carbon capture journal

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*Front cover: The Tarong PCC pilot plant, operated by CSIRO and Stanwell Corporation, is designed to capture CO2 using amine-type solvents at a rate of ~100kg CO2/hr. It is located in Queensland Australia and was officially opened in December 2010*

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# Contents

# CarbonNet - developing a commercial model for a CCS network in Australia

CarbonNet is investigating the potential for a shared, large-scale CCS network in the Gippsland region, Victoria, Australia.

**By the Department of State Development, Business & Innovation, Victoria**

How do you develop a commercial model for a government-led project when no precedent exists and a range of industries could be involved?

This is the unusual challenge faced by the CarbonNet Project (CarbonNet); a challenge the project has developed a 'bespoke' solution for.

It is envisaged that the network will integrate the supply of a number of CO2 capture projects within the region and transport the CO2 via pipeline to offshore geological storage formations to be stored, permanently, deep underground. To develop and then gain acceptance for a new commercial model, CarbonNet's solution is to engage with the market to develop a model that works for all parties.

"CarbonNet is taking a structured two-stage market engagement approach - one that reflects the complexities of CCS - and the project - and is underpinned by a solid stakeholder engagement strategy," says Project Director Richard Brookie.

"It's important that we have a solid understanding of the market for the project to meet its underlying objectives. Those objectives include scalable infrastructure to underpin the rollout and growth of a CCS network, to enable an emerging CCS industry to evolve once market conditions are supportive."

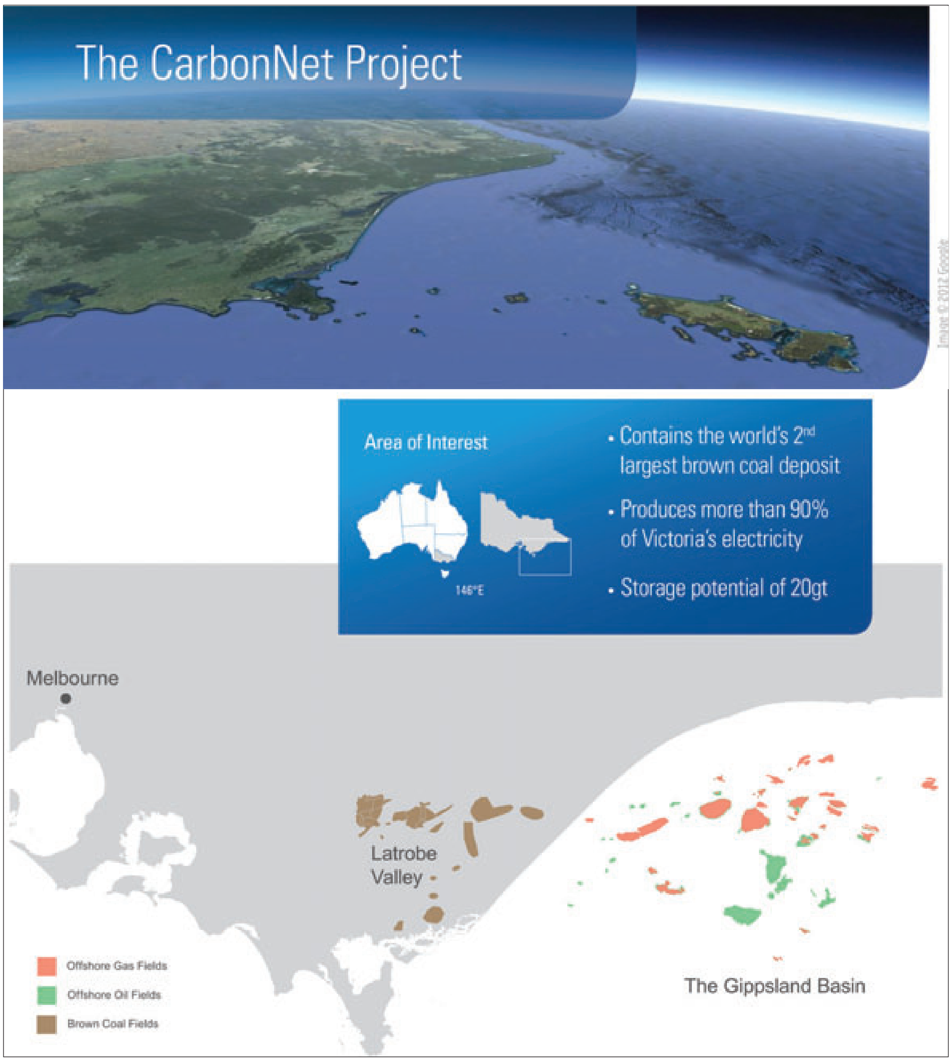
Stage 1 of the market engagement, Industry Sounding, was conducted late last year. It sought to understand how other CCS projects, globally, are progressing and highlighted the need for continued engagement with the market to help inform the model.

Stage 2, Industry Consultation, is in the pipeline. CarbonNet seeks to understand the needs of current and future potential users (CO2 emitters) of its network, and what is required for these parties to participate in the project.

A Request for Industry Submissions supporting document will be available as part of the Industry consultation, which will include meetings with some parties.

"The Industry consultation will provide an opportunity to reinforce the Victorian and Australian Governments' commitment to consider CCS and for CarbonNet's investigation of a viable CCS network. That commitment is an important message for our target market, as it involves international participants unfamiliar with the potential of the Victorian industry," Mr Brookie said.At the end of the Industry consultation, CarbonNet will have:

- A more informed understanding of the network's potential users, and appetite for CCS
- Information and market views around commercial business models
- An understanding of how different commercial options might impact private sector participation in CarbonNet.




*The CarbonNet project will integrate several CO2 capture projects within the region and transport the CO2 to offshore sites*

## More information

Organisations wishing to make enquiries about participating in the industry consultation can email :
carbonnet.industry@DPI.vic.gov.au

The industry consultation is being funded by the Victorian and Australian Governments and the Global CCS Institute.

Find out more at:
www.dpi.vic.gov.au/carbonnet

# Tarong post combustion pilot plant

Australian power company Stanwell Corporation Limited and the Commonwealth Scientific and Industrial Research Organisation (CSIRO) have developed an amine based carbon dioxide capture facility.

**By Sanger Huang, Ashleigh Cousins, Aaron Cottrell, Paul HM Feron, CSIRO**

The Tarong project is supported by the Asia-Pacific Partnership on Clean development and Climate (APP). Initial operation of the facility was completed with 30wt% monoethanolamine (MEA). This was followed by evaluation of concentrated piperazine (8 molal) sponsored by the Australian National Low Emissions Coal Research and Development program.

## Description of Tarong PCC pilot plant

The pilot plant, located in Queensland Australia, was officially opened in December 2010.

It was the third PCC pilot plant from CSIRO evaluating new and existing amine based technologies for CO2 capture from coal combustion flue gases. Australian power stations do not employ de-NOx and de-SOx technologies due to the low sulphur content of coal. A typical flue gas composition entering the Tarong pilot plant is given in table 1:

| Flue gas composition | vol% |
|---|---|
| N2 | 76 |
| CO2 | 10 |
| H2O | 8 |
| O2 | 6 |
| SO2 | 200 ppm |
| NO | 150 ppm |

*Table 1: Typical flue gas composition at Tarong power station*

## Pilot Plant Details

The Tarong PCC pilot plant is designed to capture CO2 using amine-type solvents at a rate of ~100kg CO2/hr (roughly 1000tpa). A slip stream of flue gas is taken from the power station flue gas duct downstream of the electrostatic precipitators and induced draft fan.

The process consists of three main steps: Pre-treatment / Absorption / Stripping.

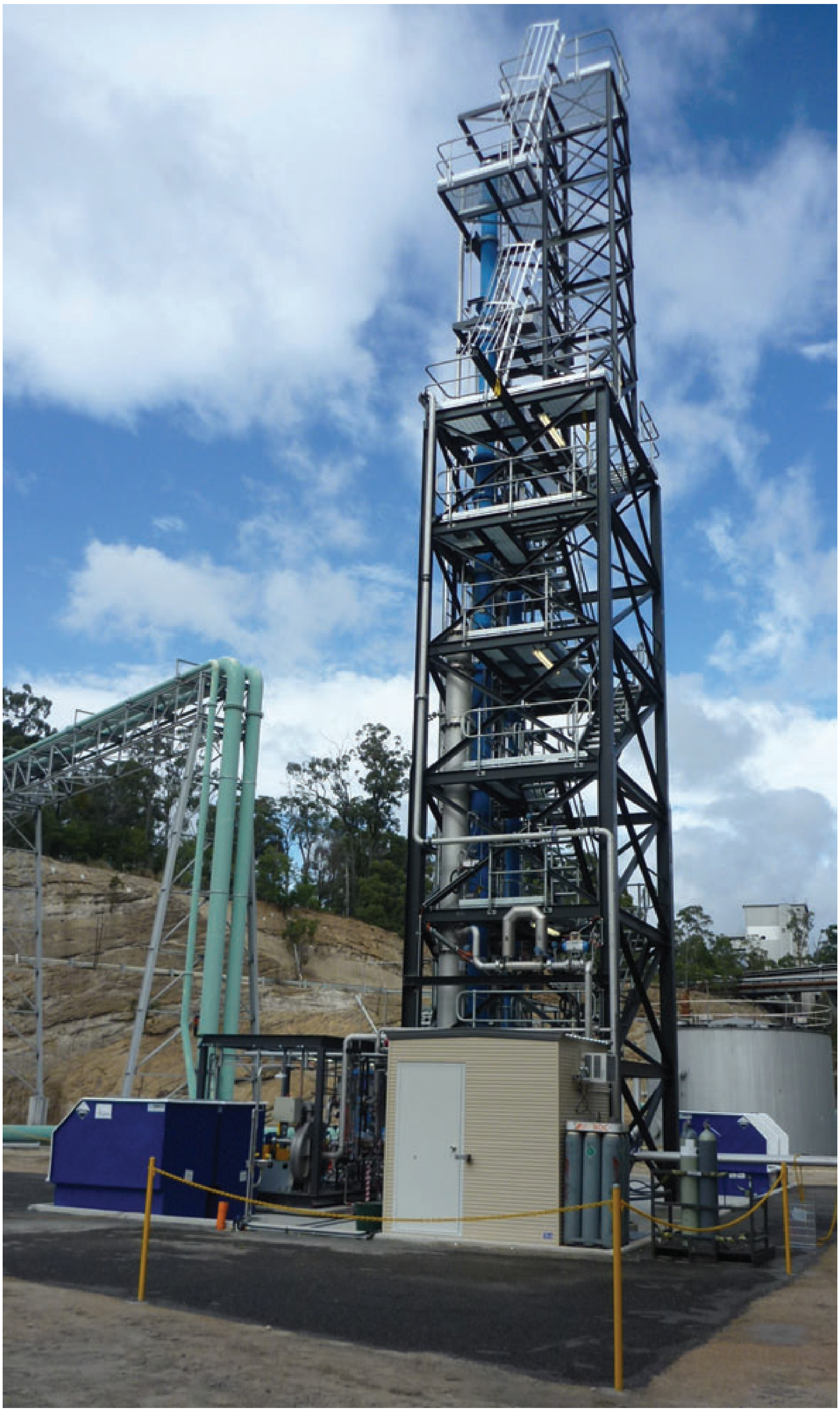


*Figure 1 - the Tarong PCC pilot plant in Queensland, Australia*

The flue gas first undergoes a basic caustic scrubbing where the hot gas (~100-110°C and 1 atm) is washed with a dilute caustic solution (pH ~9). This gas cleaning cools the flue gas to 45°C and removes some of the acid components and particulates. The cleaned flue gas then passes through a blower before entering the absorber column.

In the absorber, the solvent flows counter-currently with the flue gas to capture CO2. The Sulzer Mellapak M250X structured packing in the absorber column is divided into 4 sections. This allows gas and liquid sampling between each packed section and further provides tie-in points for various process modifications such as inter-stage cooling. The CO2 lean flue gas goes through a water wash section at the top of the absorber to remove potential solvent carry over. The CO2 rich solvent flows through a lean/rich heat exchanger where sensible heat is recovered from the lean solvent.

The heated CO2 rich solvent then enters the stripping column and flows through two Sulzer Mellapak M350X packed sections. The CO2 and water vapour generated from the reboiler rises up the column and flows to the condenser. The CO2 and condensate are separated in the knock out drum with condensate returning to the stripping column as reflux. The regenerated solvent is pumped back to the absorber to start the cycle again.

A number of gas and liquid samples can be collected from various locations around the pilot plant as indicated in Figure 2. The gas analysis employs a Fourier Transform Infra-Red Spectroscopy (FT-IR) system with an accuracy of 2% of the measurement range for each analysed component. 24 gas species are analysed, including CO2, H2O, NOx, SOx, NH3, solvent and solvent degradation products. Solvent concentration and CO2 loading are determined offline by acid-base titration.

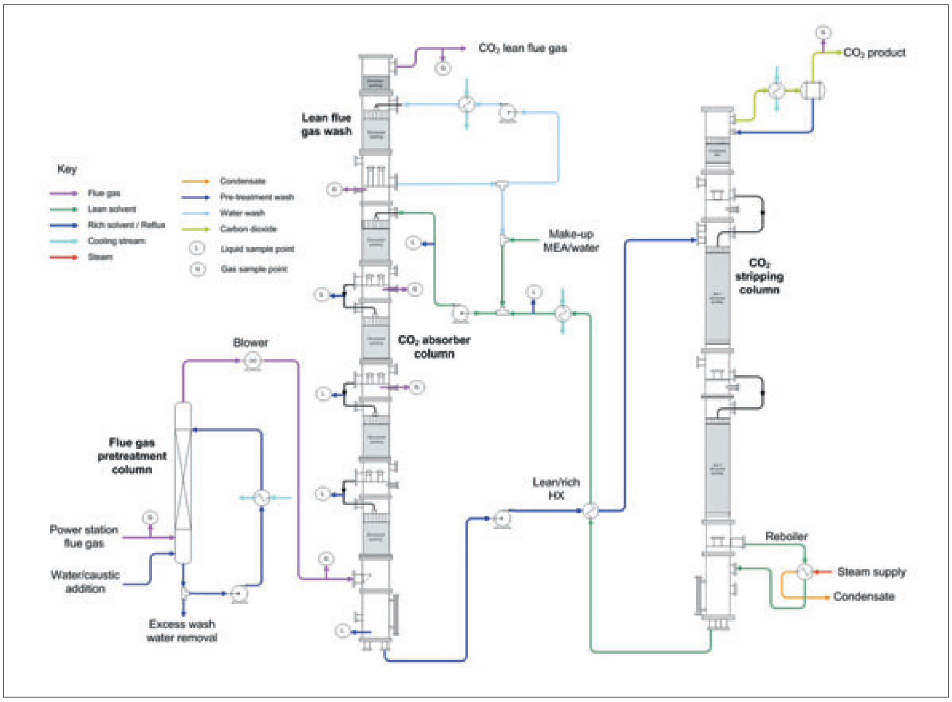



*Figure 2 - process flow diagram of the Tarong CO2 capture pilot plant*

## Special features

The Tarong pilot plant operates 24 h per day, 5 days per week. It is typically manned by two engineers during the day. After hours the control system is able to shut the plant down automatically and alert staff via SMS if required. Round the clock operation allows for extended evaluation of the solvents on real flue gases. This is necessary for the determination of solvent degradation and the effect on plant operation. Over 500 h was achieved during the initial operation with 30 wt% MEA. This was followed by 1700 h of operation when evaluating concentrated piperazine.

The flexibility built into the design of the Tarong plant allows for gas and liquid sampling at various packed heights in the absorber column. This provides CO2 concentration profiles vs. packed height in the absorber, which have provided a useful comparison with both the commercial and in-house process modelling packages used at CSIRO.

The unique design of the Tarong pilot plant allows for the evaluation of various process modifications. Process modifications such as inter-stage cooling (Figure 3) and rich split (Figure 5) have been evaluated with the plant. Inter-stage cooling typically removes heat from the solvent mid-absorber, shifting the equilibrium potentially increasing the solvent CO2 carrying capacity and efficiency of the process. The effect of inter-stage cooling on the temperature profile through the absorber column can easily be seen in Figure 4.

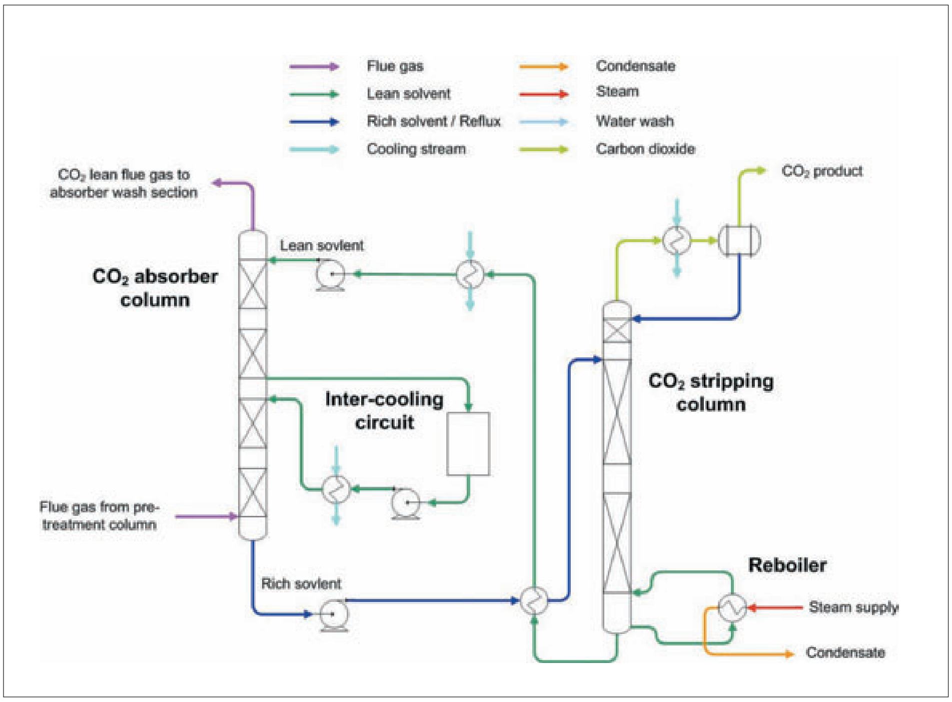



*Figure 3- process flow diagram of absorber inter-stage cooling modification*

The rich split (cold rich bypass) is another method which could potentially reduce the energy requirement of the CO2 capture process. The rich solvent leaving the absorber is split into two streams. The first stream enters the lean-rich exchanger as per normal operation while the second rich solvent stream enters the top of the stripping column cold. Vapour generated by the first stream passing through the lean/rich heat exchanger will preheat the second cold solvent stream potentially reducing the energy requirement from the reboiler.

Another noteworthy feature of the pilot plant is that it is equipped with a broad range of connection points within the system for installing corrosion coupons. A total of 128 corrosion coupons were installed at 8 different locations (5 in/around the absorber, 3 in/around the stripping column) during the campaign with MEA. Coupons were installed below packed sections in regions of gas/liquid two-phase flow as well as in the solvent storage tanks. The comprehensive location coverage of the coupons provides valuable information for material selection relevant to CO2 capture conditions

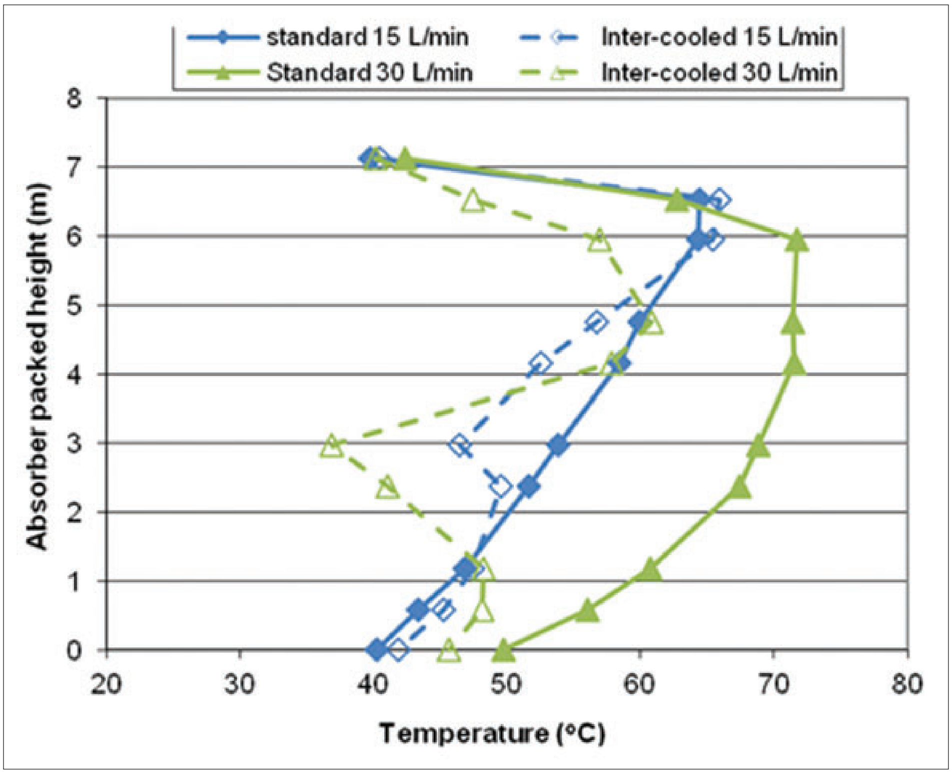



*Figure 4 - temperature profiles through the absorber column for standard operation and with inter-stage cooling for two different solvent flow rates*

## Operation with MEA and Piperazine

MEA has been used in the gas processing industry for many years, and is a well characterised solvent. It was used in the initial operation of the pilot plant to identify the operating range and also to provide a comparison to literature data. It further provides a baseline for comparing any new solvent evaluated on the plant in the future.

Concentrated piperazine is secondary di-amine that is being developed by the University of Texas in Austin as an alternative solvent for PCC processes. CSIRO has collaborated with Prof. Rochelle's research group at the University of Texas in testing the piperazine solution at the Tarong PCC pilot plant. Piperazine is the simplest cyclic member of the ethyleneamine family, and has the following formula:

$$HN(CH_2CH_2)_2NH$$

Compared to the standard 30 wt% MEA, piperazine promises double the absorption capacity, fast reaction kinetics and potentially low regeneration energy requirement. Its thermal and chemical stability with low degradation characteristics offers the potential for significant capital and operating cost saving which in turn makes it a promising solvent for CO2 capture.

Operation with MEA was completed in 2011. Results from the campaign showed MEA to be effective at capturing CO2 from the flue gas at Tarong power station with calculated energy requirements in line with literature data. Plant data (including absorber CO2 concentration profiles) showed good agreement with process modelling results. Two process modifications were also successfully evaluated during this campaign.

The recent work with piperazine was completed in April 2013 and included parametric operation and duration experiments. The parametric runs evaluated the solvent under different operating conditions and provided a feasible operating range for the solvent at the Tarong pilot plant. Duration experiments were then completed in which a constant operating condition was held for an extended period (roughly two months). This

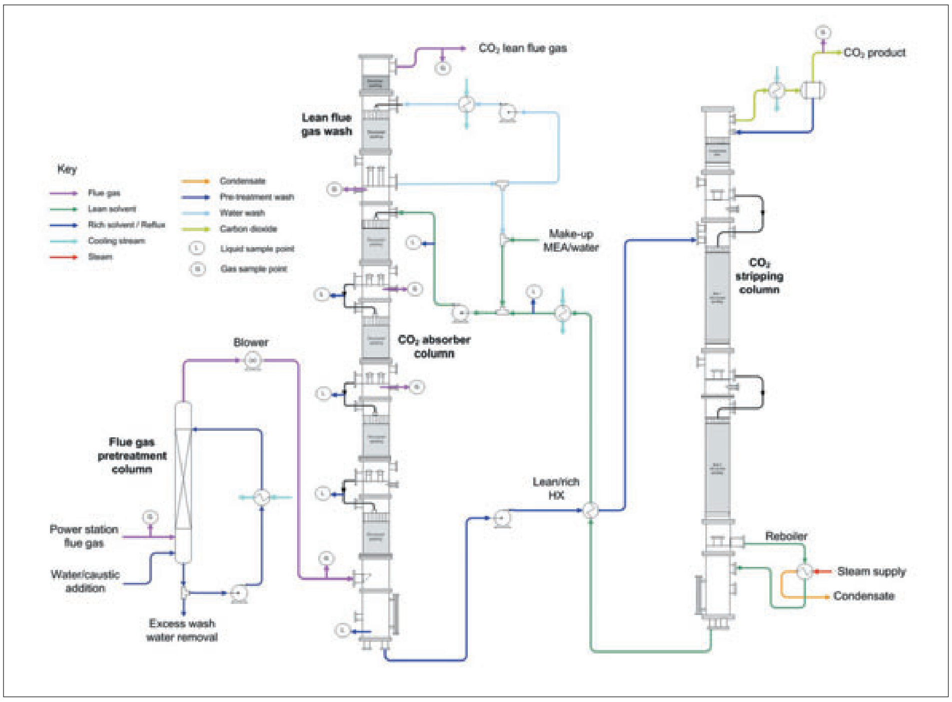



*Figure 5 - process flow diagram of rich split modification*

allowed the stability of the solvent and the formation of degradation products to be assessed. The evaluation of concentrated piperazine was successful and it shows promise as an alternative CO2 capture solvent.

## Conclusion

CSIRO, in collaboration with Stanwell Corporation Ltd have designed, built, commissioned and operated an amine solvent based carbon capture pilot plant to produce 100 kg/hr of CO2 at Tarong Power Station, Nanango, Queensland. The plant is capable of performing 24 h of continuous operation on real flue gas.

Two promising process modifications 1) Inter-stage cooling and 2) Rich split show potential in reducing the solvent regeneration energy requirement. Data from the corrosion study has provided valuable information for material selection relevant to CO2 capture processes. The trial with MEA has provided a useful baseline for any solvent evaluated on the plant in the future. Operation with concentrated piperazine was completed in April 2013. The duration experiments have provided useful information into the long term stability of the concentrated piperazine solution. The experimental campaigns undertaken at the Tarong PCC pilot plant have provided valuable information on the CO2 capture process for flue gas conditions relevant to Australia.

## Acknowledgement

The initial pilot plant project was supported by CSIRO's Advanced Coal Technology Portfolio and received funding from the Australian Government as part of the Asia-Pacific Partnership on Clean Development and Climate. The views expressed herein are not necessarily the views of the Commonwealth, and the Commonwealth does not accept responsibility for any information or advice contained herein.

The authors also wish to acknowledge financial assistance provided through Australian National Low Emissions Coal Research and Development (ANLEC R&D). ANLEC R&D is supported by Australian Coal Association Low Emissions Technology Limited and the Australian Government through the Clean Energy Initiative.

### More information

www.csiro.com.au
www.stanwell.com

# CCSNET: new drive for Australian carbon reduction research

**Led by CO2CRC, which is ten years old this month, CCSNET is a new network of CCS research facilities aimed at boosting Australian development of commercial-scale carbon capture and storage technology.**

Australian Resources and Energy Minister Gary Gray announced the establishment of the network during a visit to the Cooperative Research Centre for Greenhouse Gas Technologies' (CO2CRC) Otway Project.

Lead agency CO2CRC has received $51.6 million from the Australian Government's Clean Energy Future package, administered by the Education Investment Fund (EIF), to support CCSNET, a network of field facilities, onshore and offshore monitoring systems and world class laboratories.

"CCSNET will significantly enhance Australia's CCS research capability," said Dr Richard Aldous, Chief Executive of the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC).

"The network will help to answer many of the outstanding research questions for large-scale CCS projects."

## CCSNET activities

CCSNET will primarily support Victoria's CarbonNet Project, which is funded under the $1.18 billion CCS Flagships program, but the facilities will also be available for other Australian projects and potentially international collaborators.

The network includes:

- **The Otway Subsurface Laboratory** - a major subsurface laboratory based at the CO2CRC Otway Project in Victoria, where CO2 has been stored safely underground since 2008;
- **GipNet** - a CSIRO-driven submarine environment monitoring program in Victoria's offshore Gippsland Basin;
- **CCS Labnet** - a new imaging and analytical research capability at The Australian National University, The University of Melbourne, Monash University and The University of Adelaide.

CCSNET will also attract significant matching funds from research institutions, as well as industry and state government co-investors.

"CCSNET will provide a unique basis for quality national and international CCS research, education and training," said Dr Aldous.

"It reaffirms Australia's strong global role in taking this technology forward."

## Ten years of CCS research at CO2CRC

CO2CRC is celebrating ten years of achievement and scientific excellence in CCS research and development this month..

Achievements over the past decade include Australia's first demonstration of geological carbon storage and the development of a low cost, environmentally friendly capture technology currently being trialled at a pilot plant in Victoria.

CO2CRC has established a network of over 150 expert CCS researchers, robust international collaborations and the CO2CRC Otway Project, a globally significant CO2 storage field laboratory, assets that will be invaluable for the 2015-2020 research program currently being planned.

"CO2CRC has exceeded all expectations, keeping Australian scientists and engineers at the cutting edge of this important new technology" said Dr Aldous.

"Since 2003 we have engaged with twenty six industry partners, eleven research partners and six government partners, the majority of which are still with us, as well as several Small-to-Medium Enterprises (SMEs) and a wealth of supporting participants.

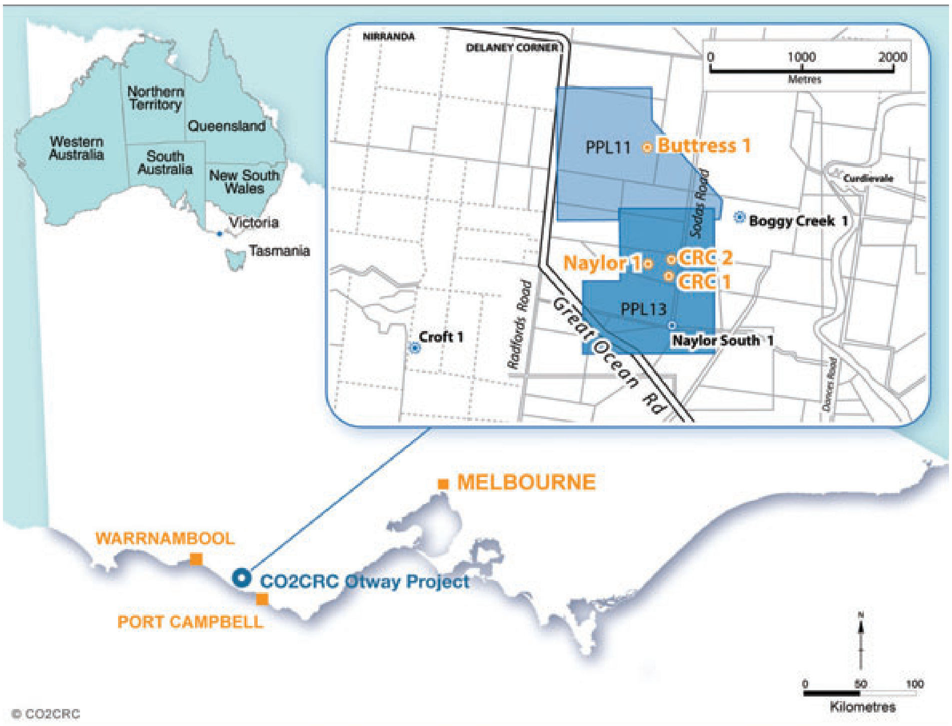
"Over the life of the CRC, 174 peer-reviewed journal articles have been published, as well as 167 conference papers, nine books or book chapters and nearly 400 reports."

"As the climate change challenge becomes ever more urgent, demonstrated by

President Obama's call last week to limit power plant emissions, it is clear Australia needs to secure the option to deploy CCS," said Dr Aldous. "CO2CRC's science and engineering expertise, experience and demonstrations will be an important underpinning to the wide-scale use of CCS that will be essential if we are to take the lowest cost pathway to meet our 2050 emission reduction targets."

CO2CRC formally commenced on 1 July 2003, growing from roots in the Australian Petroleum CRC, and has since proven to be a highly successful example of the Co-operative Research Centre model, in which multidisciplinary teams address end-user driven research.

CO2CRC is a joint venture comprising participants from Australian and global industry, universities and other research bodies from Australia and New Zealand, and Australian Commonwealth, State and international government agencies. Its resources come from the Federal Government Cooperative Research Centres Program, other Federal and State Government programs, CO2CRC participants, and wider industry.




*The CO2CRC Otway Project in Victoria has been researching CO2 storage since 2008*

## More than 1000 visitors to Otway

Fourteen researchers and engineers from China were the latest group to visit the CO2CRC Otway Project in southwest Victoria, to learn more about Australia's leading CCS research.

Organised by Geoscience Australia (a CO2CRC partner) and the Administrative Centre for China's Agenda 21 as part of the China Australia Geological Storage (CAGS) Project, the group included the thousandth visitor to the project since 2008. Nearly half of that 1000 have come from overseas.

The CAGS Project is a collaborative, bilateral project between Australia and China that aims to help accelerate the development and deployment of geological storage of carbon dioxide in both China and Australia. CAGS is funded by the Australian Government through the Australia-China Joint Coordination Group on Clean Coal Technologies.

Groups represented by the visit included the Chinese Academy of Sciences, the China University of Geosciences, the China Geological Survey and PetroChina.

"The Otway Project allows researchers to conduct rigorous trials of new technologies and techniques in a real world situation, which can then be applied to other demonstrations and eventually commercial-scale CCS projects. The facilities at the site are unique and a rare opportunity to test technologies in the field," said Dr Aldous.

New research to be conducted in 2013 includes seismic trials with a research group from Germany.

"Developing nations have shown a particular interest in the Otway Project as they are facing the competing demands of improving living standards and addressing climate change," said Dr Aldous.

### More information

www.co2crc.com.au



# Technology Centre Mongstad – progress one year on

## One year after the launch of Norway's Technology Centre Mongstad, the world's largest carbon capture testing facility, we spoke to managing director Frank Ellingsen about the developments so far.

**By Karl Jeffery**

Technology Centre Mongstad, currently the world's largest carbon capture testing facility, was launched in May 2012 in the presence of Norwegian Prime Minister Jens Stoltenberg and a choir of local children.

Over the first 12 months, the plant was in operation for 5,000 hours in the period July 2012 to May 2013 (11 months or about 8,000 hours in total).

The utility infrastructure was able to operate for 98 per cent of the time it was required to operate.

A lot of information has been generated about how a carbon capture plant can operate. This should all give more certainty to people planning to build full scale carbon capture plants in future, in particular providing a much clearer idea of the costs of construction and operation of the plant.

"What we have done is to demonstrate that these kind of units could be operated with regularity over time," says Frank Ellingsen, managing director of Technology Centre Mongstad. "That has provided some certainty to these technologies."

"These advancements have reduced the knowledge gap of CCS technological development."

The input gas comes from both a natural gas power plant and a refinery cracker.

TCM is a joint venture set up by the Norwegian state (75.12 %), Statoil (20 %), Shell (2.44 %) and Sasol (2.44 %).

*The amine plant at Technology Centre Mongstad (TCM) is testing different solvent mixes of amine, MEA and water*

*"The last year has brought new levels of certainty to expected capital expenditure and ongoing costs of CCS by establishing the viability of capture processes" - Frank Ellingsen*

As you might expect from a mainly government owned project, Mongstad is sharing the results of its research as widely as possible. This includes talks at conferences, development of knowledge sharing networks, and publishing scientific papers. 3 scientific reports have been published.

It aims to increase knowledge on carbon capture technologies, in order to reduce technical and financial risk, and accelerate the development of qualified technologies capable of wide scale international deployment

"We are just in the starting point now to establish this knowledge sharing environment," Mr Ellingsen says.

Mr Ellingsen joined Mongstad in December 2012, and was previously Senior Vice President of Grenland Group Solutions (now renamed Agility Group), an engineering company based in Sandefjord, Norway, specialising in medium sized projects.

This gives him a good background to understand what is required in getting an engineering project running like this one. Before that he was working for Norsk Hydro in various positions in including research.

### One tenth of full scale

The technology centre Mongstad can currently be considered approximately a tenth of a full scale plant, handling 100,000 tons a year of CO2, compared to 1.2m for a typical commercial gas power station.

So Mongstad is a stepping stone between the early demonstration projects and a full scale project.

"If you go from the size we have to the 1.2m or 1m ton based plant, we'll have a lot of information which makes that feasible," Mr Ellingsen says. "That's why we are doing this."

Mongstad is currently the world's largest CCS plant connected to a power station. It won't hold this crown for long - the Saskpower Boundary Dam carbon capture plant, expected to be operating in 2014 or 2015, is expected to capture 1m tonnes per year of CO2.

### Research

The project is testing out different solvents and evaluating them – looking at amines and monoethanol amine (MEA). "The amines will be better than the MEA. That's a more efficient solvent," Mr Ellingsen says.

There are 2 critical factors with solvents – absorption of the gas into the amine

(which requires heating), and the subsequent cooling. "The energy lost in those 2 processes must be as low as possible," he says.

There are 2 amine absorption plants, supplied with exhaust gas. An Aker Solutions plant is running amine technology, and an Alstom plant is running chilled ammonia technology. They have been put through a test plan.

Tests will shortly be performed using a solvent mix of amine, MEA and water, with the MEA concentration 30 weight per cent. The MEA absorption will be used as the 'base case' for comparison with other solvent technologies.

Data has been gathered from over 4,000 measuring points, with around 100 samples per day tested in a laboratory.

## Next 4 years

Technology Centre Mongstad has a budget to run for five years in total from May 2012 to May 2017.

Over the next 4 years, efforts will continue to refine the plant operations to improve efficiency, and Mr Ellingsen expects to see a series of incremental improvements.

"We can change the cost figures and also the energy penalty in the right direction."

"Gradually the cost will go down and technical certainty will go up."

There are also likely to be more technology vendors involved. Aker Solutions, Hitachi, Mitsubishi and Siemens have all registered their interest in the next invitation cycle for the amine plant, he says.

"We will also have a discussion with 15 different vendors to look at the possibility to test the technology at the large available space next to the amine plant ," he said.

## Max efficiency

So how efficient can a gas power station with carbon capture be, in terms of energy output divided by the total energy available in the gas?

Without CCS, the most efficient gas power plants can operate at 59 to 60 per cent efficiency.

"It can be 51 per cent with CCS," he says. "I think 54 per cent is achievable but there's no 54 per cent yet. We want a more energy efficient way of capturing the CO2.

"What we know today - is we can capture 90% of the CO2 from the emissions."

"We also know, when you develop technology, you will increase the efficiency, and make the technology cheaper, and that's what we aim for."

## Public support

You need government support to make it work, Mr Ellingsen believes. "It is driven by public perception, forcing the government to push the technology forward," he says. "That's really needed to get this technology up and running."

Mr Ellingsen believes that public support for measures to combat global warming will gradually increase – particularly if there is an increase in extreme weather. "You have extreme happenings which you can link to the change in the carbon dioxide in the atmosphere," he believes. "When that starts to be a public awareness, I think the pressure will come."

The BBC reported that Norwegian Prime Minister Kjell Magne Bondevik resigned in 2005 partly because he insisted that the power station then being built at Mongstad must be fitted with CCS, but his coalition partners did not agree.

Norwegian environmental group Bellona believes that if the technology centre had not been built the present government would have been 'brought down', the BBC reported.

*Aker Solutions' Mobile Test Unit (the blue container attached to the black chimney)*

## More information

www.mongstad.com

# Capturing carbon with concrete

Professor Peter Claisse of Coventry University looks at the potential for storing carbon dioxide in concrete.

The potential for capturing carbon by concrete is estimated very roughly at 266 million tonnes worldwide each year - and that is the problem, the very significant margin for error in these kinds of figures.

A lack of research and a basis for accurate measurement means we don't know how concrete can be used most effectively for sequestration. As a result, businesses are still missing out on an important new opportunity for carbon trading and hard evidence for environmental reporting.

With pressure from Government and its own tough carbon reduction targets, it's imperative there is a standard measurement for carbon capture by concrete and a new culture of recognition of its role and value.

## The process

Carbon capture is the process by which concrete, and some other materials, react with carbon dioxide in the air and so reduce atmospheric concentrations. Known as 'carbonation', this is a slow and continual process working from the outer surface of the concrete inward, slowing down as it reaches deeper within a structure.

On the one hand carbonation increases the strength of concrete, but at the same time also increases the potential for reinforcement steel to corrode. Business needs to think about how it can maximise the opportunity, the nature of its current and planned property stock, and how they can be best adapted or constructed.

In order to do this, far more needs to be known across types of concrete mixes, buildings and other structures in order to develop the high-potential materials and achieve the greatest benefits.

## The potential

The potential for optimising carbon capture is huge. Assuming an average cement content of 350kg and a total potential sequestration (if the concrete is fully carbonated) of 19%, the potential total is 65kg per $m^3$ of concrete. Typical current values are estimated to be around 3% during the initial life of a structure, i.e. 10kg.

Given the corrosion risk, there are obviously some structures - such as road bridges - where it would be very bad practice to try to increase the degree of carbonation, so it may be that only around 50% of the potential total would be suitable for sequestration.

A good example of where it could be done would be a warehouse floor, which will remain dry so the reinforcement will not corrode. If 750 $m^3$ of concrete was placed in the floor and it was made to carbonate to 50% of its potential total, this would sequester 20 tonnes of $CO_2$. The strength and hardness of the floor would also be improved by the process.

On a general level, actively using and monitoring carbon capture for concrete, just at current levels, will lead to expected reporting of savings of more than 150,000 tonnes of $CO_2$ each year in the UK (again, only a rough figure currently, with a margin for error of up to 50%).

For the concrete industry under scrutiny and pressure due to the high carbon footprint of cement production, here is an opportunity to offset this figure by developing and recording the value from carbon absorbing concrete. For construction firms there is a revenue opportunity with clients who are prepared to pay an additional cost to demonstrate they are achieving carbon saving targets through BREAM or CEEQUAL.

Landlords with large-scale property stocks involving concrete will be able to make assessments of their contribution to carbon capture. Across industries there is the potential for including the role of concrete in environmental reporting.

## Case study - demolition

One example of a specific area is the potential of the demolition process - an area that needs to be exploited by industries under pressure to demonstrate creative thinking on environmental issues.

As mentioned, carbon capture has to be limited in all reinforced concrete structures due to the need to protect steel reinforcement against corrosion. That means the sequestration is limited to the outer layer, typically a 40mm depth. However, when concrete is crushed for re-use as a foundation material for roads or an aggregate to make more concrete, the internal surface is exposed and leads to far more rapid sequestration and much higher levels of capture than at any other part of the life-cycle of the structure.

The carbonation reaction needs water - so it may be that wetting the crushed material could be an easy way to increase sequestration. It also may well be the case that substantial potential capacity may be lost on some occasions when crushed material is encapsulated into concrete as recycled aggregate without being given the opportunity to carbonate.

This can be done by recording the amount of $CO_2$ removed from the atmosphere through lab-scale tests, with samples placed in chambers in which the $CO_2$ concentration is maintained at atmospheric levels by introducing gas to make up for losses. The amount that is introduced will be accurately measured to give direct data for sequestration.

Different concrete mixes also sequestrate to different extents.  This particularly applies to mixes where cement replacements are used. Pulverised Fuels Ash (PFA) and Ground Granulated Blastfurnace Slag (GGBS) are the most common replacements and are often considered as similar alternatives. However a GGBS mix will have a far higher sequestration capacity than one with PFA because of differences in the chemical reactions in them (although no precise figures are available).

Similarly some mixes are far more permeable and will permit far more carbon dioxide to enter and gain access to their reactive components. The permeable mixes will tend to be those with lower strengths so mixes with unnecessarily high strengths should be avoided.

## Conclusion

Given the strict targets in the UK for reducing carbon emissions, the pressure on all forms of industry - leading to potential penalties and charges - will be increasingly intense in the coming years. Here is a clear opportunity for new and significant forms of carbon capture, and action is needed now to gather the all-important basis for measurement.

### More information

Professor Peter Claisse, Low Impact Buildings Centre, Coventry University.

The aim of the Low Impact Buildings Centre (LIBC) is to help create a low carbon, sustainable built environment.

www.coventry.ac.uk

# Crown Estate / BGS launches CO2Stored website

The Crown Estate and the British Geological Survey (BGS) have jointly launched an online tool providing information about carbon storage opportunities around the UK, with nearly 600 different sites included, covering storage potential of 78 billion tonnes of CO2.

**By Karl Jeffery**

The service builds on a database developed by the Energy Technologies Institute (ETI), a public private partnership organisation. The members of ETI are BP, Caterpillar, EDF, E.ON, Rolls-Royce, Shell and the UK Government.

ETI invested £4m into gathering the data, in the UK CO2 Storage Appraisal project (UKSAP). A number of different industrial and academic experts were involved, led by Senergy Alternative Energy; the project was designed to create an auditable and defensible estimate of the UK storage potential.

## Using it

The CO2Stored online database is intended to help stakeholders looking at CCS storage in UK offshore waters, managed in trust by The Crown Estate on behalf of the UK, see what the possibilities are.

Within CO2Stored you can search for a storage site using 25 different criteria, including geology; formation type; type of reservoir (aquifer / depleted oil field / depleted gas field); region of the North Sea; Irish Sea or English Channel; and storage unit type (stratigraphic trap, contained aquifer, whether it has an identified confinement).

You can also search by geological age of the rock, maximum water depth, permeability range, porosity range, formation thickness, pressures, salinity, economic data and calculated theoretical CO2 storage capacity.

The database contains summaries of Monte Carlo simulations, run on a number of variable parameters within the database, which does an analysis to work out the most likely size of the storage.

Tom Mallows, Development Manager, CCS and gas storage, says he sees it as an important tool to help develop CO2 transportation and storage projects, to help people make sure they have identified the storage location most useful for their project.

UK companies which are active in carbon capture and storage still might not be aware of all the possibilities, Mr Mallows says, and there are companies outside the UK which might find it useful evaluating the potential for CO2 storage under the UK's seabed.

The database is available under licence with a different pricing structure tailored for commercial and non-commercial users, although everyone will pay a small administration charge. All revenues will be put re-invested in developing the system.

**Characteristics**
- General
- Pore Volume
- Static Capacity
- Injectivity
- Theoretical Capacity

**Risk**
- Seal
- Faults
- Lateral Migration
- Wells
- Formation Damage
- Connectivity
- Risk Profiles

**Economics**
- Economics
- Oil & Gas Wells

**Results**
- Monte Carlo Summary

**Pore Volume**

| Description | Units | Min | Most Likely | Max | Source | Confidence (L,M,H) |
|---|---|---|---|---|---|---|
| Area | [km²] | 65.97 | 73.30 | 80.63 | BGS Shapefiles | medium |
| Average Gross Thickness | [m] | 243.56 | 250.91 | 259.24 | PGS Surfaces | medium |
| Estimated Relief | [m] | | 538.19 | | PGS Surfaces | medium |
| Shape Factor | | | 1.000 | | | |
| Average Areal Net Sand | [frac] | 0.98 | 0.99 | 1.00 | BGS Shapefiles | medium |
| Average Vertical NTG | [frac] | 0.71 | 0.91 | 1.00 | BGS held wells | medium |
| Average Porosity | [frac] | 0.05 | 0.14 | 0.24 | BGS held wells | medium |
| Gross Rock Volume | [$10^6 m^3$] | | 18392 | | | |
| Pore Volume | [$10^6 m^3$] | | 2320 | | | |
| Aspect Ratio | | | | | | |
| Thickness : Area | [$10^{-6} m^{-1}$] | | 3.4231 | | | |

Date Last Edit: 12:38:06 06 Oct 2010

*CO2Stored contains detailed information on potential UK offshore storage sites (data shown is from a demo dataset)*

## Further development

The Crown Estate and BGS are planning to jointly invest a further £1m over the next 5 years developing the system, and are interested to hear from potential users on what developments it should target.

There are already plans to upgrade the website and have an improved searchable map interface.

Many different options might be considered, such as tools to make it easier to export the data into other people's software systems.

Having this information could support other hydrocarbon systems, as through using CO2Stored their activities could link or coincide with CO2 storage, for example enhanced oil recovery, as used in the U.S.

It would be technically feasible for other datasets to be included on the website mapping tool, one of which might be a layer of existing pipeline infrastructure around the UK.

As the industry develops its understanding of storage sites, it might make sense to get better at matching different storage sites to different types of CO2 stream, such as the flow rate from the CO2 source and the rate the storage site can accept CO2. There might be oil companies looking for very specific types of geology for their storage site.

There is thought at a later date to integrate economic models to provide an indication of relative cost of storage sites.

"We have a host of ideas," Mr Mallows says. "Some of those things can be very expensive - eg purchasing geological data. So there will be a degree of prioritisation. We are seeking user feedback, to understand

what the priorities might be."

"We are looking for stakeholders to provide input," Mr Mallows says. "We welcome feedback on what people feel that they need to access through this system. We'd be interested to know how other people think they might use it through feedback on the enquiries page."

### The Crown Estate

The Crown Estate is an organisation which actively manages a highly diverse range of strategic assets, valued at more than £8 billion.

Under British law, the UK's coastal seabed is the property of the reigning monarch. The Crown Estate, through various Acts of Parliament, manages the seabed storage rights out to 200 nautical miles. It has the responsibility to maintain and enhance the value of these assets over the long term and to enhance the value of the Estate and the revenue it provides. Therefore it has rights over the UK's continental shelf, similar to being an "owner".

All profit made is ultimately given to the Treasury for the benefit of the British public, not to the Queen personally.

If companies store carbon dioxide in the UK seabed, there will be a rental fee payable to The Crown Estate for the aquifer, with the profit ending up in the public purse.

"The Crown Estate does have a duty to achieve value through the asset that it has responsibility for managing," Mr Mallows says. "We see investing in the development of CCS as a key responsibility."

"We look at any charging structure or rental regimes very carefully to ensure that they are immaterial in the context of the overall project economics," he says.

### More information

www.co2stored.co.uk
www.thecrownestate.co.uk
www.bgs.ac.uk

# CCS with EOR - comments from Ed Davey MP

At a recent Oil and Gas UK event, "An audience with Ed Davey", we asked about the potential for CCS combined with Enhanced Oil Recovery in offshore UK fields.

**Ed Davey MP, Secretary Of State for Energy and Climate Change**

Our job isn't to tell industry they've got to go down CCS + enhanced oil recovery - that's for industry to come up with the solutions. The competition we ran on CCS was inviting applications for what industry wanted to do.

We had eight applications when we opened the competition, we whittled it down to four, we've now got two, it's been a robust competition, we had criteria that we published carefully before hand.

We were worried that some people might think we weren't running the competition fairly, I don't think anyone has said that

We've been scrupulous in applying the criteria and we've got down to 2 consortiums - we're engaging to finalise those contracts.

We put a billion pounds of capital in - and behind that is the contracts for difference with revenue streams of billions of pounds going forward.

We have to get value for money for the consumer and taxpayer for that money, that's why we've had this I think very successful competition. We'll see how the industry rolls that out.

We want to have a very successful CCS industry in the UK - we want a big CCS industry commercially viable in the middle of the next decade.

The work we have been doing through the people who won the competition, and some of those who didn't win who are still looking at the opportunity, is to try to make that happen.

We're working to make that happen, we're working with other countries, the 4 kingdom's initiative with Norway, Holland and Saudi Arabia. I think the Americans are likely to go quite big into CCS, and already are.

I think the CCS story is going to be a very big story - but I don't think we should limit it - and I think commerce and industry has to decide the right way forward.We've got to put in the right framework to get things going.

**James Edens, vice president and managing director, CNR International (UK) Ltd.**

It does seem like a good solution that while we're storing carbon indefinitely we actually use it to actually mobilise some oil - it is a product that would increase the recovery from our reservoirs typically under water flood - it would displace some of the oil.

One of the challenges is that the utility of carbon dioxide to move oil - it doesn't absorb much of it - it doesn't consume much of it. What we're really getting to with carbon capture is finding a place to store large volumes for a long time. I think there's a link, but I think if we think we'll store all the carbon in our oil reservoirs that's probably not appropriate.

I expect that on the way to finding a place to store it for long term sequestration, using it en route to mobilise some oil might be an enabler for that final solution, and that's something we should explore.

But we won't be seeing, I don't believe, large volumes of carbon in oil reservoirs just to mobilise the oil out, I don't think the sink is big enough, we have to take it to saline aquifers and other places.

**Dr James Lorsong, Exploration and Production Director, 2Co Energy Limited**, provided a written comment: I agree that CO2 EOR and storage has great potential in the North Sea, to improve CCS economics, provide secure CO2 storage and to address security of energy supply while extending the lives of mature oil fields.

CO2 injected for EOR mixes thoroughly with oil in the reservoir, and a portion is produced back with the oil. The CO2 produced with the oil is separated out on the platform and re-injected without reaching the atmosphere. At the end of a project, wells are permanently sealed, exactly as they are in any storage site, and all of the injected CO2 remains in the underground formation.

There are not enough oil fields in the UK to store all of our emissions for an extended period, but there is capacity for billions of tonnes of CO2. Because CCS costs can be partially offset with oil revenues, EOR and storage is an attractive enabler for early projects and creates infrastructure that would be sufficient to support capture projects for decades.

Currently there is no CO2 storage in the UK; if CCS is widely deployed, storage in depleted gas fields and deep saline formations eventually will be needed alongside EOR and storage.

Whilst government should not mandate CO2 storage in specific sites, they have an important role in creating regulatory and fiscal frameworks that put all the necessary safeguards in place for EOR and storage, and thus early, effective deployment of carbon capture and storage.

# Land use tensions over bioenergy with CCS

The combination of carbon capture and storage with a bioenergy power plant, a technique known as bioenergy with CCS (BECCS), offers the prospect of removing carbon dioxide from the atmosphere, however there is a concern that tensions over land use could arise.

### Recommendations from the Institution of Mechanical Engineers

Given that the exclusion of biomass from the energy mix would significantly increase the cost of reducing the CO2 emissions of the UK energy system, the Institution of Mechanical Engineers urges Government to adopt the following recommendations:

1. Undertake a thorough and detailed investigation into the potential use of biomass-based technologies for UK electricity generation, taking account of future international food production needs, ecosystem preservation, economics and climate change mitigation benefits.
2. Take an international lead in encouraging a fully integrated global approach to food security, ecosystem preservation and the generation of electricity from biomass energy, to reduce the scope for related impacts on future food prices and help ensure biomass incentives do not lead to undesired land-use changes.
3. Support UK research, development and demonstration of CCS technology for use with biomass-based electricity generation while simultaneously pursuing the future inclusion of 'negative emissions' credits in international climate change mitigation agreements.

Bioenergy is widely expected to make a contribution to global electricity production in the coming decades, because of its potential to be a cost-effective source of non-intermittent power generation with low carbon emissions, says a policy statement from the Institution of Mechanical Engineers, "BECCS for electricity land-use tensions."

However, the possibility of a widespread adoption of electricity production from bioenergy has raised concerns in some that increased tensions may emerge over land use. These would arise because biomass cultivated for power generation might compete for land use with other human needs, such as food supply, transport fuels and the desire to maintain global ecosystems.

The analysis presented in the policy statement suggests that at the scale of current global ambitions for the generation of electricity from biomass, significant land-use tensions with food production and ecosystem preservation may not necessarily emerge.

## Bioenergy and the carbon cycle

The large-scale exploitation of the energy stored in fossilised biomass for fuel (such as coal, oil and gas) is resulting in substantial annual emissions of carbon back into the atmosphere and which many scientists propose will lead to climate change. However, interest in the use of non-fossilised biomass as an energy source has increased in recent decades, both as a potentially cost-effective method for the mitigation of climate change and as a possible route to security of energy supply.

### Low and negative 'net' emissions

Substituting biomass for fossil fuel usage provides two possible routes to climate change mitigation. The basis of the first of these lies in the fact that biomass absorbs CO2 from the atmosphere during growth and incorporates the carbon into its structure; later release of the stored carbon through energy use effectively replaces the CO2 that was removed.

Appropriation of this process through the managed planting, growing and harvesting of biomass for energy sourcing utilises this closed loop and effectively offers a route to a low emissions energy system (which may be close to zero, depending on the overall lifecycle emissions).

An extension of this approach offers the possibility of net removal of carbon from the atmosphere. In this second route, through the application of carbon capture technology to the energy plant, the released carbon is collected. If subsequently stored, for example underground in suitable geology or through mineralisation, the carbon may be removed from the biosphere entirely, thereby creating so-called 'negative emissions'.

It is for this reason that the BECCS idea has been developed and the concept of negative emissions credits proposed. The International Energy Agency Greenhouse Gas R&D Programme (IEAGHG) estimates that, depending on technology route selected, deployment rates and economics, an upper range from 3.5 to 10 gigatonnes (Gt) of CO2 could potentially be captured and stored globally each year by 2050, using this approach with electricity production.

### Potential of BECCS for electricity production

Biomass can be used for electricity generation through several methods that include combustion, either in dedicated power stations or by co-firing with other fuels such as coal, and gasification before combustion. Currently biomass accounts for about 1.5% (300 Terrawatt hours per year (TWh/yr)) of annual electricity production worldwide and growth projections anticipate this increasing to about 4% (1,500 TWh/yr) by 2035.

In the UK, biomass accounts for approximately 3% of total power generation and is anticipated to rise to between 5–11% by 2020, largely through co-firing or conversions in existing coal stations. Depending on selected technology route, deployment rates and economics, estimates of the annual power production realisable globally by 2050 from BECCS range from 500 to 16,500 TWh/yr. However, a future constraint on the public acceptability of biomass-based electricity generation may emerge as a result of perceptions of the land-use requirement for production of the biomass fuel.

## Land-use tension

It is anticipated by some that a future tension may potentially emerge between the need to provide biomass to meet food requirements, particularly in the context of increasing populations and changing dietary preferences, and energy policy which seeks to encourage deployment of low-carbon energy systems to meet climate change mitigation targets.

### Projected land-use needs for food production

The total amount of land surface on the planet is approximately 14.8 gigahectares (Gha), of which 10 Gha is capable of supporting biomass (ie not desert etc); some 50% of the latter, that is about 4.9 Gha, is currently utilised for food production while the rest largely supports the world's remaining natural ecosystems

Long-term projections based on population growth estimates suggest that by the mid-21st century overall demand for food is expected to grow by 70%. Although meeting this

| | Low | Median | High |
|---|---|---|---|
| Biomass primary energy (EJ/yr) | 32.5 | 40.7 | 48.8 |
| Land area (Gha) | 0.18 | 0.22 | 0.27 |
| CO2 sequestered (Gt/yr) | 2.9 | 3.67 | 4.4 |

*Table 1: Area required to grow dedicated biomass crops for electricity generation using BIGCC+CCS in 2050 and CO2 sequestered*

| Scenario | Low | Median | High |
|---|---|---|---|
| High meat, low efficiency | 0.18 | 0.22 | 0.27 |
| Low meat, low efficiency | 0.18 | 0.22 | 0.27 |
| High meat, high efficiency | 0.05 | 0.09 | 0.14 |
| Low meat, high efficiency | -0.42 | -0.38 | -0.33 |

*Table 2: 'Extra' land area (Gha) required for electricity production in each of the four 'meat consumption – production efficiency' scenarios considered*

demand will pose considerable challenges, it is an anticipated future shift by many countries to diets high in animal products such as meat and dairy that will likely represent the most significant trend. As developing nations become more affluent in the coming decades, per capita calorific intake from meat consumption is set to rise 40% by 2050.

At the core of the challenge is the fact that livestock-based food production is far less efficient in land use than that based on crops, largely because only 3% of the feed energy consumed by livestock remains in edible animal tissue. Forecasts for the amount of land that will be needed to deliver sufficient food to feed the increasing population through the 21st century are highly dependent on assumptions made regarding trends in these dietary preferences.

A recent study has attempted to comprehensively analyse the land-use needs of a range of possible dietary scenarios to 2050, ranging from a worse case of 'high-meat consumption – low production efficiency' to a best case of 'low-meat consumption – high production efficiency'. In these scenarios, 'high production efficiency' considers a sustained annual yield growth of 1%, increased recycling of wastes and residues, and adoption of a diet with a substantial pork and poultry component (less demanding in land use relative to red meats). The best and worst-case scenarios resulted in land-use figures of 4.13 Gha and 8.83 Gha respectively.

### Land-use needs of biomass for electricity production

An estimate of how much biomass-based electricity production might be realised annually across the globe by 2050, can be extrapolated from data presented by the Intergovernmental Panel on Climate Change (IPCC) and International Energy Agency (IEA) to be about 3,400 TWh/yr.

In order to gain an initial 'order of magnitude' indication of how much land would be required to produce this amount of electricity annually, the Institution considered the sole use of Biomass Integrated Gasification Combined Cycle (BIGCC) plant fitted with CCS (BIGCC+CCS) to generate the total. This would require a primary energy supply from biomass of about 40.7 exajoules (EJ) per year, or 48.8EJ and 32.5EJ for high and low bounds based on a +/- 20% estimate deviation.

Assuming a dedicated biomass source, such as Miscanthus, this could result in a land-use demand in 2050 ranging between 0.18 Gha and 0.27 Gha, as shown in Table 1, with the median projection of 0.22 Gha. These values are relatively very modest in the context of those anticipated for food production (calculated in the range 4.13 Gha to 8.83 Gha depending on dietary and production efficiency assumptions) and estimates in previous studies of the global land availability for energy crops.

Table 1 also shows that through the use of BIGCC+CCS to meet the estimated 2050 biomass-based electricity production figure, 2.9–4.4Gt of CO2 per year could be sequestered, with a median estimate of 3.67Gt. This value is consistent with previous analysis and a useful potential contribution to climate change mitigation efforts.

### Resolving potential land-use tensions between food production and electricity production

An integrated approach to managing energy and agricultural land use could further reduce the overall amount of land needed. For example, the 'high production efficiency' scenarios of the recent study referred to above show land initially used for food production in the 2020s and 30s becoming available for energy crop cultivation by 2050.

This 'freed-up' land could be used to meet a portion of the land requirements shown in Table 1 for electricity production and result in the revised figures presented in Table 2. The negative values given for the 'low meat consumption – high production efficiency' scenario indicate land available for other bioenergy crops, if desired, once the electricity production requirement has been fulfilled. The latter result is because in this scenario improved agricultural productivity over the coming decades releases more than enough bioenergy land to meet the electricity need.

### Conclusion

Although the global production of biomass for energy currently utilises a very small area (~0.014 Gha) of the land capable of supporting biomass (~10 Gha), relative to that which is utilised for food (~4.9 Gha), it is the finite nature of the available land and competing needs for food, energy and ecosystem preservation that many anticipate will likely define key land-use tensions in the coming decades.

However, from our initial analysis it is suggested that in the case of current global aspirations for electricity production from biomass, those tensions may be small. Furthermore, through the use of an integrated management approach to food and biomass-based electricity production, including careful structuring of incentives to help ensure only desired land-use changes occur, they may indeed be eliminated.

### More information

The policy statement has been edited for space. The full version, including references, can be downloaded from the IMechE website:
www.imeche.org/policy

# UK CCS Cost Reduction Task Force final report

**The final report from the Carbon Capture and Storage Cost Reduction Taskforce confirms that UK fossil power stations with carbon capture, transport and storage, have the potential to be cost competitive with other types of low carbon power generation.**

The key conclusion of the Interim Report (published on 21st November 2012) remains unchanged - CCS on fossil fuel power stations can be cost-competitive with other low-carbon technologies. The final report sets out actions agreed by the Taskforce members and recommended Next Steps.

Building on the report's findings, the Crown Estate will establish a new UK CO2 Storage Development Group, which will aim to assist delivery of proven storage sites that are both commercially and technically viable. The group will examine options for site characterisation of reservoirs and aquifers for storage, and link these to potential locations of CO2 capture plants. It will make recommendations on measures that can unlock cost reductions, maximise benefits of scale and decrease technical, commercial and financial risk in storage.

Seeking to optimise UK CCS Transport and Storage network configurations, the group will also identify options for early CCS projects and future CCS infrastructure developments, in order to minimise long-run costs and create large-scale use storage hubs. Critically, this will take into account likely related pipeline networks. The above work will all feed into an industry-led and government-supported vision of how subsequent phases of CCS projects in the UK can be developed and financed.

## New organisational structures

The UK CCS Cost Reduction Task Force, having delivered on its terms of reference, will disband following publication of this report. To ensure the actions are delivered, the Task Force recommends the following national leadership groups be created to take forward the recommendations:

A. The ‘UK CO2 Storage Development Group’. This group will be led and co-ordinated by The Crown Estate. The aim of the group will be to unlock cost reductions through the benefits of scale and to reduce risks in the CO2 storage and transport sector.

B. The ‘UK CCS Commercial Development Group’. This group will involve active Bank and Insurance industry participants. The group will be established by CCSA, the Energy Technologies Institute, The Crown Estate and the Ecofin Foundation, and be led by the Ecofin Foundation. The aim of the group will be to secure ways, together with the UK Government, of making UK CCS projects bankable, and reducing their cost of capital.

C. The UK CCS Knowledge Transfer Network. This will be led by the CCSA. Its aim will be to enhance cost saving (and value enhancing) potential for CCS projects by promoting and facilitating the flow and review of knowledge and information, for both Industry and Government, following on from early projects in the UK and elsewhere. This will identify key gaps that stakeholders should address in order to ensure that CCS plays its full potential in the broader decarbonisation of the UK energy system.

These groups should provide input to an Industry-Government partnership forum which will monitor progress in delivering the actions as well as looking at development strategically, beyond the initial next steps identified.

The report was widely welcomed with industry bodies urging the governement to rapidly implement the key findings and to establish a long term vision for CCS in the UK beyond the two current demonstration projects.

### Seven key next steps to support the large scale development of power and industrial CCS in the UK

The CRTF believes that the following seven key steps will be required if follow-on and future UK CCS projects are to be developed which deliver the identified cost reductions.

1. Ensure optimal UK CCS transport and storage network configuration
Conduct industry-led but government supported studies to identify options for developing configurations for the UK CCS transport and storage system for both early CCS projects and future CCS projects, in order to minimise long-run costs. Take into account likely future development of CO2 storage hubs and the related pipeline networks. (Led by UK CO2 Storage Development Group.)
2. Incentivise CO2 EOR to limit emissions and maximise UK hydrocarbon production
Create a UK tax regime to support the development of brownfield CO2 Enhanced Oil Recovery (CO2 EOR) in the UK North Sea. (Oil Companies, OCCS, DECC EDU.)
3. Ensure funding mechanisms are fit-for-purpose
Continue work to develop the coal and gas CfD structures, and other relevant EMR and funding instruments, ensuring their suitability for widespread use in coal and gas CCS projects. (DECC, CCSA, UK CCS Commercial Development Group.)
4. Create bankable contracts
Focus on how to construct contracts (including the detailed terms of CfDs) that will be needed to make follow-on projects bankable. This will include taking evidence from the published Commercialisation Programme ITPD, the experience of the Commercialisation Programme bidders and input from other stakeholder including finance and insurance sectors. (UK CCS Commercial Development Group.)
5. Create a vision for development of CCS Projects in the UK from follow-on projects through to widespread adoption Create an industry-led and government-supported vision of how subsequent phases of CCS projects in the UK can be developed and financed. The aim is to encourage and guide developers who are bringing the next UK CCS projects forward, that will get a CfD but no government grant. (CCSA, The Crown Estate, DECC.)
6. Promote characterisation of CO2 storage locations to create maximum benefit from the UK storage resource Examine the options for characterisation of both storage areas and also specific sites for CO2 storage in the UKCS, and recommend a way forward to Government and industry. The aim is to reduce the ‘exploration risk’ premium, thereby making storage sites bankable both commercially and technically. (UK CO2 Storage Development Group.)
7. Create policy and financing regimes for CCS from industrial CO2 Create proposed policy and financing regimes for the CCS of Industrial CO2. (BIS, CCSA and DECC.)

### More information

www.ccsassociation.org.uk

# Policy, projects and regulation news

## CO2 Capture Project launches CCS Browser

www.ccsbrowser.com

**The CCS Browser is a multi-format digital resource aimed at helping the public learn about CCS.**

Available on tablet, PC and mobile, the CCS Browser has been designed to allow people to explore the topic in the way best suited to them - by watching animations, listening to audio clips and by interacting with maps and diagrams. The site also acts as a portal to other sources to allow people to explore topics in even greater depth if needed.

"We have brought together a team of digital designers, capture, subsurface and communication experts to create one of the first dedicated, interactive websites to explain CCS to a non-technical audience," said Mark Crombie, Program Manager and Communications Team Lead. "We want this to be a resource for the whole CCS industry to use - so get in touch to tell us what you think."

*The CCS Browser released by the CO2 Capture Project is a multimedia resource to help the general public understand CCS better*

The main focus of the CCS Browser is on storage, with detailed animations used to explain areas such as geological trapping, porosity and containment, as well as storage site operation and CO2 monitoring.

"How CO2 stays securely underground is one of the biggest public concerns regarding CCS," explained Dan Kieke, subsurface consultant at Chevron, one of the CCP's partners. "Storage had to be the focus for the site. We felt that animations would help bring these quite technical areas to life for the non-technical audience and provide an insight into the scientific processes at work. We also wanted to demonstrate how our industry uses its experience with subsurface conditions to safely store CO2."

The CCP is a partnership of major energy companies, working to advance the technologies that will underpin the deployment of industrial-scale CO2 capture and storage. Currently in its third phase of activity (CCP3) its members are BP, Chevron, Eni, Petrobras, Shell and Suncor.

The CCP recently published its 2012 Annual Report. In 2012, the CCP delivered its first major CO2 capture demonstration, an oxy-firing test at a pilot-scale Fluid Catalytic Cracking (FCC) unit at a Petrobras research facility in Parana, Brazil. The demonstration has confirmed the technical viability of retrofitting an FCC unit, one of the highest emitting processes in an oil refinery. The CCP Capture team also made progress in developing a range of other capture technology tests and studies to be delivered in 2013.

It was also an important year for the Storage Team, which continued its work addressing key issues for industry and regulators. A number of important storage monitoring field trials have been completed, including successful deployment of a Modular Borehole Monitoring technology, and produced further results from a satellite monitoring programme

## Air Products Texas project begins capturing CO2

www.energy.gov

**The company has successfully begun capturing carbon dioxide from industrial operations and is now using that carbon for enhanced oil recovery (EOR) and securely storing it underground.**

The Energy Department's Acting Assistant Secretary for Fossil Energy Christopher Smith attended a dedication ceremony at the Air Products and Chemicals hydrogen production facilities in Port Arthur, Texas. Supported by a $284 million Energy Department investment, the project advances carbon capture, utilization and storage technologies and demonstrates the potential to safely secure carbon dioxide pollution underground while providing an economic benefit and increasing our energy security.

At full-scale operation, more than 90 percent of the carbon dioxide from the product stream of two methane steam reformers - or approximately one million metric tons of carbon dioxide per year - will be delivered for sequestration and EOR, which will lead to an estimated annual increase in oil production of 1.6 to 3.1 million barrels from the West Hastings oil field located about 20 miles south of Houston, Texas.

"The Energy Department is investing in cutting-edge technologies that will help us safely and more sustainably develop all of America's rich energy resources," said Acting Assistant Secretary for Fossil Energy Christopher Smith. "This groundbreaking project demonstrates the potential to produce economic benefits and increase our energy security while greatly reducing the environmental impacts of our fossil energy use."

The two retrofitted Air Products and Chemicals plants produce commercial bulk hydrogen primarily for use at the nearby Valero refinery. The approximately $431 million project, supported by $284 million from the Energy Department, included retrofitting the plants with an innovative system that separates carbon dioxide from the steam reformer product gas during hydrogen production, followed by compression and drying processes.

The Energy Department investment also helped construct a 13.1-mile-long feeder that connects the two plants to an existing 325-mile, 24-inch carbon dioxide pipeline, Denbury's Green Pipeline, that begins in Louisiana and ends at the West Hastings field. Careful carbon dioxide monitoring, verification, and accounting activities to ensure the injected carbon dioxide remains in the underground geologic formation will take place throughout the lifetime of the project.

The first plant has been capturing carbon dioxide since December 2012, while the second plant completed construction in Feb-

ruary and began carbon capture operations in March. Both units are now operating at full capacity. Over 222,000 tons of carbon dioxide have been captured and provided for storage as of early May.

## EU body calls for immediate action on CCS

www.zeroemissionsplatform.eu

**The European Technology Platform for Zero Emission Fossil Fuel Power Plants (ZEP) has called for "an urgent and fundamental re-set to the Carbon Capture and Storage programme in Europe."**

During a public hearing in the European Parliament, Dr. Graeme Sweeney, Chairman of ZEP, emphasised the urgency of deploying CCS, "Without immediate political action to enable CCS, Europe will face severe environmental, social and economic consequences. We will lose jobs, be behind on innovation and we will not meet our 2050 emissions reductions objectives."

The ZEP has called for a re-set of CCS iniatives in the EU to speed up deployment of the technology.

The ZEP stated that CCS is the single most powerful tool today for addressing climate change, and Europe cannot be cost effectively decarbonised without it. CCS represents tremendous value for money, the body said, and IEA scenarios show that decarbonising the power sector would cost $1 trillion more if the deployment of CCS is delayed for 10 years.

"China, Canada, Australia and the U.S. are all gaining ground in developing CCS, while Europe falls behind. CCS is vital to Europe's future competitiveness and economic prosperity, preserving jobs in key industries and promoting a low-carbon economy. The longer we delay delivering CCS the higher the cost, with jobs lost to other regions and industry relocating to those areas that are leaders rather than laggards."

Proper policy and funding mechanisms to deliver large scale CCS demonstration projects in Europe are urgently needed, it continued.

"We need a robust and efficient EU emissions trading system (EU ETS) able to drive investment in low carbon technology, including in CCS. In this context, ZEP urges members of the European Parliament's Environment Committee to use tomorrow's vote to endorse constructive amendments that support backloading as a temporary measure to tackle the current over supply of EU ETS allowances. This is the first step necessary before structural measures can be implemented."

"EU funding instruments are also crucial. The second phase of the NER300 funding programme, as well as recycling existing funds under the European Economic Programme for Recovery (EEPR), are essential to achieving the development of successful demonstration projects."

"To ensure the long-term availability of funding, ZEP also supports the extension of NER300 beyond phase two by introducing an "innovation fund'. Another example of how funding can be brought forward would be to establish a tradable CCS certificate scheme at the EU level, which if carefully designed, would drive the investments needed to deliver defined volumes of CCS. At Member State level actions to stimulate CCS using Contracts for Difference and Feed in Tariffs would be welcome."

MEP Chris Davies, rapporteur for the Parliament's forthcoming report on developing CCS in Europe, said, "CCS can significantly reduce the cost of building a low carbon economy in Europe. We will continue to depend on fossil fuels for our energy for many decades and we need to take action now to decarbonise that use of fossil fuels. We cannot afford further delay. When it comes to providing financial support, CCS should be treated on a level playing field with other low carbon technologies."

## SaskPower and United Kingdom announce joint research programme for CCS

www.saskpowercarboncapture.com

**The UK Carbon Capture and Storage Research Centre (UKCCSRC) and SaskPower have established a joint initiative to link practical experience on SaskPower's Boundary Dam project with a wide-ranging academic carbon capture and storage research programme.**

The three-year Memorandum of Understanding was signed on May 23, 2013, between SaskPower and the UKCCSRC to facilitate research and related opportunities aimed at improving costs and performance of CCS.

The announcement comes at the conclusion of the inaugural SaskPower CCS Information and Planning Symposium held in Regina this week. In support of the MOU programme, the UKCCSRC has allocated an initial budget of $390,000 CAD (£250,000) to meet the additional costs to UK academic researchers. A joint SaskPower/UKCCSRC panel will provide oversight and planning for the coordinated research activities.

"The knowledge and expertise that SaskPower has gained through its carbon capture and storage project at Boundary Dam Power Station is now in demand by other organizations around the world," said SaskPower President and CEO Robert Watson. "This type of international collaboration is very welcome and will benefit the energy industry as a whole."

"This joint initiative will add significant impact and value to the UKCCSRC"s research base. The ability to undertake research linked to the world"s largest post-combustion CCS project is crucial for keeping our programme at the leading edge of work to help meet global climate change targets" said Prof. Jon Gibbins, UKCCSRC Director.

The MOU comes after researchers from UKCCSRC and SaskPower officials met in 2012 on a visit to Canada supported by the UK Foreign and Commonwealth Office, followed by a visit to the UK made by SaskPower. Results and outcomes will be shared with both organization members, with scope for extended and expanded research projects in future years.

## Heriot-Watt University launches full chain CCS research centre

www.sccs.org.uk

**The Centre for Innovation in Carbon Capture and Storage (CICCS) will study the entire carbon capture and storage chain.**

The Centre has been set up under the leadership of Professor Mercedes Maroto-Valer, who holds the Robert M Buchan Chair in Sustainable Energy Engineering at the University. She heads a team drawn from across the globe, spanning disciplines from chemistry and environmental science to chemical engineering and petroleum engineering.

The CICCS team has facilities to accommodate a team of 15 researchers. Research projects under way include looking at ways to make carbon capture cost efficient for the largest producers of carbon dioxide, in particular power plants and heavy industry and, at the other end of the cycle, understanding the fate of the long-term storage of carbon dioxide in geological formations under the seabed.

Prof Mercedes Maroto-Valer said, "Our new facilities have been made possible through the generous donation of our Chancellor, Dr Robert Buchan. These laboratories will be key to delivering our existing research programmes worth £3million. We also look forward to the opportunities that these new facilities will undoubtedly bring to further strengthen the leading position for Heriot-Watt in energy research."

The Centre expects to contribute internationally relevant research, particularly focussing on rising economies such as Brazil, India and China. There were already plans to begin research exchanges with China, she

noted.

To mark the opening of the Centre, doctorate students at Heriot-Watt were invited to present posters about particular aspects of their research relating to the work of the laboratories.

Heriot-Watt University is one of the three partners in Scottish Carbon Capture & Storage (SCCS), a research partnership which also includes the British Geological Survey and the University of Edinburgh. Prof Mercedes Maroto-Valer is on the SCCS Directorate.

## Cefic energy roadmap assesses the long-term potential for CCS in chemical industry

www.cefic.org

**Published with support from energy consultancy Ecofys, the paper titled "Unlocking a competitive, low carbon and energy efficient future" explores the chemical industry's role in light of the EU's decarbonisation goals in a 2050 perspective, reports Bellona.**

The paper concludes that deep reductions of chemical industry emissions are technically possible by decarbonisation of the power sector and, in addition, for the 2030-2050 timeframe, by deployment of CCS. However, the authors note, these options are expensive and will require technological breakthroughs.

The commercial viability of CCS applied to emissions from chemical industry depends on the CO2 emissions volume, since all stages (capture, transport and storage) will be cheaper per tonne of captured CO2 with increasing volumes. The paper assesses ammonia production and steam crackers separately from other chemical products and shows the investment costs of CO2 compression, transport and storage over time.

In general, the long-term reductions of these investment costs are significant, as CCS is still a first generation technology. With the assumption of worldwide CCS deployment, the costs will go down considerably, the figures show. This will only be possible if CCS is deployed in many sectors.

This is the working assumption for the scenario where a significant share of CCS uptake is foreseen by the chemical industry. For instance, for ammonia production the costs of CO2 capture and compression from combustion sources could go down by 30% in 2030 and around 60% by 2050 from €300 per tonne of CO2 in 2020.

Apart from CO2 storage the report looks into the possibilities of the use of CO2 as feedstock in the chemical industry and other industries such as:

- Enhanced hydrocarbon production (enhanced oil recovery)
- In greenhouses (to enhance growth of the plants)
- In the food / soft drinks industry
- Fuel production industry
- As raw material for inorganic materials

## UK Committee says decarbonising electricity will save money

www.theccc.org.uk

**In a report on the UK Electricity Market Reform, the Committee on Climate Change has presented new analysis showing that there are significant economic benefits from investing in a portfolio of low-carbon technologies through the 2020s rather than investing in gas-fired generation.**

The report finds that investment in a portfolio of low-carbon technologies could save consumers £25-45 billion, rising to £100 billion with higher gas and carbon prices.

Only if the world abandons attempts to limit risks of dangerous climate change would a strategy of investment in gas-fired generation through the 2020s offer significant savings.

This conclusion is robust when possible impacts of shale gas on the gas price are accounted for. Shale gas could play a role in the gas mix that helps to balance intermittent power generation, and meet demand for heat, provided appropriate environmental safeguarding regulations are put in place.

The report highlights the current high degree of uncertainty and the unfavourable conditions for investment in the power sector and its supply chains.

The Committee urges the Government to make commitments which would support investment in a portfolio of low-carbon technologies, and estimates that this would add only around £20 to the typical annual household bill in 2030 compared to 2020.

Specifically, the Committee recommends the following package of measures that would provide more confidence to investors:

- In this Parliament, set a target under the Energy Bill to reduce the carbon intensity of power generation from current levels of 500 gCO2/kWh to around 50 gCO2/kWh in 2030

- Extend to 2030 funding allocated to support development of less mature technologies ("the Levy Control Framework").

- Set strategies for the further development of less mature technologies such as offshore wind and the commercialisation of carbon capture and storage (CCS)

- Present options to support mobilisation of new sources of finance, including roles for the Green Investment Bank and Infrastructure UK.

- Publish in the Electricity Market Reform delivery plan the amount of capacity that the Government intends to contract over the period 2014-18, and the prices that it intends to pay for onshore and offshore wind generation.

A failure to commit to this would be to bet on a low gas price world, which could lock out the much higher benefits from portfolio investment in low-carbon technologies in more likely scenarios. It would be a wager on an outcome that is the opposite of most expectations. Even if the proposition were true, and a low gas price world were to ensue, cost savings due to investment in gas-fired generation through the 2020s would be very limited.

Jeff Chapman, Chariman of the Carbon Capture and Storage Association, commented:

"We welcome the publication of the Committee's report on how Government should resolve the uncertainties within the EMR framework.

In particular, the Committee's analysis shows that up to 3GW of CCS should be contracted for in the first EMR delivery plan to 2019 - this would imply that all current proposed CCS projects should be built, including the two in the current CCS Competition, as well as those outside the Competition.

However, at present there is little detail about the process for the projects outside the competition and we are seriously concerned that without further clarity for these projects in the near future, the sponsoring companies will be unable to justify continued investment.

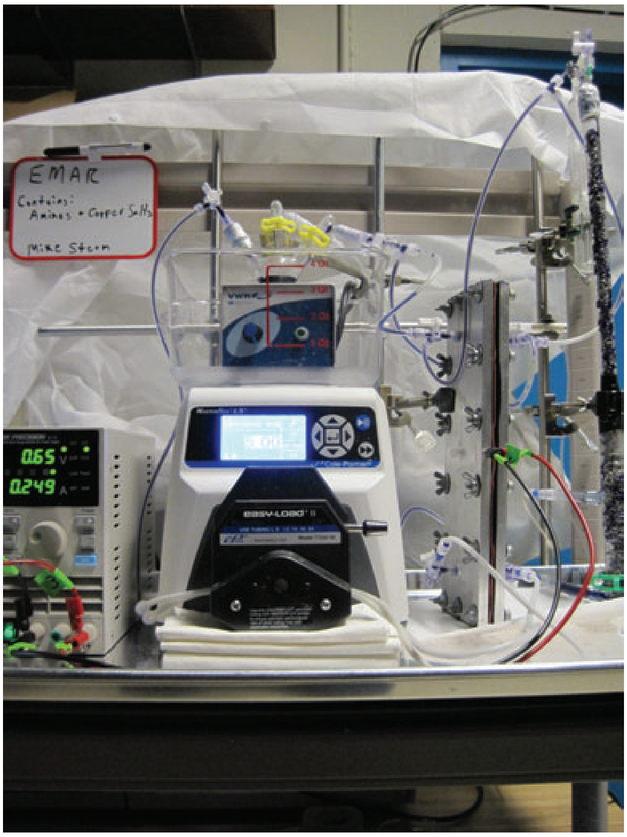
These projects must be developed in parallel to the projects in the current CCS Competition, to allow a seamless transition to the second phase of CCS projects which will create the beginnings of a CCS industry for the UK.

We therefore strongly support the recommendation in the Committee's report that Government should publish commercialisation strategies for technologies such as CCS - to give much needed confidence to investors of those projects outside the competition and beyond.

We implore Government to take on board the recommendations in this report and publish an ambitious Delivery Plan under the EMR framework - clearly setting out the objectives for CCS beyond the current competition. This should include a commitment to offer Contracts for Differences to a number of CCS projects outside the competition, to begin operating from later this decade.

# MIT tests electrochemical CO2 capture

A new proposed method using electricity to liberate CO2 captured by an amine solution could be more efficient than previous systems and easier to retrofit in existing power plants.




*Graduate student Michael Stern and his co-workers have built a laboratory-scale device to prove the principles behind the electrochemical carbon capture system. (Photo: Michael Stern)*

Researchers at MIT have come up with a scrubbing system that requires no steam connection, can operate at lower temperatures, and would essentially be a "plug-and-play" solution that could be added relatively easily to any existing power plant.

Many CO2 capture systems rely on complex plumbing to divert the steam used to drive turbines that generate power in a plant, and such systems are not always practical as retrofits to existing plants.

The new electrochemical system is described in a paper published online in the journal Energy and Environmental Science, and written by doctoral student Michael Stern, chemical engineering professor T. Alan Hatton and two others.

The system is a variation on a well-studied technology that uses amines, which bind with CO2 in the plant's emission stream and can then release the gas when heated in a separate chamber. But the conventional process requires that almost half of the power plant's low-pressure steam be diverted to provide the heat needed to force the amines to release the gas. That massive diversion would require such extensive changes to existing power plants that it is not considered economically feasible as a retrofit.

In the new system, an electrochemical process replaces the steam-based separation of amines and CO2. This system only requires electricity, so it can easily be added to an existing plant.

The system uses a solution of amines, injected at the top of an absorption column in which the effluent gases are rising from below. The amines bind with CO2 in the emissions stream and are collected in liquid form at the bottom of the column. Then, they are processed electrochemically, using a metal electrode to force the release of the CO2; the original amine molecules are then regenerated and reused.

As with the conventional thermal-amine scrubber systems, this technology should be capable of removing 90 percent of CO2 from a plant's emissions, the researchers say. But while the conventional CO2-capture process uses about 40 percent of a plant's power output, the new system would consume only about 25 percent of the power, making it more attractive.

In addition, while steam-based systems must operate continuously, the all-electric system can be dialed back during peak demand, providing greater operational flexibility, Stern says. "Our system is something you just plug in, so you can quickly turn it down when you have a high cost or high need for electricity," he says.

Another advantage is that this process produces CO2 under pressure, which is required to inject the gas into underground reservoirs for long-term disposal. Other systems require a separate compressor to pressurize the gas, creating further complexity and inefficiency.

The chemicals themselves, mostly small polyamines, are widely used and easily available industrial materials, says Hatton, the Ralph Landau Professor of Chemical Engineering Practice. Further research will examine which of several such compounds works best in the proposed system.

So far, the research team, which also includes former MIT research scientist Fritz Simeon and Howard Herzog, a senior research engineer at the MIT Energy Initiative, has done mathematical modeling and a small-scale laboratory test of the system. Next, they hope to move on to larger-scale tests to prove the system's performance. They say it could take five to 10 years for the system to be developed to the point of widespread commercialization.

David Heldebrant, a senior research scientist in materials chemistry at the Pacific Northwest National Laboratory, who was not involved in this work, says, "The electrochemical approach to CO2 capture has been previously proposed by other groups, but with varying degrees of success. What separates Hatton and his team from the field is that they have demonstrated the first comprehensive study of the thermodynamic and engineering principles that are needed to project the performance of electrochemical systems."

Heldebrant adds: "As with any process, the main questions and uncertainty pertain to the costs and lifetime of the system." But he says this research "is of the highest quality," and the team has "done a great job identifying the critical science and engineering for such a system."

Because it does not rely on steam from a boiler, this system could also be used for other applications that do not involve steam, such as cement factories, which are among the leading producers of CO2 emissions, Stern says. It could also be used to curb emissions from steel or aluminum plants.

It could also be useful in other CO2 removal, Hatton says, such as in submarines or spacecraft, where carbon dioxide can accumulate to levels that could endanger human health, and must be continually removed.

The work was supported by Siemens and by the U.S. Department of Energy through the Advanced Research Projects Agency for Energy.

**More information**
sequestration.mit.edu

# Capture and utilisation news

## Aker Solutions to perform tests of cement industry CO2 capture

www.akersolutions.com

**Aker Solutions has won a contract to test and study the capture of carbon dioxide from flue gas emitted by the cement industry.**

The award from Norcem, in cooperation with the European Cement Research Academy (ECRA) marks the first time technology to capture CO2 is used at a cement production plant

Aker Solutions will perform long-term testing on the actual flue gas to select optimum chemical solvent for high content CO2 flue gas at Norcem's plant in Brevik, Norway. Tests will be performed with Aker Solutions' in-house developed Mobile Test Unit (MTU). The MTU is a fully fledged CO2 capture plant that includes all processes and functions you will find in a large scale commercial plant.

*Aker Solutions' Mobile Test Unit will be used to test CO2 capture at Norcem's cement production plant in Norway*

The project results will provide Norcem and its parent company HeidelbergCement, valuable information for future decision-making on reduction in CO2 emissions, and help the European cement industry understand the use of technology for future full-scale CO2 capture from cement production plants.

"The cement industry is a major emitter of CO2and there is a potential to reduce emissions substantially," says Henning Østvig, Head of Front End & Technology in Aker Solutions.

The project is supported and partly financed by the CLIMIT programme, which is managed by Gassnova in cooperation with the Research Council of Norway

## Skyonic secures $128M for CCS plant

www.skyonic.com

**The $128 million will be used to support the construction of the world's first commercial-scale carbon capture and mineralization plant, located in Texas.**

The company will break ground this summer at Capitol Aggregates Cement in San Antonio, Texas, where the Capitol SkyMine carbon capture plant will be retrofitted.

The new funding includes equity investments from new investors Cenovus Energy, BlueCap Partners, Toyo-Thai Corporation Public Company Limited, and Energy Technology Ventures.

"The Capitol SkyMine plant will mark the first time that carbon-negative chemistry has reached the commercial stage," said Joe Jones, founder and CEO of Skyonic. "[...]The carbon-negative products produced, which include sodium bicarbonate and hydrochloric acid, will displace the carbon-positive products currently sold. This is a crucial step towards a cleaner global manufacturing industry."

The retrofit plant is expected to directly capture 83,000 tons of CO2 from Capitol Aggregates' emissions annually. By using this captured CO2 to make products that would otherwise generate additional CO2, the plant will also offset an additional 220,000 tons, the company said.

The plant is expected to make a profit from the sale of these products within three years.

## Recycling carbon dioxide to make plastics

energy.gov/fe

**The world's first successful large-scale production of a polypropylene carbonate (PPC) polymer using waste carbon dioxide as a key raw material has resulted from a projected funded in part by the U.S. Department of Energy's Office of Fossil Energy.**

The PPC polymer production run, conducted by Novomer in collaboration with specialty chemical manufacturer Albemarle Corporation (Orangeburg, SC), tested scale-up of Novomer's novel catalyst technology. Requiring only minor modifications to existing Albemarle facilities, the run produced seven tons of finished polymer, which will be used to accelerate product qualification.

The Novomer process uses a catalyst-a material that speeds up the rate of a reaction but is not consumed-to create PPC polymers through the co-polymerization of CO2 and chemicals called epoxides. The process results in polymers containing more than 40 percent CO2 by weight. The CO2-containing polymers can be tailored for applications with a broad range of material characteristics from solid plastics to soft, flexible foams, depending on the size of the polymer chain.

Novomer is positioning its new polymer technology to compete with conventional petroleum-based raw materials across a diverse range of applications, including flexible, rigid, and microcellular packaging foams, thermoplastics, polyurethane adhesives and sealants, and coating resins for food and beverage cans.

Conventional production of plastics such as polyethylene and polypropylene is heavily dependent on fossil fuels. The Novomer process reduces the use of these fuels by replacing up to half of the mass of the petroleum-based product with CO2. Capital requirements and operational costs to produce the new polymers closely mirror conventional production costs, and the products demonstrate increased strength and environmental resistance relative to existing polymers.

# USGS assessment of U.S. storage capacity

The U.S. Geological Survey (USGS) has concluded that the United States has the potential to store a mean of 3,000 metric gigatons of carbon dioxide in geologic basins.

Based on present-day geologic and hydrologic knowledge of the subsurface and current engineering practices, the assessment looked at the potential for CO2 storage in 36 basins in the United States. The largest potential by far is in the Coastal Plains region, which accounts for 2,000 metric gigatons, or 65 percent, of the storage potential. Two other regions with significant storage capacity include the Alaska region and the Rocky Mountains and Northern Great Plains region.

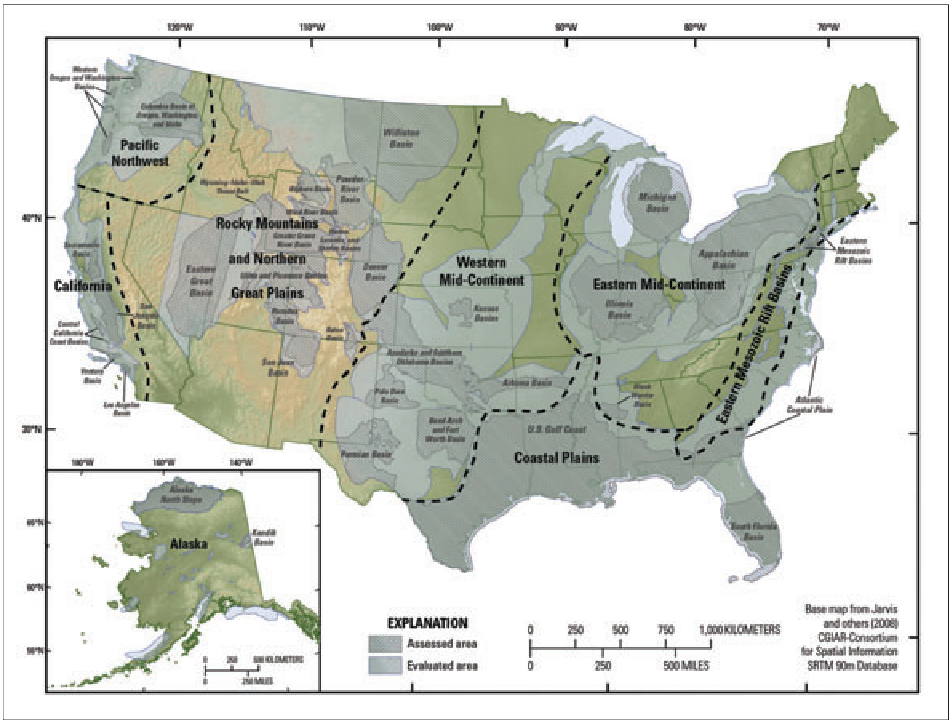
Technically accessible storage resources are those that can be accessed using today's technology and pressurization and injection techniques. The most common method of geologic carbon storage involves pressurizing CO2 gas into a liquid, and then injecting it into subsurface rock layers for long-term storage.

"This USGS research is ground-breaking because it is the first realistic view of technically accessible carbon storage capacity in these basins," said Secretary of the Interior Sally Jewell. "If enough of this capacity also proves to be environmentally and economically viable, then geologic carbon sequestration could help us reduce carbon dioxide emissions that contribute to climate change."

This assessment goes further than all previous assessments in considering the viability of sequestration, said the USGS. For example, all areas with groundwater sources that are considered freshwater by U.S. Environmental Protection Agency (EPA) standards were eliminated from consideration for carbon storage resource potential in this assessment. In addition, the rock layers included in the assessment were limited to those determined to have sufficient natural seals to prevent CO2 from escaping. This assessment also focused only on rock layers located at depths at which CO2 would stay under sufficient pressure to remain liquid.

The study did not evaluate economic viability or accessibility due to land-management or regulatory restrictions for geologic carbon sequestration within these basins.

The assessment is also the first geologically based and probabilistic assessment, estimating a range of 2,400 to 3,700 metric gigatons of CO2 storage potential across the United States. For comparison, the U.S. Energy Information Administration (EIA) estimates that in 2011, the United States emitted 5.5 metric gigatons of energy-related CO2, while the global emissions of energy-related CO2 totalled 31.6 metric gigatons. Metric gigatons are a billion metric tons.




*Map of the conterminous United States and Alaska showing 8 regions (separated by bold dashed lines), evaluated areas (bluish gray) that were not assessed, and 36 areas (pattern) that were assessed by the U.S. Geological Survey for carbon dioxide storage. Resources in federally owned offshore areas were not assessed, and Hawaii was considered unlikely to have significant storage resources. Regions and study areas are plotted over a shaded-relief image showing higher elevations in brown and tan and lower elevations in green. (©USGS)*

All sedimentary basins in the United States were evaluated, but 36 were assessed because existing geologic conditions or the available data suggested only these 36 met the assessment's minimum criteria.

The geologic foundation that underpins the assessment was facilitated by data provided by the U.S. EPA, the U.S. Department of Energy, and State geological surveys. The methodology for the assessment was developed by the USGS and consistently applied across all 36 basins, so that results are comparable.

Two general storage types, buoyant and residual, were defined in the methodology. Buoyantly trapped CO2 can be held in place in porous formations by top and lateral seals. Residually trapped CO2 can be held in porous formations as individual droplets within pores by capillary forces.

The USGS team obtained a mean estimate of 44 Gt for storage in buoyant traps. The 44 Gt (mean estimate) of buoyant trapping storage resources includes non-hydrocarbon-bearing reservoir formations, but most of the resources are well defined by hydrocarbon exploration data.

Existing oil in hydrocarbon reservoirs may be produced in the near future by using enhanced-oil-recovery technology that utilizes anthropogenic CO2, and then the reservoirs could be used for CO2 storage. Because of the depth of knowledge about the hydrocarbon reservoirs, buoyant trapping storage resources in these reservoirs may be more attractive for storage of CO2 than residual trapping storage resources, concluded the study.

### More information

energy.usgs.gov
twitter.com/USGS

# Transport and storage news

## Institute supports $CO_2$ storage mapping program in Asia

www.globalccsinstitute.com

**The Global CCS Institute has formalised a sponsorship agreement with the Coordinating Committee for Geoscience Programmes in Asia and South-East Asia (CCOP) to provide initial funding of its $CO_2$ Storage Mapping Program (CCS-M) in CCOP member countries.**

In March, the Institute took part in a CCOP meeting in Ubon Ratchathani, Thailand, agreeing to support preparation work for a $CO_2$ Storage Atlas of the best available estimates of potential $CO_2$ storage capacity.

The CCS-M is designed to support existing $CO_2$ geological storage research activities as well as initiate implementation of geological storage mapping in other member countries. The training courses and seminars planned for the initial phase will help build members' knowledge in CCS, particularly the methodologies and standards for site selection, characterisation and storage capacity estimation, as well as the various applied CCS technologies.

CCS-M will provide a forum for knowledge sharing among member countries. A guideline for national $CO_2$storage mapping, one of the expected outcomes of CCS-M, will be a useful and easy-to-use reference for all member countries for their own national storage mapping.

## National Geosequestration Laboratory takes shape in Australia

www.ngl.org.au

**Almost eight months since its funding was announced, the National Geosequestration Laboratory (NGL) has made significant steps towards establishing itself as one of the world's leading R&D providers in the field of carbon storage.**

Major equipment upgrades and laboratory enhancements to the Australian Resources Research Centre (ARRC) and construction of a new world-class $CO_2$ research facility at The University of Western Australia will shortly commence, adding to the recent installation of a state-of-the-art micro CT scanner at Curtin University. Both education powerhouses are NGL partners, along with CSIRO, and the new facilities will complement the extensive research expertise offered by the three organisations.

The progress comes amidst a report released by the International Energy Agency (IEA) this week which emphasised the increasing difficulty of limiting a global temperature increase to 2ºC, and the important role to be played by carbon capture and storage (CCS).

"CCS is part of a portfolio of solutions that will help Australia and the world to achieve large cuts in emissions, while continuing to satisfy our growing energy needs," said Dr Linda Stalker, NGL Science Director.

"There is no single solution, but CCS has the potential to significantly reduce greenhouse gas emissions by removing large quantities of $CO_2$ that would normally be released into the atmosphere, and instead storing it safely deep underground.

"It is a technology that can be safe and effective for our climate, health and environment. However, as pointed out by the IEA in its report this week (Redrawing the Energy-Climate Map), a significant increase in CCS capacity is required if it is to have a meaningful impact on global emissions."

The NGL is already providing initial scientific research behind the South West $CO_2$ Geosequestration Hub project, which is funded through the Federal Government's Clean Energy Initiative, and examining the potential for large-scale carbon capture and storage in the south-west of Western Australia.

The study area has the potential to store up to 240 million tonnes of carbon dioxide in the Lesueur rock formation, and the NGL is working closely with the Western Australian Government to determine the feasibility of the site.

"Assessing the suitability of the area has been very much a stage-gated process, where each individual requirement must be met before proceeding to the next stage," Dr Stalker said.

"The area is undergoing a rigorous assessment and so far the signs have been positive, but it's still early days in the overall process."

The NGL is being established through $48.4 million in funding from the Federal Government's Education Investment Fund, and builds on the successes of the Western Australian Energy Research Alliance.

## UK awards funding for North Sea $CO_2$ storage research

www.epsrc.ac.uk

**£3.27 million has been awarded by the Engineering and Physical Sciences Research Council (EPSRC) to four research projects to study the geological viability and safety of storing $CO_2$ underground in depleted North Sea oil and gas fields or saline aquifers**

The EPSRC funding - £37 million, is part of the Government's £125 million Research and Development programme into Carbon Capture and Storage.

All the projects will come under the umbrella of the UK CCS Research Centre, established in April 2012, to improve coordination and visibility of approximately 150 UK academics working on CCS.

The Engineering and Physical Sciences Research Council (EPSRC) awarded funding to the following projects:

1. $CO_2$ Injection and storage short and long-term behaviour at different spatial scales - £1.2 million awarded to Imperial College London in collaboration with Heriot-Watt University, Cardiff University, the University of Leeds and the British Geological Survey. Partner organisations: Progressive Energy Limited and the Energy Technologies Institute.

Drawing upon their experience in $CO_2$ storage performance assessment research at industrial field pilots such as In Salah, Snøhvit and Sleipner, the research team, led by Professor Sevket Durucan and Dr Anna Korre from Imperial College London, aim to address some of the current knowledge gaps in this technology.

The project will develop optimisation tools for $CO_2$ injection well placement and control strategies for plume behaviour. The research outcomes will support the design of industrial scale storage operations and maximise storage capacity utilisation, while accounting for uncertainties at licence and basin scales.

Through laboratory experimental and numerical modelling work, the project will investigate the effects of temperature and pressure on fracture and fault behaviour within the storage reservoir and the caprock seal. Research will improve the understanding of the effects of reservoir processes on structural integrity and containment of the stored $CO_2$.

2. Fingerprinting captured $CO_2$ and proving ownership. £236,178 awarded to the University of Edinburgh in collaboration with the Scottish Universities Environment Research Centre (SUERC).

This study, led by Dr Stuart Gilfillan from the University of Edinburgh, aims to determine if the natural tracer (noble gases and carbon and oxygen Isotopes) fingerprint inherent in captured $CO_2$ is sufficient to track its fate in the subsurface, distinguish ownership and to provide an early warning of unplanned migration out of the storage formation.

To do this the researchers will determine the fingerprint of CO2 captured from several of the UK capture demonstration projects, and at the Boundary Dam Power Plant prior to its injection into the Aquistore saline aquifer storage site in Saskatechwan, Canada. By comparing this to the fingerprint of the CO2 produced from the Aquistore monitoring well, some 100m from the injection well, they will be able to see if the fingerprint is retained after the CO2 has moved through the saline aquifer.

This will show if this technique can be used to track the movement of CO2 in future engineered storage sites, particularly offshore saline aquifers which will be used for future UK large volume CO2 storage.

3. Diagnostic seismic toolbox for the efficient control of CO2 storage. £893,883 awarded to the British Geological Survey, with the University of Leeds, University of Manchester, University of Edinburgh and the National Oceanography Centre.

Led by Dr Andy Chadwick of the British Geological Survey, the research team are developing sophisticated, non-invasive methods to monitor underground carbon storage sites. They will use a range of techniques including 3D time-lapse seismic surveys and "passive' listening devices such as very sensitive geophones, and satellite measurements of ground movements induced by CO2 injection.

These tools will provide information on CO2 movement and changes of pressure in the storage reservoir to show how the rocks and geology respond to large amounts of CO2 being injected and stored over decades.

These techniques are cheaper and safer than monitoring methods which use observation wells. Drilling into sites could cause leaks or damage to the important caprock which seals in the CO2.

For the first time, data and statistics from existing CO2 storage sites at Sleipner and Snøhvit in offshore Norway, and In Salah in the Algerian desert will be integrated to improve analysis techniques storage site monitoring. Public reaction to CCS storage will also be explored.

4. How reservoir rocks and caprocks respond to hydrocarbon depletion and subsequent CO2 injection. £925,473 awarded to the British Geological Survey, Imperial College London, and Cardiff University. Industry Partners: Shell Global Solutions International BV.

The research team will focus on how the caprock and "reservoir' rocks respond to oil and gas extraction and later "re-inflation' as CO2 is injected. They will measure changes in stress, volume and permeability in the laboratory.

Geoscientists will use this data to inform computational models looking at how different rock formations respond during injection and over long periods of storage. These simulations will help forecast the geomechanical processes in CO2 storage sites overextended periods of time (up to 10,000 years).

The project, led by Dr Jon Harrington from the British Geological Survey, will apply these results to existing storage sites, for example the Goldeneye field in the North Sea, where hydrocarbon extraction has previously taken place.

## Livermore develops deep imaging system for CO2 storage

www.llnl.gov

**Lawrence Livermore National Laboratory (LLNL) researchers have broken the record for tracking the movement and concentration of carbon dioxide in a geologic formation using the world''s deepest Electrical Resistance Tomography (ERT) system.**

The team led by LLNL's Charles Carrigan obtained time lapse electrical resistivity images during the injection of more than 1 million tons of carbon dioxide (CO2) more than 10,000 feet deep in an oil and gas field in Cranfield, Miss., which represents the deepest application of the imaging technique to date. The previous depth record of about 2,100 feet was held by the CO2SINK Project Consortium in Ketzin, Germany.

"The images provide information about both the movement of the injected CO2 within a complex geologic formation and the change with time of the distribution of CO2 in the porous sandstone reservoir," Carrigan said.

Deep geologic sequestration of CO2 is being evaluated internationally to mitigate the impact of greenhouse gases produced during oil- and coal-based energy generation and manufacturing. Natural gas producing fields are particularly appealing sites for sequestration activities because the same geologic barrier or cap rock permitting the subsurface regime to act as a long term natural gas reservoir also can serve to permanently contain the injected CO2.

ERT allowed Xianjin Yang, another member of the LLNL team, to make a movie of the expanding CO2 plume as it fills the sandstone region between the two electrode wells. To do this required analyzing months of data and using only the highest quality results to produce the images.

The team reports on the design, placement and imaging from the world's deepest ERT system in the June 1 online issue of the International Journal of Greenhouse Gas Control. The research also will appear in an upcoming print copy of the journal.

ERT can potentially track the movement and concentration of the injected CO2 as well as the degree of geologic containment using time-lapse electrical resistivity changes resulting from injecting the fluid into the reservoir formation.

Installing each ERT array in the sequestration reservoir required designing all cabling and electrodes, which were externally mounted on the borehole casing, to survive the trip more than 10,000 feet down a crooked borehole with walls made jagged by broken rocks.

The team then used the ERT array in a challenging environment of high temperature (260 degrees Fahrenheit), high pressure (5,000 psi) and high corrosive fluids to effectively detect CO2 breakthroughs and CO2 saturation changes with time.

"This is a near-real time remote monitoring tool for tracking CO2 migration with time lapse tomographic images of CO2 concentration," Carrigan said.

When converted to CO2 concentration, the images provided information about the movement of the injected CO2 within a complex geologic formation as well as how the storage of the CO2 changed with time.

Carrigan said that given concerns about injection-induced fracturing of the cap rock seal causing leakage of CO2 from the reservoir, higher-resolution ERT also may have an application as an "early-warning" system for the formation of fracture pathways in cap rock that could result in environmental damage to overlying or nearby water resources. Another potential application involves monitoring the boundary of a sequestration lease to ensure that CO2 does not migrate across the boundary to an adjacent parcel.

The ERT team includes Carrigan and Yang as well as Abe Ramirez, Roger Aines, Julio Friedmann and Neil Felgenhauer of LLNL; Robin Newmark of National Renewable Energy Laboratory; Doug LaBrecque and Bill Daily of Multi-Phase Technologies; and Dennis Larsen of Promore.

The ERT project is part the U.S. Department of Energy sponsored Southeast Regional Carbon Sequestration Partnership (SECARB) Cranfield project near Natchez, Miss., which has become the fifth ERT system worldwide and the first in the United States to inject more than a million tons of CO2 into the sub-surface.

The Cranfield study, which was led by Susan Hovorka of the Bureau of Economic Geology at the University of Texas, was funded by Department of Energy, National Energy Technology Laboratory under contract to the Southern States Energy Board.

# Status of CCS projects

## The status of large-scale integrated projects data courtesy of the Global CCS Institute

For the full list, with the latest data as it becomes available, please download a spreadsheet at:
www.globalccsinstitute.com/data/status-ccs-project-database

| Asset Lifecycle Stage | Project Name | Description |
|---|---|---|
| Operate | **Century Plant** | Occidental Petroleum, in partnership with Sandridge Energy, is operating a gas processing plant in West Texas that at present can capture 5 Mtpa of carbon dioxide for use in enhanced oil recovery. Capture capacity will be increased to 8.5 Mtpa in 2012. |
| Operate | **Enid Fertilizer CO2-EOR Project** | Since 1982, the Enid Fertilizer plant has sent around 680,000 tonnes per annum of carbon dioxide to be used in enhanced oil recovery operations in Oklahoma. |
| Operate | **Great Plains Synfuel Plant and Weyburn-Midale Project** | About 3 Mtpa of carbon dioxide is captured from the Great Plains Synfuel plant in North Dakota. Since 2000 the carbon dioxide has been transported by pipeline into Canada for enhanced oil recovery in the Weyburn Field, and since 2005 in Midale Field. |
| Operate | **In Salah CO2 Storage** | In Salah is a fully operational CCS project in Algeria. Since 2004, around 1 million tonnes per annum of carbon dioxide are separated from produced gas, transported by pipeline and injected for storage in a deep saline formation. |
| Operate | **Shute Creek Gas Processing Facility** | Around 7 million tonnes per annum of carbon dioxide are recovered from ExxonMobil's Shute Creek gas processing plant in Wyoming, and transported by pipeline to various oil fields for enhanced oil recovery. This project has been operational since 1986. |
| Operate | **Sleipner CO2 Injection** | Sleipner is the second largest gas development in the North Sea. Carbon dioxide is separated from produced gas at Sleipner T and reinjected into a deep saline formation above the hydrocarbon reservoir zone. This project has been in operation since 1996. |
| Operate | **Snøhvit CO2 Injection** | The Snøhvit offshore gas field and related CCS activities have been in operation since 2007. Carbon dioxide separated from the gas produced at an onshore liquid natural gas plant is reinjected into a deep saline formation below the reservoir zones. |
| Operate | **Val Verde Natural Gas Plants** | This operating enhanced oil recovery project uses carbon dioxide sourced from the Mitchell, Gray Ranch, Puckett, Pikes Peak and Terrell gas processing plants and transported via the Val Verde and CRC pipelines. |
| Execute | **Air Products Steam Methane Reformer EOR Project** | This project in construction will capture more than 1 million tonnes per year of carbon dioxide from two steam methane reformers to be transported via Denbury's Midwest pipeline to the Hastings and Oyster Bayou oil fields for enhanced oil recovery. |
| Execute | **Alberta Carbon Trunk Line ("ACTL") with Agrium CO2 Stream** | Agrium's fertiliser plant in Alberta is currently being retrofitted with a carbon dioxide capture unit. Around 585,000 tonnes per annum of carbon dioxide will be captured and transported via the Alberta Carbon Trunk Line (ACTL) for enhanced oil recovery. |
| Execute | **Alberta Carbon Trunk Line ("ACTL") with North West Sturgeon Refinery CO2 Stream** | Up to 1.2 million tonnes per annum of carbon dioxide will be captured at this new heavy oil upgrader in Alberta. In partnership with Enhance Energy, the carbon dioxide will be transported via the Alberta Carbon Trunk Line (ACTL) for enhanced oil recovery. |
| Execute | **Boundary Dam Integrated Carbon Capture and Sequestration Demonstration Project** | SaskPower is currently retrofitting a coal-based power generator with carbon capture technology near Estevan, Saskatchewan. When fully operational in 2014, this project will capture around 1 million tonnes per annum of carbon dioxide. |
| Execute | **Gorgon Carbon Dioxide Injection Project** | This component of a larger gas production and LNG processing project will inject 3.4 to 4.1 million tonnes of carbon dioxide per annum into a deep geologic formation. Construction is under way after a final investment decision was made in September 2009. |
| Execute | **Illinois Industrial Carbon Capture and Storage Project** | The project will capture around 1 million tonnes per annum of carbon dioxide from ethanol production. Carbon dioxide will be stored approximately 2.1 km underground in the Mount Simon Sandstone, a deep saline formation. |
| Execute | **Kemper County IGCC Project** | Mississippi Power (Southern Company) is constructing an air-blown 582 Mwe IGCC plant using a coal-based transport gasifier. Up to 3.5 million tonnes per annum of carbon dioxide will be captured at the plant and used for enhanced oil recovery. |
| Execute | **Lost Cabin Gas Plant** | This project will retrofit the Lost Cabin natural gas processing plant in Wyoming with CCS facilities, capturing around 1 million tonnes per annum of carbon dioxide to be used for enhanced oil recovery. |
| Execute | **Quest** | Quest will capture up to 1.2 million tonnes of carbon dioxide per annum from the Scotford upgrader, and transport it by pipeline for injection into a deep saline formation. |
| Define | **Belchatów CCS** | PGE EBSA intends to integrate a carbon capture plant into a new built 858 MW unit at the Bełchatów Power Plant, capturing around 1.8 million tonnes per annum of carbon dioxide. |
| Define | **Coffeyville Gasification Plant** | CVR Energy is developing a new compression facility at its fertiliser plant in Kansas. The plant currently produces approximately 850,000 tonnes of carbon dioxide which will be transported to the mid-continental region for use in enhanced oil recovery. |

| State / District | Country | Volume $CO_2$ | Operation Date | Facility Details | Capture Type | Transport Length | Transport Type | Storage Type | Project URL |
|---|---|---|---|---|---|---|---|---|---|
| Texas | UNITED STATES | 8.4 Mtpa | 2010 | Natural Gas Processing | Pre-Combustion (Gas Processing) | 256 km | Onshore to onshore pipeline | Enhanced Oil Recovery | www.oxy.com/ |
| Oklahoma | UNITED STATES | 0.68 Mtpa | 1982 | Fertiliser Production | Pre-Combustion | 225 km | Onshore to onshore pipeline | Enhanced Oil Recovery | www.kochfertilizer.com/ |
| Saskatchewan | CANADA | 3 Mtpa | 2000 | Synthetic Natural Gas | Pre-Combustion | 315 km | Onshore to onshore pipeline | Enhanced Oil Recovery | www.cenovus.com/ |
| Wilaya de Ouargla | ALGERIA | 1 Mtpa | 2004 | Natural Gas Processing | Pre-Combustion (Gas Processing) | 14 km | Onshore to onshore pipeline | Onshore Deep Saline Formations | www.insalahco2.com/ |
| Wyoming | UNITED STATES | 7 Mtpa | 1986 | Natural Gas Processing | Pre-Combustion (Gas Processing) | 190 km | Onshore to onshore pipeline | Enhanced Oil Recovery | www.exxonmobil.com |
| North Sea | NORWAY | 1 Mtpa | 1996 | Natural Gas Processing | Pre-Combustion (Gas Processing) | 0 km | Direct injection | Offshore Deep Saline Formations | www.statoil.com/en/ |
| Barents Sea | NORWAY | 0.7 Mtpa | 2008 | Natural Gas Processing | Pre-Combustion (Gas Processing) | 152 km | Onshore to offshore pipeline | Offshore Deep Saline Formations | www.statoil.com/en/ |
| Texas | UNITED STATES | 1.3 Mtpa | 1972 | Natural Gas Processing | Pre-Combustion (Gas Processing) | 132 km | Onshore to onshore pipeline | Enhanced Oil Recovery | www.exxonmobil.com/ |
| Texas | UNITED STATES | 1 Mtpa | 2013 | Hydrogen Production | Post-Combustion | 101 – 150 km | Onshore to onshore pipeline | Enhanced Oil Recovery | www.airproducts.com/ |
| Alberta | CANADA | Up to 0.59 Mtpa (initially 0.29 | 2014 | Fertiliser Production | Pre-Combustion | 240 km | Onshore to onshore pipeline | Enhanced Oil Recovery | www.agrium.com/ |
| Alberta | CANADA | 1.2 Mtpa | 2015 | Oil Refining | Pre-Combustion | 240 km | Onshore to onshore pipeline | Enhanced Oil Recovery | www.northwestupgrading.com/ |
| Saskatchewan | CANADA | 1 Mtpa | 2014 | Power Generation | Post-Combustion | 100 km | Onshore to onshore pipeline | Enhanced Oil Recovery | www.saskpower.com/ |
| Western Australia | AUSTRALIA | 3.4 - 4.1Mtpa | 2015 | Natural Gas Processing | Pre-Combustion (Gas Processing) | 7 km | Onshore to onshore pipeline | Onshore Deep Saline Formations | www.chevronaustralia.com |
| Illinois | UNITED STATES | 1 Mtpa | 2013 | Chemical Production | Industrial Separation | 1.6 km | Onshore to onshore pipeline | Onshore Deep Saline Formations | www.adm.com/ |
| Mississippi | UNITED STATES | 3.5 Mtpa | 2014 | Power Generation | Pre-Combustion | 75 km | Onshore to onshore pipeline | Enhanced Oil Recovery | www.mississippipower.com/ |
| Wyoming | UNITED STATES | 1 Mtpa | 2013 | Natural Gas Processing | Pre-Combustion (Gas Processing) | Not specified | Onshore to onshore pipeline | Enhanced Oil Recovery | www.conocophillips.com/ |
| Alberta | CANADA | 1.08 Mtpa | 2015 | Hydrogen Production | Pre-Combustion | 84 km | Onshore to onshore pipeline | Onshore Deep Saline Formations | www.shell.ca/ |
| Łódź | POLAND | 1.6 - 1.8 Mtpa | 2017 | Power Generation | Post-Combustion | 101 – 150 km | Onshore to onshore pipeline | Onshore Deep Saline Formations | www.bot.pl/ |
| Kansas | UNITED STATES | 0.85 Mtpa | 2013 | Fertiliser Production | Pre-Combustion | 112 km | Onshore to onshore pipeline | Enhanced Oil Recovery | www.cvrenergy.com/ |