supported by the two nations also include knowledge exchange, site visits and researcher exchanges.

The Centre itself, which is part of a broader UK-China collaboration in which SCCS is a founding partner, is also making good progress in developing its research portfolio and supporting academic collaboration.

It was established in 2013 after the signing of a ten-year agreement on research collaboration between Scottish Carbon Capture and Storage (SCCS), the UK Carbon Capture and Storage Research Centre (UKCCSRC), Guangdong Low-carbon Technology and Industry Research Centre (GDLRC) and the Clean Fossil Energy Development Institute (CFEDI). Its core function is to develop CCUS technologies and other near-zero emission demonstration projects.

CO2 re-use – time to pay attention?

Most readers will be aware of various technology developments going on to re-use CO2 in different products – but may have seen it as a very niche market. It may be time for a re-think, based on what we heard at the SCOT Project event in Brussels in June
By Karl Jeffery

There is a big growth in interest in the idea of trying to use CO2 to make vehicle fuels, minerals and plastics, based on what we heard at the SCOT Project conference in Brussels on June 29, 2016.

There have been research projects and small companies active for many years, pursuing a dream of trying to turn CO2 into valuable products, rather than emit it to the atmosphere.

For fuels, the basic idea is to take the usual fuel combustion reaction in reverse. We combust a liquid fuel to make energy, CO2 and water. All reactions are reversible, and to make a synthetic fuel, we take CO2, energy and water.

The obvious question is 'why would you do this'. If we have renewable electricity available, it would be more efficient to use it as it is (as electricity), rather than convert it into another form (a liquid fuel).

This is a fair question – but it does have some possible answers.

As well as liquid fuels, we can also use CO2 to make construction aggregate, fertilizer pellets, methanol and chemical compounds. By reacting CO2 with waste, we can potentially solve two environmental problems at once – one is to avoiding CO2 emissions, the other is to avoid putting the waste in landfill.

The technology makes long term sense – if we think forward to an era where we no longer use fossil fuels, all our power comes from renewable energy, and we have to manage the intermittent electricity supply. We will also still want liquid fuels for transport applications where batteries won't work, including planes, ships, and vehicles which we want to run for longer than we can on one battery charge.

If you are still not convinced, think about the story telling. Remember that one of the reasons for lack of success with carbon capture and storage is that the story has not sold very well, despite making technical sense.

Some of the speakers at the SCOT Project event in Brussels

Re-using CO2 fits with the 'circular economy' mantra of the current times, whilst standard carbon capture and geological storage fits with the 'linear' era, which some associate with the twentieth century.

Lothar Mennicken, of the German Federal Ministry of Education and Research, sees CCS as an "end of pipe technology" and CCU as a "source technology."

CO2 re-use is easy for politicians to get excited about, as a source of jobs, new business, easier ways to decarbonise, and a good story to tell.

It may be relatively easy to legislate to force purchases of products containing re-used CO2, simply by setting a quota, as governments did with a biofuel mix in liquid fuels, or the proportion electric cars required in a vehicle fleet. That sounds a lot easier than the current complex emission trading schemes.

The technology may never work. You can draw your own conclusion on that – but we hope you will agree with our conclusion that these technologies warrant more attention.

Note on terminology

The terms Carbon Capture Utilisation and Storage (CCUS) and Carbon Capture and Utilisation (CCU) have been used for many years and are well recognised. But they might not be the best choice of name, speakers at the SCOT conference said.

The term 'CO2 re-use" seems to be growing in favour, we heard in the conference. It may be a better term to use politically, and it is easier to understand. That is the term we use in this report.

One argument made at the conference, which our readers may strongly disagree with, is that the term 'carbon capture' has a bad 'brand' in the European Commission, since it is associated with so much disappointment, and the term 'CO2 re-use' avoids the need to use it.

There is also a range of terms used for fuels made from re-used CO2. The terms "e-gas" (for synthetic gas) and "e-gasoline" for synthetic gasoline is widely used, even though 'e' is usually taken to mean electronic. In this report, we will use the term 'synthetic fuels'.

The SCOT Project

The SCOT Project, with SCOT standing for "Smart CO2 Transformation," ran for 2 years, ending in September 2016, with an aim to "define a strategic European Research and innovation agenda" for CO2 utilisation.

It was supported financially under the 7th Framework Program of the European Commission.

From September 2016 onwards, the companies involved plan to set up a new association.

The project had particularly high levels of support from five regions of Europe – Wallonia (part of Belgium), Germany, France, UK and Netherlands.

It limited the scope to where CO2 is used to make other materials, so applications for CO2 directly (as a fertiliser, in carbonated drinks, or in oil reservoirs) were not included in the scope.

It identified three main routes to get value from CO2. Mineralisation (making hard materials which could be used for building or as a basis for fertiliser pellets); making liquid fuels; and making chemical building blocks, pathways to the two million or so different molecules produced by the chemicals industry.

Hans Bolscher, senior consultant at energy consultancy Trinomics, and a former director Climate and Industry at the Ministry of Environment at the Dutch government, said in his opening address that the conference that he hoped the Scot Project "has built some bricks" in the path to carbon capture and utilisation.

The SCOT project aimed to get a better idea of the potential of CO2 re-use, "which parts are dreams, which parts are reality, which parts need more hard work," Mr Bolscher said.

Altogether, "It's not a given that it's going to work."

But we can see that the leaders of the world have set a climate goal of reducing temperature rise to under 2 degrees, and do not have the instruments to achieve it, Mr Bolscher said. Maybe these technologies can show them how to do it.

Long term planning

Synthetic fuels can potentially solve many long term society problems from decarbonisation.

By 2050, we may not be using fossil fuels, but there are good reasons why we'll still want liquid fuels, including in planes and ships. In an era of self drive cars hired on demand, we may want vehicles which can run for 12 hours a day.

Synthetic fuels can also help solve the problems with intermittency of supply with renewable fuels, because they can soak up excess renewable energy to be used to make liquid fuels.

Maybe CO2 re-use technologies can show the world's leaders how to meet the 2 degrees target - Hans Bolscher, senior consultant at energy consultancy Trinomics, and a former director Climate and Industry at the Ministry of Environment at the Dutch government

There are many efforts to try to balance supply and demand with renewables, including with variable tariffs, complex automated systems, smart meters, and batteries. But just converting surplus renewable energy to liquid fuels would be a much simpler way to do it. It could need a lot of storage tanks, including CO2 tanks, but they aren't so expensive.

The supply / demand matching will need to be done over seasonal timescales, not just daily timescales, for example storing surplus solar energy from the summer to it can be used to heat homes in winter. This gets very hard to do with batteries.

In contrast, the long term picture for carbon capture and storage (from say 2050 onwards) is not so appealing, if we are planning to stop using fossil fuels altogether. We can continue making synthetic fuels if we don't have fossil fuels, by using biomass or air capture.

Could there be a market?

So how should investors and businesses set about working out what kind of market there could be here?

The total market for materials which could potentially be made from re-used CO2 is of course enormous, if you include the building aggregates market, the liquid fuels market, the plastics market and the fertilizer market. But then you have to work out how much of this market might one day be taken by materials with re-used CO2.

It will probably always be cheaper to make a certain molecule from fossil fuels than it will synthetically. In the words of one speaker, fossil fuels have been a great 'free lunch'. So we're relying on either governments to legislate requirements for synthetics, or for the combination of existing environmental pressures (CO2 emissions regulation, shareholder pressure, building environmental standards) to get there.

Appeal to politicians

If we're relying on political interest to get products made by re-used CO2 on the market, it may be helpful to consider the approach taken by a senior politician, and a senior government official, who spoke at the SCOT Project conference.

Jean-Claude Marcourt, vice president of the Walloon Government (Wallonia is one of 3 regions which make up Belgium), said he could see how work by the Scot Project could help with job creation, building businesses, meeting climate targets, and managing energy supply. He was pleased that there are many companies and organisations in Wallonia involved.

Rudolf W Strohmeier, deputy director of General Research Programmes at the European Commission, said he saw carbon dioxide utilisation as a means of managing the conflicting demands for decarbonisation, and that it is impossible to run many industries (such as steel) without producing CO2.

Work by the Scot Project could help with job creation, building businesses, meeting climate targets, and managing energy supply - Jean-Claude Marcourt, vice president of the Walloon Government

Carbon capture and geological storage still remains expensive, "and there's no business model for it," he declared. "But capture and utilisation of C02 into high value product will be an interesting alternative and could improve the economic case (for carbon capture)."

"The use of CO2 by using green energy in transforming it into polymers could allow many new business models," he said. "Using CO2 as a feedstock for chemical products will be a major step to building a circular economy in Europe."

"It will require a supportive regulatory framework."

Regulatory framework

What kind of regulatory framework could bring products using re-used CO2 to the market?

Dr Lothar Mennicken, German Federal Ministry of Education and Research, suggested, as an example, that governments could require 1 per cent of airline fuel to be made via re-used CO2. "This would significantly boost the market," he said.

Quotas like this – which could steadily rise over time – could be a much easier way to force decarbonisation than by emissions trading. They could be applied to all kinds of plastics and fuels.

Another way to force introduction of products from re-used CO2 is the construction industry environmental performance standards such as LEED. These are multi-faceted standards which lead to a building being given a score for its environmental performance. If the building is made from materials containing re-used CO2, that could be a factor in the score.

Environmental groups

A factor to consider is whether synthetic fuels will get the support of environmental groups, you, will remember, often do not like the idea of carbon capture and storage.

Some environmental groups are already saying CO2 re-use "is a figleaf so we continue to use fossil fuels," said Gernot Klotz, president of the Brussels based "Knowledge4Innovation" organisation.

Financials

Could products made from re-used CO2 be financially viable?

One speaker estimated that if electricity is available for Eur 5 cents / kWh, which is a low but achievable pre-tax price available to volume buyers, then synthetic fuel can be made for Eur 79.5 per barrel. So much more expensive than fossil fuels, but not expensive beyond possibility.

Another speaker calculated that hydrogen made by renewables and electrolysis of water would cost over 6 Eur/kg, compared to hydrogen made from fossil fuels costing under 1 Eur / kg. So a much bigger price differential. Hydrogen reacts with CO2 to form methane and water.

The cost of capturing the CO2 must be added to this. At current prices, capturing CO2 from a flue gas stream (such as power station) might be Eur 40 a tonne, capturing CO2 from air might cost Eur 400 a tonne. So it would probably take many years of technology development to make air capture viable.

There are two ways to look at the pricing. One is the price compared to fossil fuels (which a member of the public might consider, and a government might need to change through making a charge for emission) the other is the price compared to other options for decarbonisation, which is very complex,

(for example) comparing synthetic fuels with using battery storage for renewable electricity.

Cradle to grave assessment

Calculating CO2 emissions over the lifecycle is very tricky, as you will know if you have ever got into a discussion about the CO2 emitted in the construction of a windfarm is greater than the CO2 the wind farm avoids over its lifetime.

But these calculations are essential in making sure we have business models which actually reduce CO2.

This assessment must be carried out over the entire lifecycle (known as 'cradle to grave') and must be robust and transparent.

One speaker presented analysis showing that the lifecycle emissions for a vehicle fuelled on synthetic gasoline are just 23 per cent more than the emissions from a battery electric vehicle using entirely renewable electricity – yet can offer enormous advantages, if you can refuel a vehicle much faster than you can recharge it, and the engine will last much longer than a battery.

CCU and CCS

There was some interesting debate about how carbon dioxide utilisation sits together with carbon capture and storage.

Dr Lothar Mennicken, German Federal Ministry of Education and Research, who was working on CO2 utilisation for 6 years up to May 2016, said, "I believe CCS is dead in Europe. I know it is dead in the UK, it is definitely dead in Germany. It is not the technology, it is acceptance of the people. It is not going to work in a democracy, where people have to agree on it."

This point was disputed by Hans Bolscher, who said, "We don't say CCS is dead. We say, [to achieve] the 1.5 degrees [maximum temperature rise], CCS is inevitable. It will probably be the source of delivering the CO2 we need for CO2 utilisation."

Professor Peter Styring, director of research in Chemical and Biological Engineering University of Sheffield, said "CCS is not dead, it is just sleeping."

If you think carbon capture and storage is expensive compared to not doing it, the costs of synthetic fuels (compared to fossil fuels) is higher still.

But the public is generally positive to the idea of using CO2, and has not yet proven to be very warm about CO2 storage, said Jan Hopman, director of the Netherlands CCS program CATO.

Scale

Another factor to consider is scale. Carbon capture and storage is only viable on a very large scale, whilst carbon dioxide re-use projects often use CO2 on a small scale. So there is a mismatch to solve.

There have been plants to run the Fischer Tropsch process, converting a mixture of carbon monoxide and hydrogen to liquid hydrocarbons, on a mega scale, including plants in South Africa to make liquid fuel from coal, and plants in Malaysia to make diesel from natural gas.

So far, the process of making liquid fuels from CO2, rather than CO, has been done on a scale of large tanks, but not megatonne chemical plants.

The question of scale matters, because it has a big impact on the unit price.

How far along are we?

Mr Bolscher said that the business model for mineralisation, for example turning CO2 into hard materials for use in building, "was a revelation of the SCOT project. The technology is available and it is economically viable already," he said.

A particularly interesting area of research is plasma technology, as a means of converting waste into useful products. Plasma is a special state of matter, achieved through heat or electromagnetic field, and does not necessarily need very high heat. It can lead to materials reacting together in different ways, and so it might be easier to make materials from waste products through this route.

Interesting German projects include the "Kopernikus" Power-To-X project, converting renewable electrical power into various materials, and the Carbon2Chem project led by industrial group ThyssenKrupp, aiming to take 'off-gases' from steel production and use it to make chemicals, with Eur 60m funding over four years.

Car company Audi is looking for ways to use renewable electricity together with CO2 to make what it calls 'e-gas', 'e-diesel' and 'e-gasoline'.

If it becomes possible to make aggregates from waste cost competitive with normal aggregates, the potential market is enormous - Professor Colin Hills, CTO of Carbon8

There are projects to make soft foam polymers, which could be used to make mattresses, cushions and car seats, from CO2.

Air capture technology – taking CO2 out of the atmosphere – could be decades away.

C and H chessboard

Professor Walter Leitner, chair in technical chemistry and petrochemistry at RWTH Aachen University, sees the picture of re-using CO2 like a chessboard.

You have a CO2 molecule in the bottom left corner of the chessboard. As you go up the chessboard you add hydrogen atoms to the molecule, and as you go across the chessboard you add carbon atoms. So in the diagonally opposite corner you have a complex hydrocarbon or an oxygenated chemical compound.

The pawns and bishops, which help you get across the chess board faster, correspond, in this analogy, to the various catalysts and pathways which can be used to make it easier to make complex products from CO2.

Carbon8 – waste with CO2

UK company Carbon8, a spin-off from the University of Greenwich, London, has built plants which react powered waste with CO2 to form building materials, known as aggregates.

Professor Colin Hills, the company CTO, is also director of the Centre for Contaminated Land Remediation at the University of Greenwich.

Professor Hills is a geologist, and is very interested in how CO2 has been taken out of the atmosphere in the geological past, being absorbed by microorganisms to make shells, and ending up as chalk (calcium carbonate), a solid material. It is "biology and chemistry working together," he said.

Carbon8 aims to do something similar, making sold materials by reacting different forms of waste with CO2. So far it has looked at 100 different waste streams, including steel waste water sludge, quarry fines, paper ash, wood ash, metal dust, bauxite residues.

The company has 2 UK sites, in Suffolk and Avonmouth, with planning permission for a third in Leeds.

Carbon8's aggregate pellets are used to make building blocks by UK company Lignacite. Since it avoids CO2 emissions from rotting waste, it could be described as a 'carbon negative building material'. They blocks are suitable for use in construction, although are not allowed in some EU countries, he said.

The critical issue is how CO2 is exposed to the waste, Professor Hills said. The company has done a great deal of experimentation here, including changing the moisture content, rotation speed, residence time of a mixer, or using a pelletiser.

If it becomes possible to make aggregates from waste cost competitive with normal aggregates, the potential market is enormous, when

you consider the UK uses 250 million tonnes of aggregates every year, and worldwide it is 100 times more, 25 gigatonnes.

The business model would benefit if there was better availability of low cost CO2, he said.

Carbon Recycling International

Carbon Recycling International, based in Reykjavik, Iceland, produces methanol using hydroelectricity. The methanol is sold in Iceland, Sweden and the Netherlands.

The company started with a pilot plant in 2009, a full scale plant in 2012, which was upgraded in 2015, to now produce 4000 tonnes per day, said Benedikt Stefansson, director of business development.

The carbon dioxide is taken from a plant which processes gas emissions from a geothermal power plant; the hydrogen is made by electrolysing water with electricity; and they are reacted together to make methanol.

Despite being hydroelectric, Icelandic electricity costs similar to anywhere else in Europe, Mr Stefansson said, and the methanol is more expensive than methanol from fossil fuels.

Mr Stefansson noted that the company is in the middle of three industries – electricity, manufacturing and transport (the customer), which are all regulated for CO2 in different ways.

Electricity is taxed to cover the costs of building renewables; manufacturing is covered by emission trading scheme; and the transport sector is told to replace hydrocarbons with biofuels.

So for renewable methanol business to work, it is vital that governments, both at a country and EU level, can fit everything together, he said.

Heidelberg Cement

Jan Theulen, director of alternative resources, Global Environmental Sustainability at Heidelberg Cement, said that the cement industry is currently responsible for 5 per cent of man-made CO2, and his company is the 2nd biggest cement producer worldwide.

The cement industry will need carbon capture and storage in order to achieve its decarbonisation targets for 2030 to 2050. Carbon dioxide re-use "will have a very valuable contribution to it."

The company does not see that it gets competitive advantage from improving environmental performance, so it makes sense to work with other cement companies.

There are two research projects related to carbon capture and cement, a 11m euro project in Norway part funded by the Norwegian government, and another in Belgium. "We are collecting best practises worldwide," he said.

Heidelberg is also looking at CO2 minerals for building materials – Jan Theulen, director of alternative resources, Global Environmental Sustainability at Heidelberg Cement

There is research work going on to capture CO2 from cement production with algae, and use it for fish feed.

To take advantage of the costs of labour in different parts of the world, it aims to use equipment manufactured at low cost in China, grow the algae in the Mediterranean, where wages are lower, and feed the algae to fish in Scandinavia, where customers are able to pay more, he said.

Heidelberg is also looking at CO2 minerals for building materials, he said. There are strong forces in the construction industry pushing for more sustainable building materials, including when governments specify environmental performance requirements in buildings they commission.

If it would be possible to make CO2 re-use work without EU funding, "you're much faster, you have degrees of freedom to go straight to the market," he said. For example, you can look for investment from the US.

Methanol Institute

Eelco Decker, chief representative Europe for the Methanol Institute, talked about ways to accelerate the development of the industry capturing CO2 in methanol.

The Methanol Institute was founded in the US in 1989, and now has a head office in Singapore. It represents the largest methanol distributors in discussions with government, and develops standards for safe handling of methanol.

Methanol is the simplest alcohol, and serves as a chemical 'building block' to make many other substances. It can be made from a wide range of different feedstocks, but usually natural gas. It can be used as a fuel - 40 per cent of the global demand is to use methanol for energy, and the biggest growth area is using methanol to replace oil.

Making methanol from surplus renewable energy could be a form of energy storage, he said.

The company Qatar Fuel Additives makes methanol from 500 tonnes of CO2 a day, which would otherwise be emitted to the atmosphere, he said. It uses solvents to capture CO2 from combustion exhaust gas from the methanol reformer process, and uses that to make methanol.

In order to build a business case for renewable methanol, it would be good if people understood the benefit of carbon dioxide re-use – or understand that buy buying renewable methanol they can help contribute to their company's green programs. "We strongly support the initiative from SCOT," he said.

More information

www.scotproject.org

Photos are by Lisa Buck Photography

Covestro opens production plant for plastics made from CO2

The company has opened a production plant for an innovative foam component made with 20 percent CO2 at its Dormagen site near Cologne.

The new process saves a proportional amount of the traditional oil-based raw material, thus making a contribution to sustainability that Covestro believes offers considerable potential.

"We have to change the way we look at CO2, and we will. Using it as an alternative source of raw materials is a solution to some of the biggest challenges of our time – finding a replacement for finite fossil resources such as oil and gas and closing material cycles. Thanks to our innovative process and the launch of our production operations in Dormagen, we see ourselves as a pioneer in this area – true to our vision 'To make the world a brighter place'," said Covestro CEO Patrick Thomas at the opening ceremony, which was attended by more than 150 guests from business, science and politics.

"This method of using carbon dioxide as a raw material is an important step as we move toward a sustainable future. The German Federal government is promoting the use of CO2 as a raw material in order to expand the chemical industry's raw materials basis and open new avenues to sustainability," emphasized Thomas Rachel, Parliamentary State Secretary from the German Federal Ministry of Education and Research. It supported Covestro's technology financially in the research and development phase.

Professor Ernst Schmachtenberg, Rector of RWTH Aachen University, added: "Making efficient use of the carbon dioxide molecule, which is normally slow to react, is a real scientific and technical challenge. We have made a breakthrough by combining application-centric basic research with research-based industrial practices."

Covestro scientists worked hand-in-hand with experts from the CAT Catalytic Center in Aachen – a research institute operated jointly with RWTH – to find the right catalyst that would make the chemical reaction with CO2 possible.

In Dormagen, Covestro is now using carbon from CO2 to manufacture a new type of polyol. These are core building blocks for polyurethane foam – a versatile material that is used in many industries around the world and that we encounter throughout our daily lives. The carbon dioxide is chemically bound into the material.

Carbon dioxide as new raw material: At this production plant in Dormagen, Covestro is now incorporating 20 percent CO2 into an important foam component (Image ©Covestro)

The company has invested some EUR 15 million in the new plant, which has an annual production capacity of 5,000 metric tons. The CO2 used is a waste product from a neighboring chemical company.

The new CO2-based polyol has been engineered initially for flexible polyurethane foam intended for use in mattresses and upholstered furniture. In terms of quality, the foam achieves at least the same high standards as conventional material produced using only petrochemical raw materials, i.e. crude oil.

By eliminating the use of crude oil and saving the energy otherwise used to process that oil, the method is more environmentally friendly than conventional production processes. Thanks to the catalyst and the considerable energy contained in the remaining content of petrochemical raw materials, no additional energy needs to be expended to make the low-reactivity CO2 react.

If the new CO2-based products are received as warmly as is hoped, Covestro can envisage significant production expansion. In addition to flexible foam, the company is also working on manufacturing many other plastics with carbon dioxide. Its vision is to one day largely dispense with crude oil in plastics production.

With 2015 sales of EUR 12.1 billion, Covestro is among the world's largest polymer companies. Business activities are focused on the manufacture of high-tech polymer materials and the development of innovative solutions for products used in many areas of daily life.

More information

www.covestro.com

Columbia Engineers develop low-cost way to capture carbon

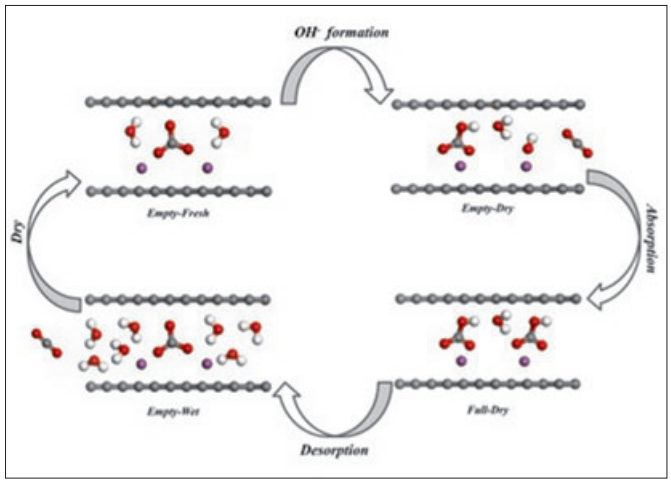
A new chemical reaction offers a lower cost way to capture CO2 than other methods.

A recent study led by Xi Chen, associate professor of earth and environmental engineering at Columbia Engineering, and Klaus Lackner at Arizona State University, reports an unconventional reversible chemical reaction in a confined nanoenvironment. The discovery, a milestone in clarifying the scientific underpinnings of moisture-swing chemical reaction, is critical to understanding how to scrub CO2 from the Earth's atmosphere, and the researchers have already used it to capture CO2 more efficiently and at a much lower cost than other methods.

Water is the key player in this new study. The group found that reducing water quantities in nanoconfinement could promote CO32- (carbonate) ions to hydrolyze H2O into a larger amount of OH- (hydroxide) ions. This discovery also led the team to find a new nanostructured CO2 sorbent (a material used to absorb or adsorb liquids or gases) that also binds CO2spontaneously in ambient air when the surrounding is dry, while releasing it when exposed to moisture. The work was published in Angewandte Chemie in February 2016.

"Water confined in nanoscopic pores is essential in determining the energetics of many chemical, physical, biological, and environmental systems," says Chen. "Our finding sheds light on a vast number of chemical processes in nanoconfinement while also giving rise to a wide array of potential applications. For instance, we can convert this new efficient sorbent from absorption to desorption simply by using water, which is readily available and at very low-cost. Current sorbent materials consume a great deal of energy, so our discovery could lead to cheaper and more efficient energy conservation absorbents. And if we can achieve negative carbon emission standards, then we will have invented a nanomaterial solution to a critical global challenge."

Finding an efficient absorbent has long been a challenge for most absorption and desorption processes. A successful CO2 absorbent must have fast reaction kinetics (the rate of chemical processes), be low in cost, and be able to regenerate with a low energy barrier to complete the whole CO2 capture-release cycle. Chen notes that, to his knowledge, all previous CO2 absorbents have required a large energy barrier to regenerate and are thus not very efficient, consuming more extra energy to regenerate. The mechanism of the moisture-swing chemical reaction in nanopores will lead to new classes of sorbents driven by water: evaporation in ambient air through solar energy drives the sorbent to absorb CO2 as it dries, and hydration releases CO2 when wet.



Reaction pathway of CO2 absorbption/desorption on nanostructural absorbent

"With water as the trigger, our energy cost of the whole CO2 capture cycle is very small," Chen adds, "and that makes grand-scale application very promising for the first time."

Chen, whose research is focused on the mechanics of nanoporous materials, has long been interested in studying fundamental interactions between water and ions in a confined space. When confined to nanopores, the hydrogen bonding of water and ions changes and this affects both the physical structure and dynamics of water molecules and the chemical energy transfer through the formation of highly structured water complexes.

"Water is the most magical substance in the world—it produces life," says Chen, who worked on the study with Klaus S. Lackner, formerly at Columbia Engineering and now director of the Center for Negative Carbon Emissions and a professor at Arizona State University. "Its hydrogen bond is incredibly strong—except, as we discovered, when you have a very small environment with very few molecules. Then everything changes and we were able to actually reverse chemical reactions when the number of water molecules fell below about 10."

Chen's team ran experiments to control the humidity in the nanoporous material and found that the free energy of CO32- hydrolysis in nanopores is reduced with a decrease of water availability. This process promotes the formation of OH-, which has a high affinity to CO2. They also found that this humidity-driven sorption effect is not limited to carbonate/bicarbonate but is also extendable to a series of ions and thus the study opens a new approach to gas separation technology.

"This is an outstanding work, " comments Agustin J. Colussi, senior scientist at the Linde Center for Global Environmental Science, California Institute of Technology, who was not involved in the study. "It reports convincing experiments, provides a novel explanation for counterintuitive results, and thereby opens the vast scope of new chemistry in nanoconfined water."

Chen and his team, which includes his PhD students Xiaoyang Shi (the study's lead author) and Hang Xiao (second author), plan to explore the influences of a range of parameters, including pore size, spacing of ions, and surface hydrophobicity, on his water-driven CO2 capture absorbent, to design a more efficient direct air capture CO2 system.

More information

engineering.columbia.edu

Capture and utilisation news

ION Engineering to test solvent at Mongstad

www.tcmda.com

www.ion-engineering.com

U.S. technology developer ION Engineering (ION) has signed a contract to test its solvent technology at Technology Centre Mongstad.

ION is currently developing its solvent system to scale up to the commercial level. After successfully testing at the National Carbon Capture Center (NCCC) in the U.S., ION moves to TCM as the next step toward commercialization.

ION's test program at NCCC was funded under a multi-year Cooperative Funding Agreement with the U.S. Department of Energy's National Energy Technology Laboratory (NETL). In June of this year, ION was granted a $7.5 million dollar continuation of that program to fund the TCM test campaign.

With these advancements in its technology, ION is striving to define the future of carbon capture as a cost-effective solution to reducing greenhouse gas emissions. Carbon capture, utilisation and storage technology is critical to the de-carbonisation of power and industrial applications, and essential for addressing climate change.

Roy Vardheim, Managing Director of TCM, says: "TCM continues to play a crucial role in the development of carbon capture technologies, helping a number of companies to test and reduce the costs and risks of scaling up carbon capture. We are very satisfied that ION Engineering is now heading for Mongstad to further prove their technology in an industrial environment at commercial scale."

Buz Brown, CEO and Chairman of ION Engineering says: "TCM provides ION with tremendous opportunity for advancement of our technology. At the 12 MWe scale, TCM is a vital step in the scale-up process as ION continues to make positive strides towards world-wide deployment of our CO2 capture technology at commercial scale facilities. We look forward to working with the world-class team at TCM."

The purpose of the test campaign is to demonstrate the performance of ION's solvent by investigating amongst others energy consumption, CO2 loading, corrosivity, degradation, water balance management and emissions.

ION Engineering is testing its solvent at Technology Centre Mongstad as the next step towards commercialisation

The test window will start in October this year and last until April 2017 and will constitute a 3,5 months effective test period.

York University's 'greener' method of carbon capture

www.york.ac.uk

Scientists from the University of York have developed a CO2 capture method using synthetic materials called 'starbons'.

Starbons, made from waste biomass including food peelings and seaweed, were discovered and first reported 10 years ago by the York Green Chemistry Centre of Excellence. Using these renewable materials provides a greener, more efficient and selective approach than other commercial systems of reducing emissions.

Current widespread methods of carbon capture, such as amine treating, use liquid solutions for the treatment of emissions from chemical plants and refineries. However, these are expensive to run and require a lot of input energy compared with a relatively low output.

The synthetic make-up of Starbons, which contains pores, results in the absorption of up to 65 percent more CO2 than other methods.

Starbons are also more selective in capturing CO2 when mixed with nitrogen, with results showing a capture rate of 20:1 rather than 5:1 - four times more selective than other methods.

The materials also retain their CO2 absorption and selectivity in the presence of water, and have extremely fast rates of CO2 absorption and desorption.

Such enhanced properties for carbon capture, in a material that is sustainable and low-cost to make, holds significant potential for helping to reduce emissions from many manufacturing plants and power stations in the UK and around the world.

Professor Michael North, Professor of Green Chemistry at the University of York, said: "This work is of fundamental importance in overturning established wisdom associated with gas capture by solids. It defies current accepted scientific understanding of the efficiency of carbon-capturing CO2, and has the

potential to be of significant commercial and governmental value in helping the UK meet its CO2emissions reduction promises.

Professor James Clark, Head of York's Green Chemistry Centre of Excellence, said: "The high CO2 adsorption, high selectivity, rapid kinetics and water tolerance, combined with the low cost and ease of large scale production from waste biomass, gives Starbons great potential. We hope to offer the product as a commercial capture agent for separating CO2 from chemical or power station waste streams."

The paper, Importance of micropore-mesopore interfaces in CO2-capture by carbon-based materials, is published in Angewandte Chemie.

PHYCO2 completes Phase 1 algae trial

phyco2.us

PHYCO2 and Michigan State University (MSU) have proved performance of their bioreactor to grow algae and capture CO2 without sunlight.

The technology partnership set out to capture manmade carbon dioxide and create renewable alternative energy feedstock. Phase I proved the technology can capture significant amounts of CO2 for high-density algae cultivation with the PHYCO2 Patented algae photo bioreactor.

PHYCO2's patented technology allows uncontaminated microalgae to grow indoors 24 hours a day, without sunlight, in any geographic location, year round. It is the first photo bioreactor to optimize algae growth by managing all the growth parameters (light, CO2 and nutrients).

Unlike previous open and closed systems, the PHYCO2photo bioreactor system eliminates possible contamination from outside sources. Discovering the specific amount of time that algae needs to be exposed to light, as well as the time needed to rest in order to properly cultivate, PHYCO2 developed a system that is market sustainable and commercial.

Working closely together, MSU and PHYCO2 found breakthrough results that out perform current open-pond systems, as well as competing studies being done at other universities. Within the first round of testing, the two-month period showed an algae density of 1.7 g/L, a CO2 absorption rate of 52 percent, and a productivity rate of 0.34 g/l solution/ day, higher than the algae and production rates found at recently reported studies.

Built in the T.B. Simon Power Plant, PHYCO2's photo bioreactor absorbs CO2 emissions directly from the plant, creating pure algae strands that can be used for a multitude of products. Algae are used for an array of everyday products, from lipstick to ice cream, to gasoline and animal feed. The team is preparing for a second round of testing, in which the focus will be on doubling their algae density and reaching a productivity rate that is eight times the Phase I rate.

"With the strong industry-university collaboration, the integration of the patented PHYCO2's reactor and MSU selected algal strains could lead to a soon-commercially-available solution to sequester CO2 and produce high-value chemicals. Co-locating the APB with the power plant allows the process to utilize waste heat from the power plant to dry and process the produced algae to further improve the energy balance", said Dr. Susie Liu, an assistant professor in the Department of Biosystems and Agricultural Engineering at Michigan State University.

"Results from Phase I testing demonstrates that our technology can be applied to manufacturers worldwide to reduce emissions, and create pure microalgae to be used as an alternate energy source, as we strive to create a market sustainable solution to address our environment without negatively impacting businesses," said PHYCO2 CEO William Clary. "The next phases of testing will focus on how effective the photo bioreactor can be for power plants looking to reduce their carbon footprint, and how the technology can be implemented to absorb other airborne pollutants for further algae cultivation."

The collaboration is a direct response to the White House and U.S. Environmental Protection Agency's call documented in the Clean Power Plan, and the UN Climate Change Conference, recently held in Paris.

CO2 Solutions to provide CO2 to beverage industry

www.co2solutions.com

CO2 Solutions has formed an alliance with Mojonnier Limited to provide lower cost CO2 for beverages.

The alliance builds on CO2 Solutions' existing collaboration agreement with GasTran Systems (GTS), who licensed its technology to Mojonnier Limited in January 2016. Mojonnier has been a leading supplier of carbonated soft drink, beer and dairy equipment and services since its founding in 1919.

The GTS rotating packed bed (RPB) mass transfer technology has now been integrated with Mojonnier's beverage equipment business. Mojonnier has an established client list in the beverage industry and, with CO2 Solutions, they will jointly market a low cost and environmentally-friendly solution for the supply of CO2 to this sector.

The new solution, an integration of Mojonnier's RPB technology with CO2 Solutions' enzyme based carbon capture process, benefits the beverage industry by providing CO2 at low cost and with a positive environmental impact, says CO2 Solutions.

Bottlers of carbonated beverages typically have sterilization operations that use boiler-generated steam. While these boilers emit CO2 into the atmosphere, bottlers have to purchase CO2 for their beverages from commercial sources at a substantial cost. The joint solution closes the loop and allows for the reuse of the boiler-emitted CO2.

While mass marketed on a global scale, carbonated beverages are generally produced locally. This means that each bottler must secure its own CO2 supply, which in various parts of the world comes at great expense and with considerable supply and quality uncertainties. The CO2 Solutions-Mojonnier solution therefore has the benefit of securing the supply chain for this critical component in any bottler's operations. Finally, the environmentally-friendly nature of the technology provides additional marketing, sustainability and financial benefits for the bottler and the brand that it represents.

CO2 Solutions' Valleyfield, Quebec demonstration project, which ran successfully for 2,500 hours in 2015, yielded beverage-grade CO2 capture results. Tests by CO2 Solutions of the GasTran/Mojonnier RPB technology this past fall confirmed the potential for substantial reductions in equipment size.

Consequently, both companies anticipate reducing the net carbon capture costs even further from the already low-cost packed tower solution developed by CO2 Solutions. A scaled-up version of the new joint RPB solution will be tested at a third-party test facility in North Dakota over the coming summer,

Transport and storage news

DOE Announces $68.4 Million in Funding to Advance the Safe and Permanent Storage of CO2

energy.gov/fe

The Department of Energy (DOE) announced $68.4 million for cost-shared research and development (R&D) projects.

DOE's Office of Fossil Energy, under two funding opportunity announcements (FOA), seeks cost-shared projects that will determine the feasibility of developing onshore and/or offshore geologic storage complexes capable of cumulatively accepting commercial-scale (50+ million metric tons) volumes of CO2.

Currently, projects supported by the Carbon Storage Program involving CO2 injection have focused on pilot or short-term, large-scale injection tests. The Carbon Storage Assurance and Facility Enterprise (CarbonSAFE) initiative is intended to develop integrated CCS storage complexes, constructed and permitted for operation in the 2025 timeframe over a series of sequential phases of development.

Phase I CarbonSAFE: Integrated CCS Pre-Feasibility is soliciting and competitively seeking R&D projects that will provide a pre-feasibility study for a commercial scale geological storage site. Objectives include the formation of a CCS coordination team capable of addressing any regulatory, legislative, technical, public policy, commercial, financial, and other issues specific to commercial scale deployment of the CO2 storage project.

The projects will develop a plan encompassing technical requirements, as well as both economic feasibility and public acceptance of an eventual storage project. In addition, selected projects will perform a high-level technical evaluation of the sub-basin and potential CO2 source(s).

Phase II, CarbonSAFE: Storage Complex Feasibility FOA is soliciting and competitively seeking R&D projects to perform the initial characterization of a storage complex identified as having high potential. They will also establish the complex's feasibility for commercial storage (50+ million metric tons CO2).

The objectives of this phase include and extend the pre-feasibility work under CarbonSAFE: Integrated CCS Pre-Feasibility, focusing on one or multiple specific reservoirs within the defined storage complex, and comprising efforts in data collection; geologic analysis; identification of contractual and regulatory requirements and development of plans to satisfy them; subsurface modeling to support geologic characterization, risk assessment, and monitoring; and public outreach.

CarbFix project demonstrates permanent CO2 storage in rocks

www.or.is/english/carbfix-project

CarbFix has published a paper in Science that demonstrates that it is possible to permanently store carbon dioxide as minerals in basaltic rock.

The paper shows that over 95% of CO2 injected is mineralized within two years, instead of centuries or millennia as previously thought.

The paper's abstract states:

Carbon capture and storage (CCS) provides a solution towards decarbonization of the global economy. The success of this solution depends on the ability to safely and permanently store CO2. This study demonstrates for the first time the permanent disposal of CO2 as environmentally benign carbonate minerals in basaltic rocks. We find that over 95% of the CO2 injected into the CarbFix site in Iceland was mineralized to carbonate minerals in less than two years. This result contrasts with the common view that the immobilization of CO2 as carbonate minerals within geologic reservoirs takes several hundreds to thousands of years. Our results, therefore, demonstrate that the safe long-term storage of anthropogenic CO2 emissions through mineralization can be far faster than previously postulated.

CarbFix is a collaborative project between Reykjavik Energy, the University of Iceland, CNRS in Toulouse and Columbia University.

Ancient rocks yield hard facts on safe storage of greenhouse gas

www.carboncapture.eng.ed.ac.uk

Natural underground reservoirs of carbon dioxide are giving scientists vital clues how best to store man-made emissions of the greenhouse gas.

A study of ancient geological pools of CO2 around the world is enabling researchers to identify key criteria for storing the gas effectively.

Their research will inform development of technology known as Carbon Capture and Storage (CCS), in which CO2 from power stations is held deep underground, to prevent emissions from contributing to climate change.

The findings provide further evidence that this approach is secure in the long term, and will influence the selection and design of future CO2 storage sites.

In the most complete analysis of its kind, researchers from the Universities of Edinburgh and Strathclyde studied data on 76 natural

CO2 reservoirs in America, Europe, Asia and Australia. These gas pools - many more than a million years old - were formed as a result of geological changes, volcanic activity, or from decayed plants and animals.

Researchers have identified geological conditions best suited to long-term CO2 storage - such as optimum temperature, pressure, and type of rock. They found that sites deeper than 1200 metres, high density of gas and multiple, thick rocks to cap reservoirs were all beneficial.

They have shown that the biggest cause of leaks was movement of gas through geological faults. Leaks of CO2 from storage would not only contribute to greenhouse gas emissions to the atmosphere, but pose a health risk and undermine public confidence in CCS technology.

The study, published in the International Journal of Greenhouse Gas Control, was supported by the European Community and the Scottish Centre for Carbon Capture and Storage.

Dr Johannes Miocic, of the University of Edinburgh's School of GeoSciences, lead researcher on the study, said: "Lessons for safe CO2 storage can be learned from nature, which has been containing greenhouse gas securely for millennia."

Dr Stuart Gilfillan, also of the School of Geosciences, the study co-ordinator, said: "This study confirms that our current approach to creating CO2 stores is effective, and will help ensure that future CCS sites are safe and secure."

DOE selects projects demonstrating water production from CO2 storage

energy.gov/fe

The U.S. Department of Energy (DOE) has selected two projects that will test emerging enhanced water recovery (EWR) technologies for their potential to produce useable water from carbon dioxide storage sites.

The two projects were competitively selected from the five Brine Extraction Storage Test (BEST) projects awarded in September 2015.

The purpose of BEST field projects are to develop and validate engineering strategies and approaches for managing formation pressure, as well as plume movement in the subsurface, through brine extraction. The field projects will also help to find cost effective ways to treat extracted brines in order to generate a usable water supply and support DOE's objectives to improve water management and conservation for power generation, hydrocarbon production, and industrial processes; particularly in regions where water resources are scarce.

The initial five BEST projects, which were provided an initial $7 million in funding in September, have been working to develop engineering strategies and approaches for managing reservoir pressure and the flow of stored CO2 in saline reservoirs. The two projects selected today will receive a total of $31 million in funding from the Department to implement their field plan to validate their proposed approaches. Of the total funding $5 to $6 million will be used to test EWR technologies.

The BEST projects support the clean energy and climate goals announced by President Obama and President Xi in November 2014 and September 2015, which included two provisions on Carbon Capture Sequestration (CCS), including a new, commercial-scale CCS project in China and collaboration on CO2-EWR. Under the U.S.-China Clean Energy Research Center (CERC), the two countries have already completed a pre-feasibility study for a pilot project in Tianjin that will use CO2 captured from the GreenGen facility – China's first integrated gasification combined cycle plant.

The two projects set to receive the funding announced today will be managed by the Department's National Energy Technology Laboratory's (NETL) Carbon Storage Program:

Electric Power Research Institute, Inc. and its partners will demonstrate and adaptive management strategy of subsurface pressure, fluid movement, and differential pressure plume behavior using existing wastewater disposal wells and new wells at Plant Smith near Panama City, Florida, operated by Gulf Power Company.

The University of North Dakota Energy and Environmental Research Center and its partners will evaluate active reservoir management (ARM) approaches developed during Phase I for managing formation pressure, predicting and monitoring differential pressure plume movement, and validating pressure and brine plume model predictions at an operating commercial saltwater disposal facility located near Watford City, North Dakota.

Heriot Watt receives European award for growing smart rocks

www.hw.ac.uk

Professor Mercedes Maroto-Valer at Heriot-Watt has received a European Research Council Advanced Award to grow 'smart rocks'.

Professor Maroto-Valer's team plan to 3D print their own porous rocks with incorporated micro sensors. Thus they will replicate in laboratory conditions what actually happens deep underground and provide information at a microscopic level which was simply not available before.

Professor Maroto-Valer said, "While extensive work over the years has given us some idea about how liquids and gases move through porous rocks at a large scale, we haven't been able to understand how the process works at the very small pore scale, and how that process can differ between different types of porous rocks.

"We are very excited about this award and the opportunity to bring interdisciplinary innovation building upon Heriot-Watt's world leading expertise in process and petroleum engineering and manufacturing. This will allow us to unlock engineering research challenges in reactive transport in porous networks, transforming technological and environmental engineering applications.

"By 3D printing our own core samples we can decide exactly what sort of rock we wish to study, and implanted micro-sensors will be able to tell us directly, in real-time, what is going on as gases and liquids pass through them. This fundamental knowledge at such a tiny scale will feed hugely into our understanding of such processes at the large scale and enable us to maximise the success of industries from oil extraction to water safety and the storage of captured CO2."

This project has received funding from the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation programme (grant agreement No 695070).

UK CO2 storage asset reaffirmed

Energy Technologies Institute project confirms there are no major technical hurdles to storing industrial scale CO2 offshore in the UK with sites able to service mainland Europe.

The 12 month CO2 storage appraisal project was delivered by the ETI and funded with up to £2.5m from DECC. It progressed the appraisal of five selected storage sites towards readiness for Final Investment Decisions, de-risking these stores for potential future storage developers. Aberdeen-based consultancy Pale Blue Dot Energy supported by Axis Well Technology and Costain conducted the project.

It has identified 20 specific CO2 storage sites (from a potential 579 sites) which together represent the tip of a very large strategic national CO2 storage resource potential, estimated to be around 78GT (78,000 million tonnes). The top 15% of this potential storage capacity would last the UK around 100 years.

Five of these sites were then selected for further detailed analysis given their potential contribution to mobilise commercial-scale CCS projects for power and industrial use in the UK. Outline storage development plans and budgets were prepared for each.

Under the terms of the DECC funding package, the ETI is publishing on its website the detailed reports from the project and providing access to the sub-surface geological models.

The project has built on data from CO2 Stored – the UK's CO2 storage atlas – a database which was created from the ETI's UK Storage Appraisal Project. This is now publically available and being further developed by The Crown Estate and the British Geological Survey.

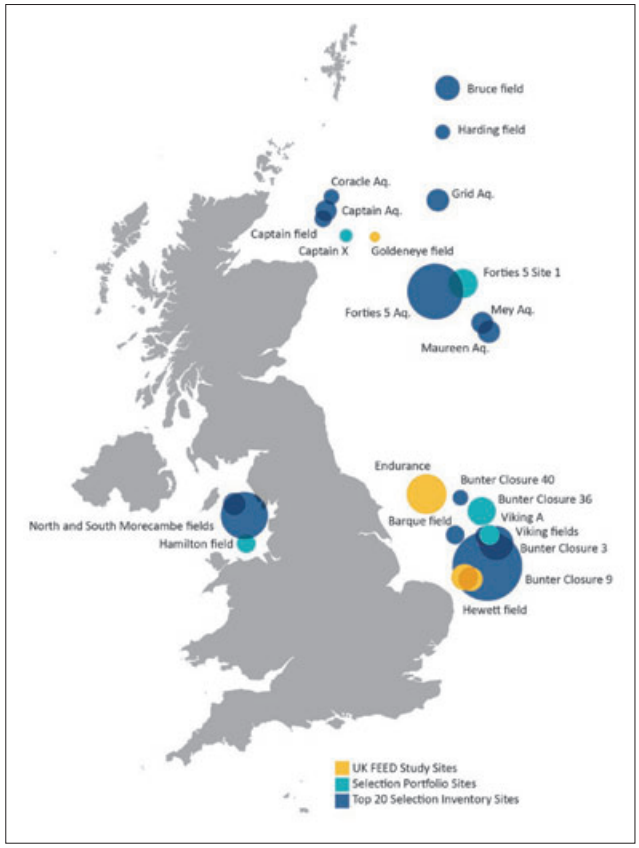
Dr Luke Warren, Chief Executive of the CCSA, commented, "This report further demonstrates that the UK is one of the best places in the world to develop CCS and that we have vast storage capacity that is well understood and can be made available at low cost. This storage resource provides a significant economic opportunity for the UK; the Committee on Climate Change believes that developing CCS will allow us to halve the cost of reaching our climate goals while providing a long-term sustainable future for our energy intensive industries. There is also the potential for the UK to sell its storage space to other countries that are not so fortunate to have access to storage capacity."

"Despite the clear advantages to developing a UK CCS industry the Government has withdrawn funding for CCS at the Spending Review and there is currently no clarity on the way forward for CCS in the UK. This is jeopardising significant investment opportunities for the UK and Government urgently needs to come forward with a strategy that sets out how the UK will deliver commercial-scale CCS projects or lose out on the opportunity to develop this critical technology."

Scottish Carbon Capture and Storage (SCCS) Director Professor Stuart Haszeldine welcomed the study. "Their work shows that affordable, well-engineered CO2 storage is within reach," he said. "With huge progress also being made in CO2 capture engineering, from innovations both in the UK and other countries, it is probable that the cost of capturing CO2 will tumble by anything from 20% to 90% in the next five years. Coupled with effective and viable storage, this will bring climate clean-up within viable price ranges for applications as diverse as electricity generation, heat supply, transport and particularly the process industries."

SCCS explained the significane of the study for delivering a UK CCS industry in a press release. The project identified a very large UK CO2 storage resource potential, estimated at 78 gigatonnes, of which 15% could serve the UK for 100 years. Pale Blue Dot's analysis shows an average levelised cost for transport and storage of around £15 per tonne of CO2 and a range of between £11 and £18 per tonne. Calculated in the same way as for electricity generation by the Department of Energy and Climate Change, this adds just £7.50 per megawatt hour (MWhr) to the levelised cost of power from gas (current cost around £50-70 / MWhr). This is a very low cost.

This cost can be further reduced if efficiencies in subsurface engineering are used to ensure that injected CO2 fully pervades the pore space of the reservoir sandstone. And identifying "clusters" of geographically close offshore sites can encourage a shared use of large diameter pipelines by emitters, which reduces the cost per tonne of CO2 by a further 10-30%.



Strategic UK CO2 Storage Appraisal Project select site inventory – the areas of the circles are indicative of CO2 storage resource potential

More information

The full report is available from the Energy Technologies Institute

www.eti.co.uk

CO_2 Concentration evolution in atmosphere

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