

# carbon capture journal

Jan / Feb 2012

Issue 25

Review of 2011

2012 - a crucial year for  
UK leadership in CCS

CCS in the CDM -  
outcome at Durban

Ionic liquids for CO<sub>2</sub>  
capture



CEFCO's lower energy penalty CO<sub>2</sub> capture system  
CO<sub>2</sub> hydrate as a possibility for CO<sub>2</sub> storage

# Safe CO<sub>2</sub> Geologic Storage ...anywhere in the world

- *Applied risk mitigation and performance assessment -- protocols*
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- *Public Trust – community engagement and education*
- *Asset evaluation -- storage capacity evaluation and design*

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## Carbon Capture Journal

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Front cover: Lower energy penalty CO<sub>2</sub> capture: the CEFCO 1 to 3 MW thermal equivalent pilot plant at Peerless Manufacturing Company's premises in Wichita Falls, Texas



## Leaders

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The year followed a similar pattern to 2010, with positive announcements of funding agreed or construction beginning at some major projects tempered by news of project cancellations elsewhere, and ended on a tentative high point with CCS formerly included in the UN Clean Development Mechanism

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2011 has seen its fair share of CCS related legislative activity and the amount of legislation, regulation and policy that must be considered by CCS developers continues to rise. This edition's column looks at some of this and highlights a few of the issues which continue to vex and perplex as we enter 2012

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The Global CCS Institute has published five CCS project reports, across a range of disciplines, from assisted projects across the globe

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### CIUDEN completes initial oxycombustion testing phase

The Fundación Ciudad de la Energía (CIUDEN) has successfully completed the initial testing phase of oxycombustion in its 30 MWth Circulating Fluidized Bed boiler, burning coal using oxygen instead of air

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CEFCO (Clean Energy and Fuel Company) has developed a process with a total energy penalty of less than 15% for capture of CO<sub>2</sub> and other pollutants including NO<sub>x</sub> and SO<sub>2</sub> from coal fired boilers. It also has a lower capital cost and a smaller footprint than some other comparable technologies. By Robert E. Tang, President, CEFCO Global Clean Energy and Dr. Anupam Sanyal

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# Carbon Capture Journal review of 2011

The year followed a similar pattern to 2010, with positive announcements of funding agreed or construction beginning at some major projects tempered by news of project cancellations elsewhere, and ended on a tentative high point with CCS formerly included in the UN Clean Development Mechanism.

## January

**Australian Government reduces and delays CCS funding** - the Australian PM announced spending cuts and deferrals of AUS\$250 million to its Flagship CCS program and the Global CCS Institute to help pay for Queensland flood relief.

## February

**Twenty two carbon capture projects bid for EU NER300 funds** - these include 6 pre-6 post- and 4 oxyfuel combustion projects, including 9 from the UK.

**Maersk Oil - plan to make CCS pay for itself** - Maersk Oil believes that it can significantly reduce the costs of carbon capture and storage by burning gas directly from an oil-field in oxygen, generating electricity, using the resulting CO<sub>2</sub> immediately for enhanced oil recovery, and possibly selling the resulting water if it is in a region of water shortage.

## March

**Plant Radcliffe construction begins** - construction began at Southern Company's IGCC project in the U.S., which is set to be the world's first large-scale CCS project in the power sector.

**Enel opens CCS pilot in Brindisi** - Enel inaugurated the first pilot plant in Italy for capturing and storing carbon dioxide at its Federico II power plant in Brindisi.

**Denbury signs contracts to purchase CO<sub>2</sub> from US projects** - oil and natural gas firm Denbury Resources entered into two contracts to purchase carbon dioxide from future anthropogenic sources in the Gulf Coast and Rocky Mountain regions of the US.

**UK carbon price floor** - the U.K. government set a price floor for tradable carbon emissions credits in a move designed to increase spending in low-carbon electricity by providing certainty for the companies investing the billions required in new power projects.

**IEA paper on CO<sub>2</sub> capture performance** - the IEA released a working paper on "Cost and Performance of Carbon Dioxide Capture from Power Generation".

## April

**Saskatchewan approves Boundary Dam**

**project** - the government of Saskatchewan approved construction of the Boundary Dam Integrated Carbon Capture and Storage Demonstration Project, which is among the first commercial-scale carbon capture and storage facilities in the world.

**Alcoa launches carbon capture and reuse pilot** - Alcoa announced a new pilot program, in collaboration with CO<sub>2</sub> Solution and Codexis, focused on carbon capture technology designed to create a commercially viable product.

**Clean Energy Ministerial agrees steps to speed up CCS deployment** - Energy Ministers from around the world agreed to proposals to help speed up the global deployment of carbon capture and storage.

**IEA releases first Clean Energy Progress Report** - the International Energy Agency released its first Clean Energy Progress Report, which assesses global deployment of clean energy technologies and provides recommendations to countries on future action and spending.

## May

**Alstom announces Mountaineer project results** - Alstom Power announced the successful operation of a chilled-ammonia CCS validation project at American Electric Power's Mountaineer Plant in New Haven, West Virginia

**Air Products' CO<sub>2</sub> capture technology goes online at Schwarze Pumpe** - Air Products' proprietary carbon dioxide capture, purification and compression system at Vattenfall AB's research and development facility in Schwarze Pumpe, Germany went on-stream.

**Vattenfall opens a new carbon dioxide capture plant** - the CO<sub>2</sub> capture pilot power plant Willem-Alexander in Buggenum, the Netherlands, was officially opened.

**CIUDEN lights first fire in coal boiler and launches PISCO<sub>2</sub> pilot project for CO<sub>2</sub> biomonitoring tools** - the Fundación Ciudad de la Energía (CIUDEN) started up its coal boiler at the Technology Development Centre in Spain, and launched a new project to develop biomonitoring strategies of potential CO<sub>2</sub> leakages through testing biogeochemical effects of CO<sub>2</sub> injection in soils.



*A portion of Air Products' carbon dioxide purification unit at Vattenfall's Schwarze Pumpe pilot in Germany. (Image courtesy of Air Products and Chemicals, Inc.)*

## June

**Alstom Power study says 'CCS is cost effective'** - unveiling the results of a detailed study, based on Alstom's 13 pilot and demonstration projects and validated by independent experts, Alstom Power President, Philippe Joubert, said at a PowerGen Europe conference in Milan last week that, "We can now be confident that carbon capture technology works and is cost effective".

**Mitsubishi begins CO<sub>2</sub> capture at plant Barry** - Mitsubishi Heavy Industries Ltd. (MHI) launched operations at a 25 megawatt coal-fired carbon capture facility at Southern Company's Plant Barry, owned and operated by Alabama Power.

**Six in ten Europeans wants CCS in new coal power plants** - the European Commission published a Eurobarometer report about public awareness of CCS in 12 EU member states. Public knowledge is still generally low, but a higher proportion thought that CCS is effective to combat climate change, than those who did not. Also, 60 % said that CCS should be compulsory in new coal power plant.

## July

**Funding agreed for Shell Quest Project** - Shell signed agreements with the Governments of Alberta and Canada to secure \$865 million in funding for its Quest Carbon Capture and Storage Project in Canada.

**AEP cancels CCS demo plans at Mountaineer plant** - American Electric Power terminated its cooperative agreement with the U.S. Department of Energy and placing its CCS plans on hold, citing the current uncertain status of U.S. climate policy and the continued weak economy as contributors to the decision.

**Texas Clean Energy project to sell CO2 to Whiting Petroleum Corporation** - Summit Power Group and Blue Strategies announced the signing of a sales agreement with Whiting Petroleum Corporation for CO2 that will be captured by Summit's Texas Clean Energy Project.

## August

**Illinois CCS demonstration begins construction** - construction activities began at Archer Daniel Midland's ethanol plant in Decatur, Illinois, that will supply CO2 for injection into a saline reservoir in the Illinois basin.

## September

**Health fears over CO2 storage are unfounded, study shows** - capturing CO2 from power stations and storing it deep underground carries no significant threat to human health, despite recently voiced fears that it might, an Edinburgh University study showed.

## October

**UK Longannet project scrapped** - Iberdrola said it will use the CCS technology developed at its Longannet power station on similar projects in Mexico after the UK Government withdrew funding for the Scottish scheme.

## November

**Global CCS Institute - CCS 'competitive' in reducing power sector emissions** - the Institute has released a report suggesting that CCS is a competitive power sector emissions abatement tool when compared to other low-carbon technologies.

**U.S. approves \$2B funding bill** - the U.S. Senate approved a fiscal 2012 spending bill that allots \$2 billion for carbon capture and storage projects.

**DNV issues first certificate of fitness for CO2 storage** - DNV has awarded the world's first certificate of fitness for safe CO2 storage to Shell's Quest Carbon Capture and Storage project in Canada.

**Statoil selects technology suppliers for**

**Mongstad** - Gassnova and Statoil have chosen suppliers of CO2 capture technology to participate in a technology qualification program for full-scale CO2 capture at Mongstad. **SSE and Shell agree to work on Peterhead project** - a new joint development agreement was signed between Scottish and Southern Energy (SSE) and Shell UK for the development of a CCS project at SSE's gas-fired power station in Peterhead, Scotland.

## December

**CCS included in UN-backed Clean Development Mechanism** - CCS has been included in the Clean Development Mechanism (CDM) carbon offsetting scheme.

**Ferrybridge power station carbon capture plant opens** - the UK's largest carbon cap-

ture pilot plant has opened at SSE's Ferrybridge Power Station in West Yorkshire.

**CCS awareness higher in Saskatchewan than Europe** - a survey by IPAC-CO2 suggests that public awareness and acceptance of CCS as a tool to combat climate change is higher in Saskatchewan than Europe.

**Vattenfall abandons Jaenschwalde project** - the project in Germany was cancelled because of local opposition over fears that leaks could be uncontrollable and that the CO2 could impair the quality of drinking water.

**Otway project findings support geological CO2 storage** - the CO2CRC Otway Project at Nirranda South in southwest Victoria, Australia, provided verification of the underlying science of geological carbon dioxide storage.

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## Capture CCS Knowledge Today!

### Introduction to CCS Workshop

- February 6<sup>th</sup> - Orlando, Florida 8 a.m. - 5 p.m.

### Site Characterization Workshop

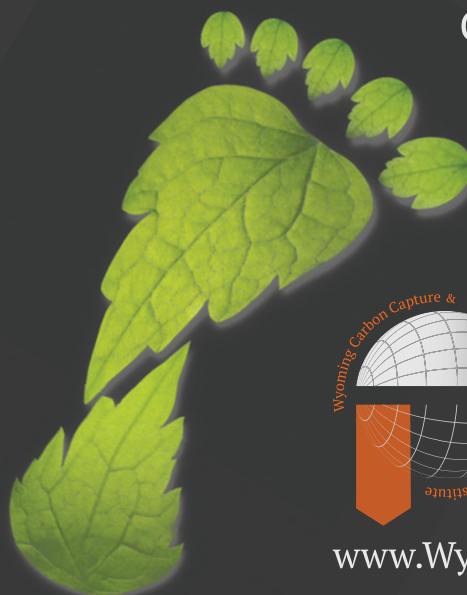
- February 10<sup>th</sup> - Orlando, Florida 8 a.m. - 5 p.m.

Workshops will be held at the Caribe Royale Hotel & Convention Center before and after the Carbon Management Technology Conference.

Register online:

[www.WyomingCarbonStorage.com](http://www.WyomingCarbonStorage.com)

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# 2012 – a crucial year for UK leadership in CCS

Carbon capture and storage (CCS) has had a tough time trying to get going in UK but the CCSA believes that the UK is placed to take a World leadership position. In the following article Professor Jeff Chapman sets out his thoughts.

In the UK the government has spent an abortive four years on a competition for the first commercial scale CCS plant culminating in the cancellation of the chosen project at Longannet power plant. A competition for a further three projects has also been delayed.

Frustrating though that has been for all concerned, at least the government remains committed to undertake four projects and to accelerate the process of project selection.

There are plenty of lessons to be learned from the first competition and there is a commitment not to repeat the errors made. In addition, all the information generated in the engineering studies is being made available in a knowledge sharing exercise for the benefit of the industry.

At an "Industry Day" on 16th December the DECC Office for CCS laid out plans for the UK CCS programme starting with four initial projects. These projects will be supported by a combination of the £1bn previously earmarked for Longannet together with support from the UK Electricity Market Reform (EMR) through Contract for Difference Feed-in-Tariffs (CfD FiTs). They may also benefit from EU support under the NER 300 programme.

The projects will be regarded as forming a foundation for the future roll-out of CCS in the UK and will be selected partly on the contribution that they will make towards that aim. There will be an initial discussion period of two months with potential developers prior to a formal call for proposals.

In this paper I set out some of the imperatives that need to be addressed to get these initial projects established and progress to full CCS deployment.

In 2008, the UK committed to a legally binding national target of an 80% reduction in greenhouse gas emissions by 2050. The Committee on Climate Change (CCC) has recommended as a necessary milestone the almost complete decarbonisation of the power sector by 2030. In a recent report prepared by the Carbon Capture and Storage Association (A Strategy for CCS in the UK and Beyond) we concluded that this will necessitate at least 20 to 30 GW of installed capacity of fossil fuel power plant fitted with CCS by 2030.

Decarbonisation of the power sector relying solely on inflexible nuclear and intermittent renewable energy sources is not real-

istic. A good proportion of complementary, reliable and flexible power generated by fossil fuel will be the key to security of supply and grid functionality and that fossil plant will need to be equipped with CCS.

The cost of generation must always be a leading factor in a market-based energy supply regime, particularly in tough economic times. From that point of view, figures published by the Committee for Climate Change and others demonstrate CCS to be highly cost-effective compared with other low-carbon technologies. The cost of CCS is very project specific and, although pilot projects and desk studies have been carried out and experience of the plant for capture, transport and storage chain exist at commercial scale, we have yet to get hands-on design, build and operational experience of full chain CCS projects on power plant. The sooner we get some momentum behind building the first CCS plants, the faster the process of technology optimisation and cost reduction can take place.

The first CCS projects, while promisingly cost effective in themselves, have high initial capital costs because, like many new technologies, they are subject to significant first of-a-kind (FOAK) costs. The costs of sub-optimal engineering will quickly be driven out with experience, as has been the case for technologies like CCGT and FGD. But CCS also includes the one-off FOAK cost of establishing and proving infrastructure in the form of CO<sub>2</sub> pipelines and stores which can accept and store CO<sub>2</sub> with high reliability.

The first projects have a unique risk associated with the consequential losses resulting from shortfalls in the reliability of any one element of the capture, transport and storage chain. This risk can be eliminated for follow on capture projects using the same transport and storage infrastructure resulting in lower risk and lower cost projects. Effective provision of comprehensive CO<sub>2</sub> infrastructure will be the key to the widespread adoption of CCS in the UK and elsewhere.

There has been a tendency to focus on supporting early CCS projects which are simply single point-to-point schemes, involving a capture plant, a dedicated pipeline and a store sized only for the project. This misses the very large opportunity to cost effectively create reliable transport and storage infra-

structure sized to accommodate all CO<sub>2</sub> expected to require storage in a particular area.

The simple fact is that 10 times the capacity can be transported in a pipeline by doubling the spend to increase the pipeline diameter. The solution going forward is to build up several regional pipeline hubs able to service a number of emissions sources delivering CO<sub>2</sub> to a network of stores. The coming call for proposals must embody a mechanism that rewards the incremental cost-effective spend to lay down strategically sized pipelines and high capacity interconnected stores.

In proposals for the first four projects the government has previously expressed a preference for a project size of 300/400 MW which, although commercial in scale, is smaller than the capacity of power plants needed to be fully competitive in the UK electricity market. Hence, clearly economy of scale is lost and the opportunity to benefit from full emissions reduction is forfeit. We understand that future proposals will have more flexibility as to plant size. The treatment of infrastructure will be a litmus-test for the viability of future CCS policy.

The UK Government's Electricity Market Reform has set an international precedent in establishing the CfD FiT, enabling central procurement of value-added low-carbon power from a range of sources (including CCS) on a similar and comparable basis. This arrangement will be more effective when capture plants are able to tie-in to established infrastructure.

We must not forget that power plants are only one major source of industrial emissions. Potential exists for decarbonising steel, cement, oil refining, chemicals and a number of other industries once infrastructure is in place



*Prof. Jeff Chapman is chief executive of the Carbon Capture & Storage Association*

to transport and store their CO<sub>2</sub>. For a large proportion of these industries, there is no realistic means of decarbonisation other than CCS, because the CO<sub>2</sub> is process as well as fuel generated.

Furthermore, because in most cases the emission sources have relatively high concentrations of CO<sub>2</sub>, the capture cost can be lower than for power. Whether on tax-payers or consumers, the costs of decarbonising the economy fall on society. It is clearly sensible to spend, for example, around £50 per tonne CO<sub>2</sub> avoided by capture from steel works when we are already paying several times this figure through other policy measures.

The CCS challenge got off to a frustratingly faltering start in the UK, but there is still everything to play for

in terms of large-scale, cost-effective emission reductions and a leading role internationally if effective CCS incentive policies are delivered urgently. But the cost to project developers of preparing projects for competition runs into very large sums and already many tens of millions have had to be written off, not just by the lead developers but also by their consortium partners and suppliers. A number of players in the CCS arena have

hung up their boots (at least for now) out of frustration over lack of any foreseeable return.

However, most participants, no matter how weary, remain committed to stay in the game because they recognise the inevitable role of CCS in climate mitigation. But they will not be prepared to progress without a clear view of a policy that underpins full deployment of CCS otherwise they risk being left not just with a stranded asset but also a stranded project development resource.

We eagerly await publication of the government's much delayed Roadmap for CCS in the UK. This document must provide for industry the concerted policy that will enable developers to put more development capital at risk based on a good likelihood of success not only for the first projects but for the ensuing roll-out of CCS investment.

An important factor for confidence in policy at a government as well as an industry level is how CCS will fit alongside international climate policy. At the end of the year the deal was struck in Durban that commits all Parties to negotiate an agreement before 2015. Though this is not a commitment in itself, it commits to making one and it brings in the big developing countries. We think that

this was the most optimistic outcome that could have been achieved. But in addition to that, after 6 years of negotiation CCS is recognised in the Clean Development Mechanism (CDM), the significance of which cannot be overstated. Whatever climate deal is now negotiated must recognise CCS as a mitigation option.

In the CCSA we are extremely encouraged by the policy developments in the UK supported by international climate action. The UK has abundant storage near to emissions clusters, a tremendous skills base, political as well as NGO support, a clear need to replace and decarbonise power capacity, enormous business engagement and finally the UK has the CCSA. In the CCSA we believe the UK is poised to become an international leader in CCS and we look forward to carrying the agenda rapidly forward in 2012.



## More information

**Prof. Jeff Chapman** is chief executive of the Carbon Capture & Storage Association  
[www.ccsassociation.org.uk](http://www.ccsassociation.org.uk)



# Upcoming Events

**New technologies for accessing, listening to, and producing from, your reservoir.**  
 Aberdeen, 24 Jan 2012

**South East Asia exploration - where are the big fields hiding?**  
 London, 21 Feb 2012

**Optimising supply chains**  
 Stavanger, 28 Feb 2012

**Developments with subsurface data**  
 Aberdeen, 13 Mar 2012

**New ideas in geophysical technology**  
 London, 21 Mar 2012

**East African Exploration - where are the big fields hiding?**  
 London, 17 Apr 2012

**New ideas in Improved Recovery and EOR**  
 Aberdeen, 25 Apr 2012

## Extending the life of the North Sea - building a CO<sub>2</sub> utilisation and storage industry

**Wednesday, January 18, 2012**  
**London**  
**The Geological Society**

How can we get carbon capture and storage projects running?

It is proving tough to get carbon capture and storage projects financed, if the only stated benefit of them is environmental (greenhouse gas).

We have gathered the top UK experts in carbon capture and storage in a business context, to discuss what they think is the best way to get carbon capture projects off the ground, and talk about how they are doing it.

**Reserve your place at [Findingpetroleum.com](http://Findingpetroleum.com)**

# CCS included under the CDM at COP17

With the agreement of a set of modalities and procedures for CCS projects under the Clean Development Mechanism of the Kyoto Protocol, the possibility of CCS projects earning credits on the carbon market moved a step closer.

By Lodewijk Nell and Andrew Gilder

After a two week marathon negotiation, COP17 of the United Nations Framework Convention on Climate Change (UNFCCC), including CMP7 of the Kyoto Protocol, came to an end in the early morning hours of Sunday, 11 December 2011 in Durban, South Africa – nearly thirty-six hours after its scheduled conclusion. Governments, including most developed countries, agreed to a second commitment period of the Kyoto Protocol starting from 1 January 2013 and to a legal framework for a comprehensive global agreement for responding to climate change - to be negotiated by end of 2015 and signed by end of 2020.

Unlike in the first Kyoto period, the second period's emissions reduction targets are to be determined in a "bottom-up" manner with those countries that have committed themselves to economy-wide quantified emission reduction or limitation objectives (QELROs) having until 1 May 2012 to make submissions to the UNFCCC secretariat in this regard.

### CCS inclusion under the CDM – an important step forward

Among the list of successes notched-up by COP 17 is the formal inclusion of CCS in the Clean Development Mechanism (CDM) of the Kyoto Protocol. International negotiations lasting some seven years came to a positive conclusion with the adoption of modalities and procedures which seek to ensure appropriate and safe implementation of CCS projects as CDM project activities while making provision inter alia for the prevention of leakage, relevant ownership rights and long term liability.

This brings ever closer the potential for CCS projects to be implemented according to the rules of the CDM and to earn certified emissions reductions (CERs – the species of carbon credit generated by a CDM project), which have a commercial value on the international carbon market.

The modalities, currently, only apply to the capture, transport and storage of carbon dioxide in geological formations within the boundaries of one nation, although the issue of transboundary movement of carbon dioxide for the purposes of storage is expressly

indicated as being on the agenda of the next CMP (Qatar, December 2012). The combination of storage of carbon dioxide and Enhanced Oil or Gas Recovery (EOR/EGR), as a CDM project activity, is not finally dealt with. It will be important, in the future, to obtain clarity on EOR/EGR enhanced CCS projects for the reason that this combination could facilitate early implementation because of the upside of higher volumes of oil and gas produced.

### Permanence

Permanence (of removal of emissions from the atmosphere) is a particularly thorny issue for sequestration projects, e.g., CCS and forestry. CDM afforestation and reforestation projects use the device of temporary and long-term CERs (respectively tCERs and lCERs) with tCERs being required to be replaced with lCERs after the elapse of a specific period of time.

This solution to the permanence issue is not optimal. Fortunately this route has not been taken in the CCS context. Instead a more robust solution is found by combining a long term monitoring requirement of at least twenty years with a project based CER reserve account for the purpose of accounting for any net reversal of storage. The project based reserve account will hold five per cent of the CERs issued in respect of the CCS CDM project activity for the purpose of offsetting any net reversal of stored emissions.

Only after long term monitoring of the geological storage site has been terminated, a request can be made to forward any re-

maining CERs in the reserve account to the registry accounts of the Parties and project participants. Monitoring shall not be terminated earlier than twenty years after the end of the last crediting period of the CDM project activity or after the issuance of CERs has ceased, whichever occurs first.

Moreover, monitoring can only be terminated if no seepage (leakage of carbon dioxide outside of the confines of the storage site) has been observed at any time in the previous ten years and if all available evidence from observations and modelling indicates that the stored carbon dioxide will be completely isolated from the atmosphere in the long term.

In addition to the project based reserve the establishment of a global reserve of CERs for carbon dioxide capture and storage project activities has been proposed for consideration. The idea of a "global reserve" hints at aggregating the risks of individual projects and providing overall assurance for the coverage of any potential non-permanence problems in one of the projects.

This is in line with global general insurance practices and could be an appropriate addition to the project based reserve. Parties and admitted observer organizations are invited to submit to the secretariat, by 5 March 2012, their views on the issues regarding a global reserve and the previously mentioned outstanding issue of multinational CCS project activities.

Please refer to the table opposite for an indication of the select characteristics of the CCS modalities.

### About the authors

Lodewijk Nell is Director at EcoMetrix Africa and leads the consultancy practice in carbon management and new energy technologies.



[www.ecometrix.co.za](http://www.ecometrix.co.za)

Andrew Gilder leads the Carbon Markets and CDM Consultancy practice for IMBEWU Sustainability Legal Specialists (Pty) Ltd.



[www.imbewu.co.za](http://www.imbewu.co.za)



**Table – Selected Characteristics of the Modalities and Procedures for CCS in the CDM**

Download the modalities from:

[unfccc.int/files/meetings/durban\\_nov\\_2011/decisions/application/pdf/cmp7\\_carbon\\_storage\\_.pdf](http://unfccc.int/files/meetings/durban_nov_2011/decisions/application/pdf/cmp7_carbon_storage_.pdf)

<p><b>Participation requirements</b></p> <p>General CDM participation requirements apply along with a set of CCS-specific requirements, including:</p> <ul style="list-style-type: none"> <li>• A Non Annex-I country Parties to the Kyoto Protocol may only host a CCS project activity under the CDM if it has submitted an expression of its agreement to the UNFCCC secretariat to allow the implementation of CCS project activities in its territory and provided that it has established laws or regulations which inter alia:</li> <li>• Set procedures that include provisions for the appropriate selection, characterization and development of geological storage sites;</li> <li>• Define means by which rights to store carbon dioxide in, and gain access to, subsurface pore space can be conferred to project participants;</li> <li>• Provide for timely and effective redress for affected entities, individuals and communities for any significant damages, such as environmental damage, including damage to ecosystems, other material damages or personal injury, caused by the project activity, including in the post-closure phase;</li> <li>• Provide for timely and effective remedial measures to stop or control any unintended seepage of carbon dioxide, to restore the integrity of a geological storage site, and to restore long-term environmental quality significantly affected by a CCS project activity.</li> </ul>	<p><b>Obligations on Designated Operational Entities</b></p> <p>General obligations Designated Operational Entities (DOEs) apply along with a set of CCS-specific requirements, including the DOE being required to confirm:</p> <ul style="list-style-type: none"> <li>• The geological storage site has been characterized and selected in accordance with paragraphs 1 to 5 of appendix B to this annex and the conditions set out in paragraph 1 to 3 of appendix B to this annex are fulfilled;</li> <li>• A risk and safety assessment has been carried out, in accordance with the laws and regulations of the host Party;</li> <li>• Environmental and socio-economic impact assessments have been carried out in accordance with the laws and regulations of the host Party including with regard to potential transboundary impacts and also including a detailed description of the planned monitoring and remedial measures to address any environmental and socio-economic impacts identified;</li> <li>• Provisions for liability have been agreed in accordance with the laws and regulations of the host Party;</li> <li>• Financial provisions have been put in place;</li> <li>• The project participants have provided a description and analysis of the environmental conditions in the area of the geological storage site prior to any storage of carbon dioxide, including a description of the hydrology, aquifer and groundwater properties, such as acidity and dissolved gases; where appropriate - the soils and soil gas properties such as a carbon dioxide isotope analysis and carbon dioxide flux rate; ecosystems and the possible presence of rare or endangered or sensitive species and their habitats; climatic data.</li> </ul>
<p><b>Addressing non-permanence</b></p> <p>Where a net reversal of storage has occurred the CDM Executive Board shall:</p> <ul style="list-style-type: none"> <li>• Cancel CERs issued for the CCS project activity held in the CDM registry up to the amount of the net reversal of storage; firstly, from the reserve account established for the purpose of accounting for any net reversal of storage; secondly, from the pending account; finally, from the holding accounts of the project participants, proportional to the amount of CERs • for the CCS project activity held in each holding account; and,</li> <li>• Determine any outstanding amount of the net reversal of storage for which no units were cancelled and, where such an amount is outstanding, request the project participants to transfer an amount of Kyoto carbon credits (including assigned amount units (AAUs), CERs, emission reductions units (ERUs) or removal units (RMUs)), equivalent to the outstanding amount to the relevant cancellation account.</li> </ul>	<p><b>Long term liability</b></p> <ul style="list-style-type: none"> <li>• The CDM Project Design Document (PDD) must clearly show how liability obligations arising from the proposed CCS project activity or its geological storage site are allocated during the operational, closure and post-closure phases.</li> <li>• Until such time as transfer of liability to the host Party has been effected, liability shall reside with the project participants.</li> <li>• Transfer of liability from the project participants to the host Party shall be effected after: the monitoring of the geological storage site has been terminated in accordance with the conditions for termination of monitoring;</li> <li>• The host Party has established that the conditions set out in the letter of approval granted for the project by the CDM Designated National Authority and arising from the relevant laws and regulations applicable to the storage site have been complied with.</li> </ul>

## Markets

Although the inclusion of CCS in the CDM is an important step forward from a regulatory point of view, it does not mean that developing countries will automatically be able to tap into international markets by selling carbon credits from CCS projects. The position of the European Union, the largest and most willing buyer of CERs appears to remain unchanged with respect to the exclusion of non-LDC projects registered after

2012. Although it is rightfully so stated by IETA<sup>1</sup> that the market will eagerly await clarification from the Commission of how, if at all, Durban has changed anything here. Pending that, it would seem unwise for developers to assume the EU is back in the demand game, outside LDCs.

1. IETA, the International Emissions Trading Association, “The consequences of the Durban COP for the carbon market and climate finance”, December 2011.

With the aforementioned post-2012 exclusion of non-LDCs by the European Union in place, there is practically no real future market in sight at the moment for credits from CCS projects in developing countries. One could however debate whether alternative markets, for example the Australian cap and trade scheme envisaged commencing by 1 July 2015, could provide relief in this regard.

# CCS legal and policy – Jan / Feb 2012

2011 has seen its fair share of CCS related legislative activity and the amount of legislation, regulation and policy that must be considered by CCS developers continues to rise. This edition's column looks at some of this and highlights a few of the issues which continue to vex and perplex as we enter 2012.

### International

Starting at the international level, recent developments in Durban at the 17th Conference of the Parties to the UN Framework Convention on Climate Change (UNFCCC) have the potential to affect CCS projects everywhere. The inclusion of CCS projects in the UN's Clean Development Mechanism (CDM) is a breakthrough that has been a long-time coming. The CDM allows authorised CO<sub>2</sub> emissions reduction projects in developing countries to earn Certified Emission Reductions (CERs) in proportion to the CO<sub>2</sub> emissions that the project avoids.

The Durban announcement means that CCS projects can now benefit from the scheme. CER's can be used by Annex 1 countries under the Kyoto protocol to meet their emission reduction commitments and they are partially fungible with EUAs in the EU Emissions Trading Scheme. They therefore have a market value. Forward selling of the CERs that will be earned by a project once it is operational allows the project developer to raise finance to fund the projects construction. This is undoubtedly positive for CCS generally but raises concerns for European projects; if CCS can now be financed and demonstrated at

commercial scale in the developing world, might this not prove an economically preferable option to demonstrating it in costly and regulation laden Europe?

On a more positive note for CCS in the EU, the Durban conference saw an eleventh hour agreement that appears to have the potential to lead to a replacement for the Kyoto Protocol by 2020. Whilst this timescale is long (and has already come in for a great deal of criticism because of that), it is notable that it would dovetail perfectly with end of the third phase of the EU Emissions Trading Scheme (ETS) and therefore should give increased security that the ETS will continue to operate past 2020. This is an important issue for those considering investing in long term investments in the EU with revenue streams based upon the carbon price, like CCS.

### EU

At the EU level, the Directive on the Geological Storage of Carbon Dioxide (the CCS Directive) continues to be the central piece of legislation of interest to the CCS industry and the transposition of its requirements is ongoing. The Directive, in the main, deals with the permitting of CO<sub>2</sub> storage and the measures

that are to be taken by, and the obligations on, the storage site operator. The Directive constitutes an essential part of the CCS legal framework and helps to bring clarity in many important areas but it also raises some interesting issues.

The Directive's provisions include requirements that, once injection into a storage site has ceased, the operator must seal it, remove the injection facilities, and thereafter maintain and monitor it in accordance with a 'post-closure plan'. The plan is initially drafted at the time of the grant of the storage permit but is subject to amendment at site closure.

The site maintenance and monitoring period will last for a period after site closure that is unlikely to be less than 20 years, but may be much longer, and only at the end of this time can all legal obligations relating to the store be transferred to the state. Until that occurs the storage operator is responsible for a long list of liabilities and must maintain a 'financial security' of a value which covers all of these liabilities for the entirety of the period. In addition, at the point of transfer of responsibility to the state the operator must provide a 'financial mechanism' providing the



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necessary funds for the state to continue to monitor the site for a further 30 years or so. The magnitude of this funding is, again, subject to amendment up until the point of transfer.

The above requirements are prohibitively expensive and, possibly more importantly, they are indeterminate at the time that the project developer is trying to reach the final investment decision. A certain amount of useful guidance has been forthcoming from the EC regarding the financial security and mechanism but this has not removed the central problem of uncertain cost. What is really needed is commercially available insurance but with such a small group of insured parties over which to socialise the risk it seems that this would have to be underwritten by the state. It remains far from certain how this problem will be resolved.

The Directive also addresses third party access to CO<sub>2</sub> transportation and storage infrastructure. This is a very important area for taxpayers and consumers for the following two principal reasons. Firstly, it is generally true that with increasing infrastructure capacity there comes concomitant economies of scale, therefore the more 'third-parties' that can be encouraged to take the opportunity to purchase incremental capacity in an infrastructure development, the larger the total system capacity should be developed, the greater the economies of scale that will be yielded and the lower the marginal price of capacity will become.

This should, subject to a well designed capacity charging mechanism and the right long term signals from Government, lead to the maximum number of emitters being able to afford to purchase capacity. Open third party access should therefore assist in enabling the market to signal an economically efficient infrastructure capacity and thereby help to ensure that taxpayer funded CCS demonstration projects yield the best value for money.

Secondly, open third party access should help to prevent the manipulation of energy markets by energy generators who may wish to hoard CO<sub>2</sub> transport and storage infrastructure capacity in order to obtain a competitive advantage over generators who have no access to such infrastructure and who therefore have to bear the full carbon price overhead. If such a situation was to develop, and the low energy prices ensured by a competitive energy market were to be protected, it would seem likely that the CCS industry would be required to go through a lengthy and expensive unbundling exercise similar to that seen in the energy markets.

Another Directive that came into force in 2009 and continues to be important to CCS is the Emissions Trading Scheme Amending

Directive. Inter alia this Directive made a site in which CO<sub>2</sub> was geological stored, under a permit granted in accordance with the CCS Directive, an 'installation' for the purposes of the ETS and thereby made such a site's operator liable to submit carbon allowances for any emissions from that site, including leaks. Notably, it did not make all CO<sub>2</sub> injection sites 'installations' and this has some curious interrelations with UK legislation.

## UK

The Energy Act 2008 was the first significant piece of CCS legislation to make the UK statute books. It established Gas Importation and Storage Zones in UK waters, granted the Crown property rights with respect to gas storage in those zones and also prohibited unlicensed storage of CO<sub>2</sub> in them. Significantly, the 'storage' of CO<sub>2</sub> in association with the getting of hydrocarbons (enhanced oil recovery) is explicitly excluded from these provisions (although the Secretary of State may alter this by Order).

This leaves EOR projects in a strange situation; CO<sub>2</sub> injection as part of EOR can be authorised by an oil production licence, and apparently no lease from The Crown Estate or CO<sub>2</sub> licence would be required if this were to be the licensing route taken. No CO<sub>2</sub> licence means no CO<sub>2</sub> permit and hence, as I mention above, the injection site is not an installation for the purposes of the ETS scheme and therefore leaks do not attract any carbon allowance liability.

This would, presumably, also reduce the level of the financial instrument required under the CCS Directive, that I also mention above, as a large part of the value of that instrument covers leak related carbon allowance submission liabilities. All of this reduces the regulatory overhead of EOR projects enormously in comparison with CCS projects where storage is to be in a depleted hydrocarbon field or saline aquifer. Could it also be that an EOR project licensed under the oil and gas production regime might receive state CCS funding? It seems entirely possible that it might.

The Climate Change Act 2008 is another piece of UK primary legislation which is important to CCS. It is this Act that established the UK's carbon budget system and gave the Secretary of State the duty to ensure that the UK's carbon emissions reduced by 34% by 2020 and 80% by 2050 against a 1990 baseline. These targets are driving the rapid implementation of wind generation schemes in the UK and the intermittent nature of the electricity supply from these schemes means that controllable fossil fuel plant is also required if black-outs are to be avoided when the wind does not blow.

The Government is advised that if the Act's targets are to be met then these fossil fuelled plants must be fitted with CCS. The Government's choice seems stark: fail to meet the legal obligations under the Act; watch the

lights go out; or pay for fossil fuelled plants with CCS; time is running out and there is currently no other choice is how the argument goes. Of course, this is not this is not the whole story: in the UK, Parliament is sovereign and can change the laws it has made; if the Climate Change Act becomes too troublesome it can be amended and if this were to happen it would fundamentally change the need case for CCS in the UK. This is a central regulatory risk for those sinking capital into CCS developments in the UK which cannot be avoided.

There are many other areas of law, regulation and policy that should currently be at the front of CCS project developer's minds and could have been mentioned above: tax law with respect to transfer of oil and gas assets to CCS use; the interpretation of the requirements of the Pipeline Safety Regulations; the effect of the developing Electricity Market Reform; International Maritime Law with respect to dumping at sea and transboundary export of waste; and the developments in the consenting regime are only a few. 2012 proves to be another interesting year. I hope it is a happy and prosperous one for all CCJ readers.

Finally, with reference to the previous edition of this column, it has come to my attention that its content was erroneous with regard to the date of transposition of the CCS Directive into Italian law. That transposition was formally signed on September 14 and published in the OJEU of the 4 October. I am indebted to Mr Federico of the Italian Osservatorio CCS for highlighting my error and hope it will not discourage him from reading future editions of this column.



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Calum Hughes, Yellow Wood Energy

# Global CCS Institute releases project reports

The Global CCS Institute has published five CCS project reports, across a range of disciplines, from assisted projects across the globe.

From Europe, the Dutch ROAD project, which is currently in the process of obtaining its permits, recently completed its front end engineering and design (FEED) studies and has prepared a special report for the Institute summarising the main results of the FEED study for the capture plant.

To aid the early deployment of a Rotterdam CCS Network, the Institute also sup-

ported Vopak and Anthony Veder to conduct a feasibility study on their CO<sub>2</sub> Liquid Logistics Shipping Concept that will provide emitters, including ROAD, with a complete logistical transportation solution for captured CO<sub>2</sub> from their site to an offshore storage location.

In this report the business principles for the Liquid Logistics Shipping Concept are

further elaborated upon. In addition, estimated transportation costs for the various shipping and pipeline routes are compared.

The Romanian CCS Demonstration Project is to implement a full-chain operational CCS system capturing 1.5 million tonnes of CO<sub>2</sub> per annum. The purpose of the Getica CCS Demo Project – Permitting Report from the GETICA project is to identify relevant permits and competent authorities involved in the permitting process, to create a ‘permitting map’ and time schedule. This report aims to help similar CCS projects (using post-combustion capture technology) to identify the attention points and needed conditions to get a successful permitting process.

From North America, the first report from Project Pioneer, an overview of their project located nearby Edmonton, Alberta in Canada, is now available. Project Pioneer is a consortium project headed by TransAlta who, along with their partners Capital Power Corp and Enbridge, plan to retrofit a carbon capture facility onto their newly built Keephills 3 power plant. This report outlines their schedule, approach to knowledge sharing and other key items such as stakeholder engagement and their regulatory environment – topics which will all be detailed in future distinct reports.

Tenaska published the third in a series of financial and commercial reports on their Trailblazer project located in West Texas, USA. Following their Consortium report and report on market conditions in their jurisdiction, Tenaska have outlined their financing strategy for developing a CCS project.

The financing report sheds light on the project developer’s approach to managing risk, examining financial models and securing finances from markets. This is the tenth report from Tenaska on various aspects of its Trailblazer projects. A final report on the findings of their FEED study will be published shortly.

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## Policy, company and regulation news

### CIUDEN completes initial oxycombustion testing phase

[www.ciuden.es](http://www.ciuden.es)

The Fundación Ciudad de la Energía (CIUDEN) has successfully completed the initial testing phase of oxycombustion in its 30 MWth Circulating Fluidized Bed (CFB) boiler, burning coal using oxygen instead of air.

The tests were carried out in the CIUDEN Technology Development Centre for CO<sub>2</sub> Capture (es.CO<sub>2</sub>), using indigenous coal (low reactivity anthracite).

The process was initiated two months ago with the start-up of the CFB boiler, using gas and later coal. A week ago the operation was switched to oxycombustion using oxygen rather than air.

Using oxygen it is possible to reach CO<sub>2</sub> concentrations in flue gas of around 60% instead of 15% as in conventional combustion.

The process is expected to be complete within the first half of 2012 with the start-up of the CO<sub>2</sub> purification and compression unit, completing the integration of the CO<sub>2</sub> capture system, making it ready for transport and storage.

"Several R&D&D activities will be carried out such as design assessment and optimisation, operation in advanced high performance conditions, and the selection of the most appropriate materials," said Prof. Vicente Cortés, Director of the CO<sub>2</sub> Capture Programme at CIUDEN.

Pedro Otero, Technical Director of the Centre, emphasised that these tests allow the identification of possible technical difficulties previously unknown that once studied and solved will be of great help for technological development.

### CCS awareness higher in Saskatchewan than Europe

[www.ipac-co2.com](http://www.ipac-co2.com)

A survey by IPAC-CO<sub>2</sub> suggests that public awareness and acceptance of CCS as a tool to combat climate change is higher in Saskatchewan than Europe.

According to Carmen Dybwad, CEO of IPAC-CO<sub>2</sub>, "Four in ten (40%) Saskatchewan people surveyed have heard of CO<sub>2</sub> capture and storage and know what it is, and an additional one third (36%) have heard of it but don't really know what it is while one quarter (23%) have not heard of it at all."

The survey of 1,104 Saskatchewan individuals commissioned by IPAC-CO<sub>2</sub> was conducted by Insightrix Research, Inc. between Sept. 27 and Oct. 11. The online



*Aerial view of CIUDEN Technology Development Centre for CO<sub>2</sub> capture*

Saskatchewan poll parallels a Eurobarometer survey of 13,000 individuals in 12 European countries.

"Comparing the awareness levels to the Eurobarometer study shows a much higher level of awareness in Saskatchewan compared to Europe, where two thirds (67%) have not heard of the technology and just one in ten (10%) have heard of it and know what it is," Dybwad said.

Overall, respondents are divided on how effective they believe that CCS would be in combating climate change. Few (6%) respondents believe that CCS technology will be very effective in fighting climate change, while an additional 31% believe that it would be fairly effective.

"About the same proportion of respondents in Saskatchewan believe that CCS would be very (6% in both cases) or fairly (31% in Saskatchewan; 33% in Europe) effective in fighting climate change," Dybwad said.

"However, the proportion who are unsure of its effectiveness is much higher in Europe (36%) compared to Saskatchewan (20%), likely related to the very different knowledge levels in the two areas."

Dybwad added, "Our survey identified the most trusted source of information about CCS is scientists and researchers (77%)."

Like the Eurobarometer results, television is the most cited source of information on climate change in Saskatchewan (80% in Saskatchewan, 81% in Europe).

A summary of the Saskatchewan survey is available online. Upon request IPAC-CO<sub>2</sub> can provide the full survey to individuals and organizations.

### Environmental organizations announce CCS Network

[www.engonetwork.org](http://www.engonetwork.org)

Nine environmental organizations have launched the Environmental NGO Network on Carbon Capture and Sequestration (ENGO Network on CCS).

Network members plan to share knowledge and work toward common positions on international developments related to CCS.

Current members include: Clean Air Task Force, Environmental Defense Fund, Green Alliance, Natural Resources Defense Council, The Bellona Foundation, The Climate Institute, The Pembina Institute, World Resources Institute and Zero Emission Resource Organisation.

Timothy O'Connor, Environmental Defense Fund said, "CCS is an important climate change mitigation tool, and our new international NGO network can play an integral part in helping to ensure that the highest standards are met for public safety, atmospheric and environmental protection."

### Ferrybridge power station carbon capture plant opens

[www.sse.com/ferrybridge](http://www.sse.com/ferrybridge)

The UK's largest carbon capture pilot plant has opened at SSE's Ferrybridge Power Station in West Yorkshire.

The project is the first of its size to be integrated into a live power plant in the UK. It is a collaboration between SSE, Doosan Power Systems and Vattenfall.

The plant will capture 100 tonnes of carbon dioxide per day from the equivalent five megawatts (MW) of coal-fired power generating capacity.

# Lower energy penalty CO2 capture system

CEFCO (Clean Energy and Fuel Company) has developed a process with a total energy penalty of less than 15% for capture of CO<sub>2</sub> and other pollutants including NO<sub>x</sub> and SO<sub>2</sub> from coal fired boilers. It also has a lower capital cost and a smaller footprint than some other comparable technologies.

**By Robert E. Tang, President, CEFCO Global Clean Energy and Dr. Anupam Sanyal, President, International Environmental & Energy Consultants**

**Look out for part two of this article featuring recent results from the CEFCO process pilot plant in the next issue**

Coal-fired power plants are the largest contributor to U.S. greenhouse gas (“GHG”) emissions, and coal combustion accounts for 40% of global man-made carbon dioxide (“CO<sub>2</sub>”) emissions.

U.S. DOE and EPA plan to overcome the barriers to the deployment of Carbon Capture and Sequestration (“CCS”) within ten years with a goal of bringing five to ten commercial demonstration projects online by 2016.

Capture of CO<sub>2</sub> from industrial gas streams has occurred since the 1930s. The history of transporting CO<sub>2</sub> via pipelines in the United States spans nearly 40 years. Approximately 50 million tonnes of CO<sub>2</sub> are transported each year in the United States through 3,600 miles of existing CO<sub>2</sub> pipelines.

Though CCS technologies exist historically, “scaling up” these existing processes and integrating them with coal-based power generation poses technical, economic, and regulatory challenges. Of the 74 large-scale integrated CCS projects around the world, 14 projects are either coming into operation recently or under construction. In the electricity sector, estimates of the incremental costs of new coal-fired plants with CCS relative to new conventional coal-fired plants typically range from \$60 to \$95 per tonne of CO<sub>2</sub> avoided. Approximately 50–90% of that substantial energy cost is associated with capture and compression of CO<sub>2</sub>.

The major cost for CCS alone is the energy penalty or “parasitic load” ranging from 20% to over 30% in applying the technologies. The current major emphasis is in pre-, post- and oxyfuel combustion capture applied to power stations (and other industrial applications). There are several research activities in to reducing this cost. For example, U.S. DOE, through its National Energy Technology Laboratories (“NETL”), is promoting multiple projects to minimise energy penalty.

However in contrast to the uneconomic prospects, an EPA-recognised Hazardous Waste Combustion Maximum Achievable Control Technology (HWC MACT) is available and ready at demonstration stage which is designed for CO<sub>2</sub> Capture and Multi-Pollutant Capture (“MPC”) — all at under 15% total energy penalty together with the co-pro-

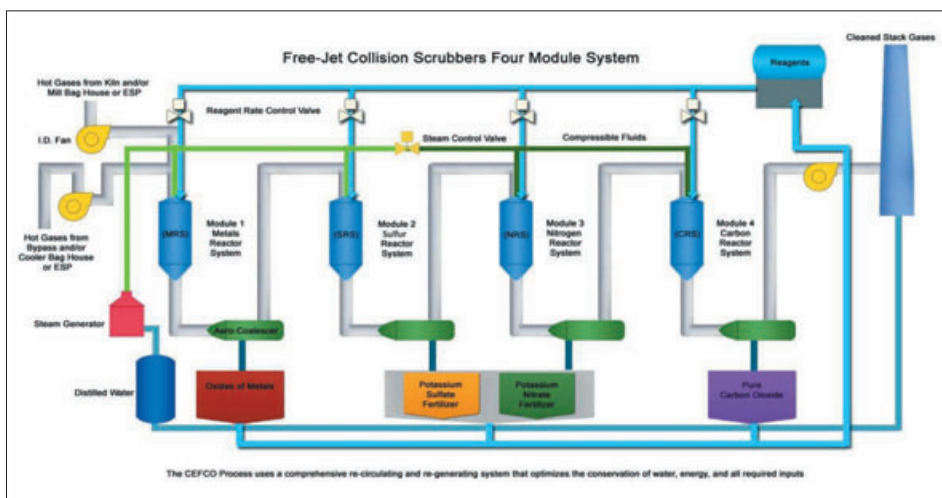


Figure 1 - flow diagram of the modularized CEFCO Process

duction of multiple saleable end-products, thus making this technology a “Profit Center” process.

It is designed to remove 90% of the CO<sub>2</sub> as well as 99+% of SO<sub>2</sub>, NO<sub>x</sub> and particulates (including metallic solids) from coal and oil fired boilers, cement kilns and petro-chemical plants, and has both a significantly lower capital cost and O&M cost, in addition to having a smaller footprint than those employing conventional technologies. It is suitable for “greenfield” and “retrofitting/upgrading” application.

### CEFCO Process Introducing a New Technology

The CEFCO (Clean Energy and Fuel Company) Process is a major improvement in Air Quality Control System (“AQCS”) efficiency and CO<sub>2</sub> capture levels compared to the currently available conventional technologies. It uses and embodies the slogan: “Physics first, Then Chemistry”.

The traditional processes currently on the market use conventional thermo-chemistry based reactions for capturing CO<sub>2</sub> and acid rain gases. They require substantial addition of expensive heat, pressure and catalyst that are referred as their “energy penalty”.

On the other hand, the CEFCO Process is based on using shockwaves generated by “spent” or “post-power-production” steam in

aerodynamic reactors as a low-cost substitute, thereby not only minimising energy penalty but also ultimately producing valuable end-products, making the CEFCO Process a “Profit Center” instead of a “Cost Center”.

This article aims at citing the history of the technology, its acceptance by U.S. EPA, DOE and DOD as the Maximum Achievable Control Technology (“MACT”), its case histories and finally its recent extension to coal/oil fired boilers, cement and petro-chemical industries.

### The Process Essentials

The CEFCO Process consists of two components: The capture of the pollutants and their conversion into saleable end-products.

The first component of the CEFCO Technology was invented by Thomas K. Ewan (a co-inventor of the CEFCO Process) and his team of aerophysicists. It applies a sequence of reactors and aero-coalescers, designed on aerodynamic principles that strips emissions of all metals, fine particulates, SO<sub>x</sub>, NO<sub>x</sub> and CO<sub>2</sub> and captures them using a remarkable capture mechanism. Ewan’s shockwave “free-jet collision scrubbing” has been duly tested, recognized and put into use at various U.S. Nuclear Waste Incineration facilities by the U.S. DOE and its Nuclear Regulatory Commission for years. The technology was adopted by the U.S. EPA as a component of its Haz-



ardous Waste Combustors ("HWC") MACT, which was codified and published by the EPA on May 22, 2002<sup>1</sup>.

The operating principle of the capture mechanism is best described by the U.S. EPA as stated in its review, analysis and selection of the "Free-Jet" Technology in Section 3.4.2.2 of the "Technical Support Document for HWC MACT Standards", Vol. I: Description of Source Categories" (dated February 1996), as follows:

"... When a gas stream is saturated with water and then cooled, a portion of the moisture will condense, and the fine particles in the gas stream serve as condensation nuclei. As moisture condenses on the particles, they grow in mass and are more easily collected by conventional impaction. Therefore, the condensation enhances the scrubbing system's collection of fine particles, acid gases and metals... (emphasis added)

The second component of the CEFCO Process is a series of chemical processes invented and patented by Hal B.H. Cooper (a co-inventor of the CEFCO Process) which use chemical reagents for the selective conversion of each targeted compound in succession, resulting in captured and converted forms of recovered metals, potassium sulfate and potassium nitrate fertilizers, and pure CO<sub>2</sub> from a bicarbonate solution.

## CEFCO Process Patent

CEFCO Global Clean Energy ("CEFCO") was formed for the purpose of providing air emissions capture technology and capabilities for all fossil fuels, especially targeting the high pollutant coal-fired power industry, the cement industry and the petro-chemical industry. CEFCO applied for a patent titled: "Process and apparatus for carbon capture and elimination of multi-pollutants in the flue gas from hydrocarbon fuel sources and recovery of multiple by-products" in 2008. On 30 November 2010 the U.S. Patent and Trademark Office issued a patent certificate covering the CEFCO Process to the company (U.S. 7842264B2).

## Process Details

Under the CEFCO Process, the targets for capture are trace metals (including Mercury), fine particulates (including sizes as low as 2.5 microns), SO<sub>x</sub>, NO<sub>x</sub> and CO<sub>2</sub>. The CEFCO Process is a comprehensive CO<sub>2</sub> Capture and MPC control technology that is designed to meet or exceed compliance with the ensuing MACT, NESHAPs<sup>2</sup> and CSAPR ("Cross-State Transport Rule")<sup>3</sup>. When future GHG6 or Carbon Rules are established in the U.S. by the EPA, the CEFCO Process will also offer com-

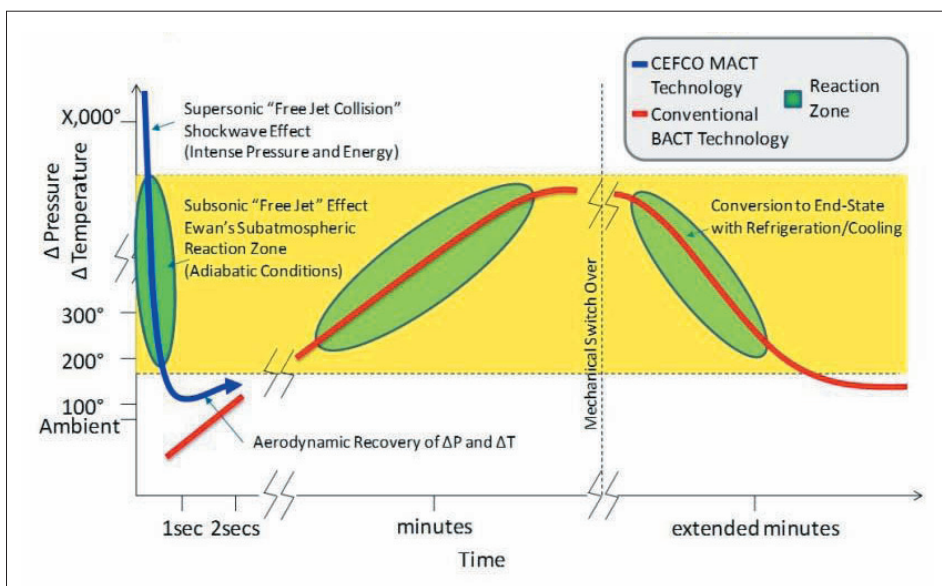


Figure 2 - comparison of parasitic load or energy penalty

pliance for carbon control.

The Process comprises multiple aerodynamically-shaped reactors and aerodynamic coalescers (gas/liquid separators) in series for sequential pollutant separation and removal. Each reactor system is designed to remove one of the targeted groups of pollutants, and the steps are repeated in sequence for the remaining pollutants. CEFCO believes that its Process will remove virtually all (99+%) of the pollutants and at least 90% of the CO<sub>2</sub>.

The invention is based on highly efficient "molecular surface chemistry" that is achieved with proprietary aerodynamic reactor technology. The flue gas being treated is kept moving, with short residence time in each reactor system. A key concept of the CEFCO Process is that, by using the technology and injecting steam or air through aerodynamic nozzles exiting at Mach speeds (referred to in the EPA and the Department of Energy literature as well as in the MACT Standards as "hydro-sonic", or "free-jet collision", or "collision scrubber", or "supersonic collision"), supersonic shockwaves are generated resulting in the formation of a sub-atmospheric and adiabatic reaction zone in each reactor module.

Under this condition, each targeted group of the pollutants of the flue gas intimately collides with and mixes with very fine, fast moving liquid droplets of the appropriate absorbing or adsorbing reagent(s). The pollutants are captured and encapsulated by the liquid droplets (and reacted with the reagent).

The droplets then are "grown" to a phys-

ical size sufficiently large to permit separation by a flow separating aero-coalescer. (The capture and mass transfer mechanisms are detailed in the published patent). Consequently, the sub-atmospheric and adiabatic reaction zone enables the occurrence of endothermic-then-exothermic chemical reactions that capture the pollutant and then form the desired end-product almost instantaneously<sup>4</sup>. The CEFCO Process is thus based on the reactions being completed extremely rapidly in contrast to the traditional bulk chemistry reactions in other conventional processes, which rely on much longer residence time for proper contact with absorbents, catalysts and adsorbents, as dictated by Newtonian thermodynamics.

CEFCO describes this mechanism as "molecular surface chemistry" because the fine droplets have a large "ratio of surface area to mass" which makes it possible for the rapid chemical reactions to take place. There is no addition of a chemical or complex catalyst which serves to simplify the chemistry as well as to significantly reduce overall capital and operating costs. The shockwave performs all the requisite functions for energy, pressure and catalyst.

## Overview of the CEFCO Process Equipment System

The complete CEFCO Process comprises a series of four reactor modules, for the sequential capture of all four groups of air emissions: the Trace Metals and Particulates are captured in the Metals Reactor System ("MRS"), the SO<sub>x</sub> are captured in the Sulfur Reactor System ("SRS"), the NO<sub>x</sub> are captured in the Nitrogen Reactor System ("NRS"), and the CO<sub>2</sub> is captured in the Carbon Reactor System

1. Ewan's Technology was recognized and codified in US Federal Legislation under 40 CFR §63.109 et al. on May 22, 2002.

2. NESHAPs is the acronym for New Emissions Standards for Hazardous Air Pollutants as promulgated by the U.S. EPA.

3. CSAPR is the acronym for Cross-State Air Pollution Rule promulgated by the U.S. EPA that severely limits air pollutants from being transported across state-borders to adversely affect the health and well-being of the victims in states downwind from the polluter.

4. Readers are welcome to contact the authors to discuss the application of Hess's Law and its effect.

# Capture and Conversion

("CRS").

Each of the systems includes subsequent processing of the captured pollutants into marketable end-products. Since the CEFCO Process is designed to be installed in modules, the users among the diversified groups of power producers (who may already have various conventional technologies, such as FGD, SCR, or baghouses installed with Activated Carbon Injection for significant Mercury removal) may want to retain their sunken investments, but to install some of the modules of the CEFCO Process in conjunction with or to augment their other recently installed processes, in order to meet compliance of the new regulations. The CEFCO technology is flexible and capable of accommodating such situations.

CEFCO Global Clean Energy designed the system for CO<sub>2</sub> Capture and MPC to work below 15%<sup>5</sup> total energy penalty or parasitic load. Moreover, the CEFCO Process uses post-power-generation "waste steam"<sup>6</sup> that is returning via the Return-Loop to be condensed for re-boil, etc. The shockwave is generated by channeling the low-quality or spent steam (through aerodynamically designed supersonic nozzles) that exits into a sub-atmospheric and adiabatic zone of the reactor at such energy and pressure that no other heat, pressure or catalyst are needed.

This will enable endothermic, then exothermic, reactions to capture the intended target and make a product. Thus, the CEFCO Process creates the most economical energy and reactive condition where all reactions take place within seconds, so the equipment footprint and spatial volume are very small in comparison to other technologies. Furthermore, the source of heat applied to liberate the purified CO<sub>2</sub> from the bicarbonate-carbonate is a slipstream of the same spent steam (from the Return-Loop of the steam on its way to be condensed).

This heat as directed into the captured-product tank will cause the KHCO<sub>3</sub> contained inside to release the CO<sub>2</sub> to be sent to other uses<sup>7</sup>. By releasing the CO<sub>2</sub>, the KHCO<sub>3</sub> is regenerated into K<sub>2</sub>CO<sub>3</sub> and returned to be reused in the process, as shown in relevant



Figure 4 - CEFCO's 1 to 3 MW thermal equivalent pilot plant at Peerless Manufacturing Company's premises in Wichita Falls, Texas

equations later.

The mass-transfer, capture mechanism and chemical reagents<sup>8</sup> injected applicable in each module of the CEFCO Process, and the co-production of Potassium Sulfate and Potassium Nitrate Fertilizer end-products have been described in great detail in the published patent. The CEFCO Process uses alkaline reagents<sup>9</sup> that are used for capturing the SO<sub>x</sub>, NO<sub>x</sub>, as well as the CO<sub>2</sub>, and converting each of them into useful end-products. The use of K<sub>2</sub>CO<sub>3</sub> and KOH combination injected into the shockwave reactor modules is the proposed complete replacement for all the current chilled amine, ammonia and designer-amines, and any other conventional technological methods, for CO<sub>2</sub> Capture at the exit of the system.

The CEFCO Process is able to maintain the selectivity of capturing each group of pollutants in sequential order for Metals and Fine Particulates in the MRS, and in series SO<sub>x</sub> in the SRS, NO<sub>x</sub> in the NRS and CO<sub>2</sub> in the CRS by manipulating the five parameters of the Process: residence time, velocity, temperature, pressure and pH in each reactor module.

7. The CEFCO system is an energy-saving technology. Carbon Capture can be turned into an economic process for producing alternative fuels in conjunction with other alternative fuel-technologies, such as via combination with introducing water or hydrogen in the modern Syngas (CTL) or in the Methane (GTL) process, or with algae production using the Potassium Sulfate and Potassium Nitrate Fertilizers end-products for making bio-diesel, etc.

8. Using a Hydroxide Solution (such as KOH) and/or a Carbonate Solution (such as K<sub>2</sub>CO<sub>3</sub>) in different respective modules for capturing each group of the SO<sub>x</sub>, the NO<sub>x</sub> and CO<sub>2</sub> respectively and converting each group of them into useful and sellable end-products. By using such a combination of reagents, the CEFCO Process anticipated the capability of some CO<sub>2</sub> being captured in the SRS, as well as some more CO<sub>2</sub> being captured in the NRS, thus lessening the overall load for 90% plus Carbon Capture in the CRS.

9. The co-inventors of CEFCO have studied and worked with NaOH + Na<sub>2</sub>CO<sub>3</sub>, as well as with KOH + K<sub>2</sub>CO<sub>3</sub>, for the past 30 years, and have specified them in the published patent. The CEFCO preference is for the Potassium-based reagents because they can make much more valuable end-products and will react faster with the targeted pollutant than Sodium-based reagents.

These parameters represent the intersection of physics and chemistry with the concept of reaction kinetics.

The CEFCO Process' final exit stack gas would be cleaned of metals, particulates, sulfur, NO<sub>x</sub> and carbon, leaving only pure O<sub>2</sub>, N<sub>2</sub>, Noble Gases, and water vapor. The next step is to harvest and separate such industrial gases. The final exit stack would only have to be normal industrial building-code height. No more tall stacks would be required in the future for power plants complex.

The following graphic will compare the time-and-energy saving features of using the aerodynamic principles in the CEFCO MACT Technology versus the time-and-energy consuming conventional thermodynamics used in the BACT technologies commonly available in the market place. The contrast is immediately apparent and the results are dramatically in favor of the CEFCO Process.

## CEFCO's Pilot Plant

In the spring of 2011, CEFCO Global Clean Energy and Peerless Manufacturing Co. (the licensed manufacturer of the CEFCO Process equipment in the USA) have established a variable control size ranging from 1 to 3 MW thermal equivalent pilot plant at a Peerless factory in Wichita Falls, Texas. In the recent months, systematic parametric testing has been in progress and certain operational and performance steps are being developed at the request of several power producers and cement producers.

## Energy Penalty Comparison of Post Combustion Carbon Capture Processes

In general the post-combustion CO<sub>2</sub> Capture technologies using conventional chemistry are reported to be in more advanced stages of commercialization compared to the Pre and Oxy-combustion processes. CO<sub>2</sub> absorption

5. Fifteen Percent (15%) is the maximum total energy penalty and parasitic load targeted by the Department of Energy, NETL, and many power producers as a reasonably acceptable commercial cost for pollution control and regulatory compliance.

6. This is the saturated steam that departs and exits from the fourth or last turbine in typical legacy power-generation on its way to the condenser, and the CEFCO Process will divert a slipstream of it for use to generate the shockwaves in the CEFCO Process. CEFCO uses between 3% to 6% in weight of such low-quality "spent" steam relative to the total mass (weight of 100%) of the polluted flue gas to generate shockwaves for the attack in each of the reactor module. Therefore, the CEFCO Process should not be regarded as "parasitic" on the energy to run electric power generation as a commercial consideration. It is to be considered as "borrowed water" which could be returned to the plant later (to be described).



in solvents such as amines is a technology (which has been in use in petro-chemical industries for almost 50 years) and offers a costly solution for capturing CO<sub>2</sub>. However, while it is a proven technology with predictable performance, it has the disadvantage of high energy consumption for solvent regeneration, equipment corrosion, high solvent losses due to fast evaporation and degradation by oxygen, and the slippage of the solvent into the captured CO<sub>2</sub>.

Conventional CO<sub>2</sub> Capture technologies significantly affect the plant design, thermal efficiency and turbo-machinery of a coal-fired power plant. The plant design must account for the CO<sub>2</sub> Capture system components from the exit of AQCS to the CO<sub>2</sub> scrubber and low pressure ("LP") steam has to be brought from the turbine to the scrubber. The "Balance of Plant" equipment needs to be enhanced to meet the CO<sub>2</sub> Capture system. The electrical system capacity may also be required to be upgraded for retrofits.

Moreover, a large quantity of steam is required to regenerate the solvent of an amine-based process. That steam requirement is estimated to be at 44 psi and 518°F and may range from 2.9 to 3.5 lbs to remove 2.2 lb of CO<sub>2</sub> from the flue gas. This would represent more than 50% of LP steam turbine's flow for a 90% CO<sub>2</sub> capture.

Consideration must be given for the turbine design to be able to change the configuration that allows the LP module to operate under zero-extraction conditions. There are four options available for extracting steam from the system: throttle LP, floating pressure LP, LP spool with clutched LP turbine, and backpressure turbine. The power losses for these steam extraction systems range from 7.0% for backpressure turbine to 12.3% for Throttle LP, the figures for floating pressure LP and LP spool with clutched LP turbine are 11.2% and 10.5%, respectively.

Additionally, the capacity of the condenser and the cooling tower must be able to accommodate the extra steam required when the capture system is not in operation. The overall impact of adopting a conventional amine CO<sub>2</sub> Capture system needs a detailed review of its complication.

Table 1 provides an example of the negative impacts of an Amine-based CO<sub>2</sub> Capture system on the overall performance of an 800 MW (net) power plant.

The above figures are of course dependent on a specific design and the type of technology used. As each steam turbine vendor uses a different cycle design with dissimilar IP module exhaust pressures, the output power of the non-condensing turbine varies accordingly.

PARAMETER	WITHOUT CCS	WITH CCS	PERFORMANCE PENALTY (%)
Plant Gross Power (MW)	865	702	19.0
Plant Net Power (MW)	800	542	32.3
Steam Turbine Gross Power (MW)	865	662	23.5
Auxiliary Loads (MW)	65	160	145
Auxiliary Load (%) on net power sent out	7.5	22.7	
Non-condensing Turbine Output(MW)	NA	40	NA
Crossover steam extraction	0	62% of IP Exhaust flow	NA

Table 1 - impacts of an Amine-based CO<sub>2</sub> Capture system on the overall performance of an 800 MW (net) power plant. (Table from POWER Magazine, June, 2008. Justin Zachary, "Options for Reducing a Coal-fired Plant's Carbon Footprint: Part 1.")

## CEFCO Process Energy Penalty Analysis Methodology

The preliminary design specifications, provided by CEFCO, for the 1 to 3 variable MWe pilot plant were the primary source of data used to calculate the total parasitic load for the CEFCO system, which can be divided into three main categories:

1. Injection Steam – the loss of usable steam from the power plant required by the CEFCO system
2. Electrical – all pumps and motors required to move reagent and other liquids through the CEFCO regenerating/recirculating system; including heat recovery and re-injection and miscellaneous lighting
3. Thermal – heat required for the decarbonation of CO<sub>2</sub> and fertilizer-product drying

The sum of these loads results in an overall parasitic loss value for the CEFCO System.

### Basis

1. Net output of the pilot plant to be 900 kW
2. 65% efficiency for turbine equivalency, pumps including motors
3. Steam taken from power cycle at an appropriate extraction point in the turbine
4. Steam requirement to be 4% of the flue gas mass flow for each stage of cleaning (conservative)
5. Thermal loads are satisfied via the utilization of waste heat from the pilot plant; i.e. thermal loads do not contribute to the parasitic load calculation.

Other minor assumptions were made based on the typical performance characteristics of industrial and auxiliary electrical and

mechanical equipment and basic thermodynamic properties.

Based on the preliminary information available and general engineering calculations for all four MPC and Carbon Capture Modules, the CEFCO Process' original total system energy penalty calculation of ≤ 15.0% (which does not include CO<sub>2</sub> transmission) is supported. The co-authors believe that CEFCO's estimated total system-wide energy penalty is advantageous relative to other experimental and conventional carbon capture technologies which typically range from 20% - over 30% for Carbon Capture alone, respectively.



## More information

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Plant Output (Design: 1 MW gross)	Net 900 KW
66 psia Low-Quality Steam:	36 KW
Electrical Loads:	
• Pumps & Motors	25 KW
• Lights & Misc.	1 KW
• Heat Rejection & Recovery	5 KW
<b>Parasitic Load — Total System:</b>	<b>67 KW (7.45%)</b>
Aux Loads (outside of CEFCO Process):	
• CO <sub>2</sub> Compression <sup>13</sup> (conventional method)	62.7 KW (conventional)
• Material Handling	N/A
<b>Parasitic Load (CEFCO + Aux) Total</b>	<b>129.7 (14.41%)</b>
Thermal Loads**	
Decarbonator	178.9 KW
Product Drying	91.6 KW

Table 2 - Calculated Energy Penalty of the CEFCO Process:



## A review of recent progress in ion liquids for CO<sub>2</sub> capture from flue gas

Recently, significant progress has been made in the application of Ion Liquids (ILs) as alternative solvents for CO<sub>2</sub> capture due to some of their unique properties.

By Maoqi Feng and Srinivasa Reddy

Ion liquids (ILs) are regarded as environmentally-benign solvents due to their immeasurably low vapor pressure. Recently, significant progress has been made in the application of ILs as alternative solvents for CO<sub>2</sub> capture due to their unique properties such as very low vapor pressure, a broad range of liquid temperatures, excellent thermal and chemical stabilities, tunable physicochemical characteristics and selective dissolution of certain organic and inorganic materials [1,2].

### What are ion liquids?

Ionic liquids (ILs) are liquid organic salts at ambient conditions. Typical ILs include two parts: the cation part, such as imidazolium, quaternary ammonium, pyrrolidinium, pyridinium, or tetra alkylphosphonium as the base, and the anion, such as hexafluorophosphate [PF<sub>6</sub>]<sup>-</sup>, tetrafluoroborate [BF<sub>4</sub>]<sup>-</sup>, bis(trifluoromethylsulfonyl) imide [(CF<sub>3</sub>SO<sub>2</sub>)<sub>2</sub>N]<sup>-</sup>, triflate [CF<sub>3</sub>SO<sub>3</sub>]<sup>-</sup>, acetate [CH<sub>3</sub>CO<sub>2</sub>]<sup>-</sup>, trifluoroacetate [CF<sub>3</sub>CO<sub>2</sub>]<sup>-</sup>, nitrate [NO<sub>3</sub>]<sup>-</sup>, chloride [Cl]<sup>-</sup>, bromide [Br]<sup>-</sup>, or iodide [I]<sup>-</sup>, etc. Figure 1 shows a typical IL, 1-n-butyl-3-n-propylamine imidazolium tetrafluoroborate, used for CO<sub>2</sub> capture.

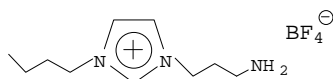


Figure 1. A typical ion liquid for CO<sub>2</sub> capture

CO<sub>2</sub> in these ILs is much higher than many other gases, including N<sub>2</sub>, O<sub>2</sub>, and CH<sub>4</sub>; at room temperature and atmospheric pressure, typically the solubility is around 0.02 mol CO<sub>2</sub>/mol IL. More detailed studies on the solubility of CO<sub>2</sub> in imidazolium-based ILs using attenuated total reflection IR (ATR-IR) spectroscopy and molecular simulation revealed that the interactions between the anions and CO<sub>2</sub> play a major role through weak Lewis acid-base or electrostatic interactions, while the cations play a secondary role.

Other applications for ILs include selective CO<sub>2</sub> separation from natural gas which contains a gas mixture of N<sub>2</sub> and CH<sub>4</sub> using ILs such as 1-butyl-3-methylimidazolium hexafluorophosphate ([bmim][PF<sub>6</sub>]). High pressure will make the process more efficient, because the CO<sub>2</sub> solubility in ILs increases with the pressure. At 8

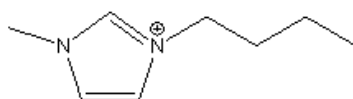


Figure 4. Molecular structure of 1-n-butyl-3-methyl imidazolium (BMIM)

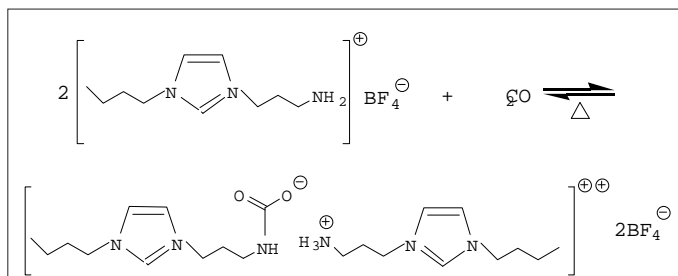


Figure 2. Reaction between ion liquid and CO<sub>2</sub>

MPa of pressure, CO<sub>2</sub> is highly soluble in [BMIM][PF<sub>6</sub>], reaching a mole fraction of 0.6, and the two phases are not completely miscible [4].

### Task-Specific Ionic Liquids for CO<sub>2</sub> Capture

The CO<sub>2</sub> absorption capability for conventional ILs is still not very high compared with some organic amines; it is necessary to modify ILs with the specific functional groups for high CO<sub>2</sub> capture capability. Due to the unique characteristics of ILs, alkaline group such as -NH<sub>2</sub> can be attached to the structure of cations or anions of ILs while still keeping the merits of the ILs [4].

The designed task-specific ILs (TSILs) can break the limitation of the conventional ILs and tackle the disadvantages of the commercially applied solvent such as aqueous amines. TSILs are expected to have dramati-

### Ion liquids Advantages for CO<sub>2</sub> Capture

ILs is a new and exciting class of compound that has the potential to overcome many of the problems associated with current CO<sub>2</sub> capture techniques. ILs are particularly applicable in the absorption of CO<sub>2</sub> (see Figure 2) while effectively avoiding the loss of the sequestering agents.

The solubility and phase behavior of CO<sub>2</sub> in ILs, such as imidazolium-based, phosphonium-based, and pyridium-based ILs, have been extensively studied in literature [2,3]. Figure 3 shows the CO<sub>2</sub> solubility for ILs with different anions. Experimental results also revealed that the solubility of

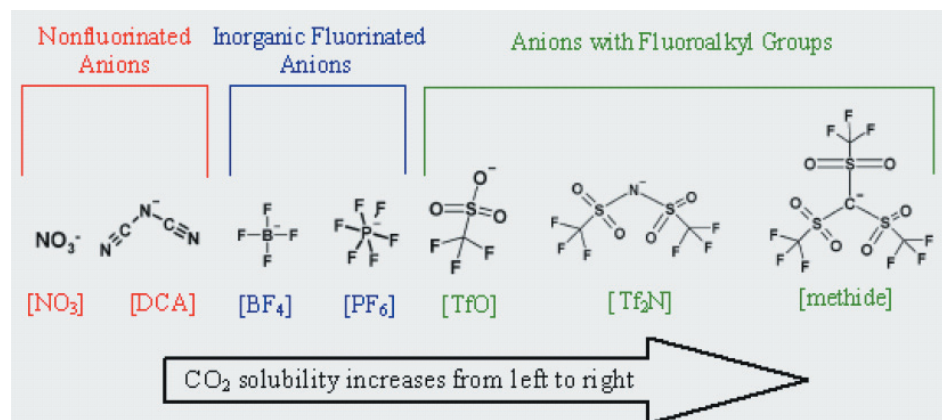


Figure 3. CO<sub>2</sub> solubility in [BMIM] cation (as shown in Figure 4) based ILs with seven different anions [3]

cally higher CO<sub>2</sub> solubility than physical absorbents.

Experimental study shows that the molar uptake of CO<sub>2</sub> per mole of TSIL during the 3 h exposure period reached 0.5, the theoretical maximum for CO<sub>2</sub> sequestration as an ammonium carbamate salt (Figure 5) [4]. The per mole uptake of CO<sub>2</sub> by the amine-appended TSIL is comparable to those of standard sequestering amines such as monoethanolamine (MEA), β,β'-hydroxyaminoethyl ether (DGA), and diisopropanolamine (DIPA). The process of CO<sub>2</sub> absorption is reversible, CO<sub>2</sub> can be extruded from the IL upon heating to 80–100°C for several hours under vacuum. The recovered ionic liquid has been repeatedly recycled for CO<sub>2</sub> uptake for multiple times with no observed loss of efficiency.

## Ion Liquid Polymers for CO<sub>2</sub> Capture

Recent progress on ILs for CO<sub>2</sub> capture is that ion liquids can be combined into polymeric forms; ion liquid polymers are formed as shown in Figure 6. This new type of ion liquids significantly increased the CO<sub>2</sub> sorption capacity compared with ionic liquids, and greatly facilitates the separation and ease of operation [5].

For example, the CO<sub>2</sub> sorption capacities for the polymers of tetraalkylammonium-based ionic liquids are 6.0–7.6 times of those of room temperature ionic liquids. Other advantages include: 1) the CO<sub>2</sub> sorption and desorption of the polymer solids are

fast, 2) the desorption is reversible. These polymers are very prospective as sorbent for CO<sub>2</sub> capture and as membrane materials for CO<sub>2</sub> separation.

The CO<sub>2</sub> sorption property of P[VB-TMA][BF<sub>4</sub>] as a function of pressure is shown in Figure 7 [6]. The sorption capacity increased with the increase of the CO<sub>2</sub> pressure. At 12 atm. pressure, P[VB-TMA][BF<sub>4</sub>] absorbed 44.8 mol% of CO<sub>2</sub> (in terms of its monomer units), which is much higher than that of room temperature ionic liquids.

The CO<sub>2</sub> absorption of the polymers is quite selective. There was no weight gain when the polymers were exposed to N<sub>2</sub> or O<sub>2</sub> under the same conditions. Moisture could slightly decrease the CO<sub>2</sub> absorption capacity. For example, wet P[VB-TMA][BF<sub>4</sub>] with 13.8 mol% water had a CO<sub>2</sub> absorption capacity of 7.9 mol%, lower than that of dry P[VB-TMA][BF<sub>4</sub>] [6].

Ionic liquid polymers are polymer materials that selectively absorb CO<sub>2</sub> with higher absorption capacity and faster absorption/desorption rates than room-temperature ionic liquids. These characters make these polymers exceptionally promising as absorbent and membrane materials for CO<sub>2</sub> separation. The ionic liquid polymer membranes can also be used for CO<sub>2</sub> separation.

## Future Trend

In literature, there are more than 1,500 ionic liquids, and some 500 ionic liquids are produced commercially. ILs selected from the commercially available pool for CO<sub>2</sub> capture from flue gas still need recycling and degradation study. Functionalized ionic liquids containing amine group(s) are preferred because the CO<sub>2</sub> absorption capacity for these ILs is much higher. For ease of operation and reducing energy consumption, ion liquids in

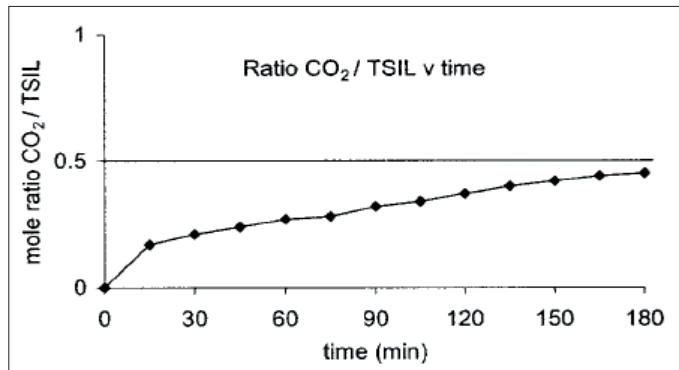


Figure 5. CO<sub>2</sub>/TSIL molar ratio as a function of time [4].

polymer form, and ion liquids supported on solid sorbents, such as silica gel [6], will be more and more popular.

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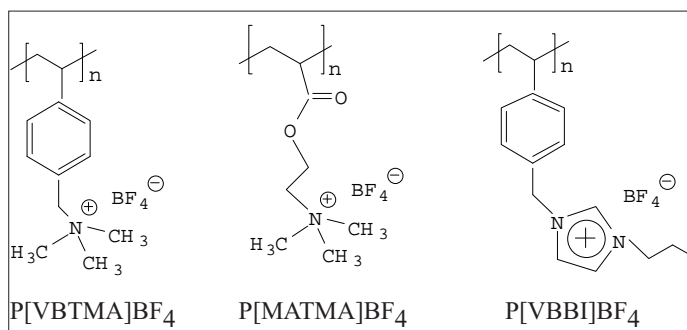


Figure 6. Polymer ion liquids for CO<sub>2</sub> capture [5]. Here P[VB-TMA]BF<sub>4</sub> = poly[p-vinylbenzyltrimethylammonium tetrafluoroborate]; P[MA-TMA]BF<sub>4</sub> = poly[2-(methacryloyloxy)ethyltrimethylammonium tetrafluoroborate]; P[VBB]BF<sub>4</sub> = poly[1-(p-vinylbenzyl)-3-butylimidazolium tetrafluoroborate].

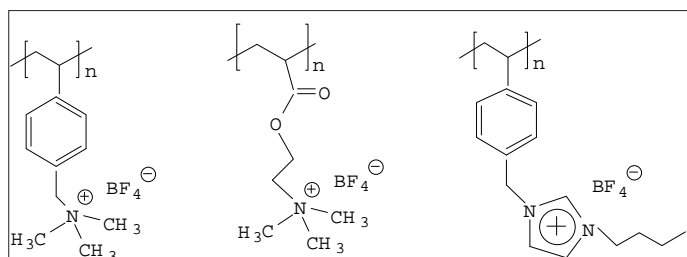


Figure 7. CO<sub>2</sub> sorption capacities of P[VB-TMA][BF<sub>4</sub>] at different CO<sub>2</sub> pressures at 22°C [6]

# Capture and Conversion

## Capture news

### Aker's SOLVit research programme enters second stage

[www.akercleancarbon.com](http://www.akercleancarbon.com)

Aker Clean Carbon has signed agreements with E.ON and EnBW for the second stage of the SOLVit research and development programme.

The aims of stage 2 of the SOLVit programme are to select a "green and energy efficient" solvent, measure emissions and degradation in pilot plants and develop emission control systems.

EnBW's carbon capture pilot in Heilbronn in Germany will be integrated as part of the on-going programme. Two comprehensive test campaigns are scheduled to be run at Heilbronn during next year. The EnBW pilot has a capture rate of 300 kg of CO<sub>2</sub> per hour and is connected to a 816 MWel, gross coal fired power station. The operating results will be compared to similar data from the Tiller R&D pilot rig in Trondheim and the Mobile Test Unit (MTU), presently operating at the National Carbon Capture Centre in Alabama, USA.

E.ON has been an active partner in SOLVit from the start and has now entered into stage 2.

The main goal of the SOLVit pro-



*Aker Clean Carbon's mobile test unit*

gramme is to develop functional and environmental friendly post combustion systems, utilising absorption chemistry and adapted process design. The technical target is to

demonstrate a 50% reduction in energy demand of the capture process within 2016, based on a reference case from 2008.



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# CO2 hydrate as a possibility for CO2 disposal

CO2 hydrate offers a possible technology for capturing and disposal of CO2. In this technology CO2 can be captured in the form of hydrate, transported and released at great depths into the ocean. Another option is to form the hydrate in the ocean at conditions that allow the hydrate to be thermodynamically stable.

By Jerome Rajnauth and Maria Barrufet

Hydrates are crystalline materials made up of water and one or more hydrate forming substances such as CO2, nitrogen, methane etc. Within the hydrates, the hydrate forming molecules are held by Van der Waals forces in a metastable crystal lattice made up of water molecules (Makogon, 1985). The water molecules form a three dimensional shell, into whose voids, molecules with low molecular weight and small rotational diameter enter and become stable. At high pressures and/or at low temperatures, thermodynamically stable hydrates will form.

Disposal of CO2 in form of CO2 hydrate in the ocean may be a possibility of reducing the atmospheric concentrations of this greenhouse gas and assist in mitigating global warming. CO2 emitted from burning fossil fuels is believed to be a major contributor to the amount of CO2 levels in the atmosphere. CO2 hydrate is denser than seawater (Adam, 1995), and therefore CO2 hydrate deposited in the ocean will sink to the seabed as long as the disposal site is within the hydrate formation envelope.

## CO2 Hydrate Potential

PVTSim(Calsep, 2008) was used to analyze the CO2 hydrate potential for CO2 disposal. We estimated hydrate equilibrium lines for different samples and salinity environments without making an attempt to calibrate the model with experimental data.

Fig.1 compares the equilibrium curves of a dry gas sample (99% methane), 100% CO2 in fresh water, and 100% CO2 sample in seawater. This figure indicates that salinity has a pronounced inhibitor effect on the hydrate equilibrium formation pressure of CO2. Above 37 oF, the pressure for 100% CO2 sample in seawater to form hydrates increases drastically. Therefore it is important to form hydrate in seawater below < 37 oF. The seawater composition used in the analysis was 96.5% water and 3.5% NaCl.

## CO2 Disposal Options

The options for carbon dioxide disposal using hydrate technology are listed below.

1. The first option is to use pure CO2, form the hydrate at surface and dispose it at

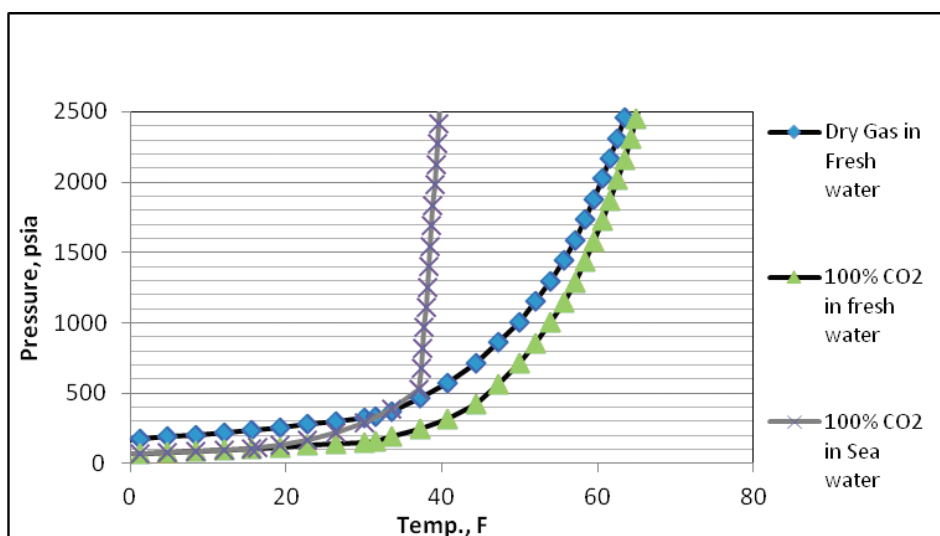


Fig. 1 - Hydrate equilibrium curves for dry gas, 100% CO2, and 100% CO2 using seawater composition (3.5% NaCl).

sea. This option requires a hydrate formation plant and large amounts of water. In some countries water is available from produced water or through desalination plants.

2. The second option is to obtain CO2 (pure or with impurities) and to dispose it using hydrate technology at sea.

These options are shown in Fig. 2

## CO2 Hydrate Formation

Hydrate technology can be used to capture CO2 gas in the form of hydrates. The optimal mole ratio between water to CO2 gas is approximately 6:1, thus large amounts of water is required for the process. As seen in Table 1, the mole ratio of water to gas affects the volume of hydrate formed. A 6:1 mole ratio gives 100% volume of hydrate however if a smaller ratio is used, some free CO2 gas would remain.

Using a 6:1 mole ratio a linear relationship can be obtained which provides the amount of water required in bbl/d per MM-SCF/d of gas feed. This is shown below:

$$V_{\text{water}} = 811.6 \times V_{\text{gas}}$$

where  $V_{\text{water}}$  = amount of water in bbl/d and  $V_{\text{gas}}$  = CO2 gas feed in MM-

SCF/d

For example a 25 MMSCF/d CO2 gas feed as much as 20,290 bbl/d of water is required. Excess water may be used to ensure all gas is captured. Likewise the mass of CO2 hydrate (tonnes/d) formed as a function of CO2 gas feed in MMSCF/d is given by:

$$M_{\text{hydrate}} = 180.1 \times V_{\text{gas}}$$

For a typical plant capacity of 25MM-SCF/d gas feed, 4502 tonnes/d of hydrate is produced. The total weight of hydrate can be split into water and CO2 as follows:

$$M_{\text{water}} = \frac{6M_{\text{hydrate}}}{7} \text{ and } M_{\text{CO2}} = \frac{M_{\text{hydrate}}}{7}$$

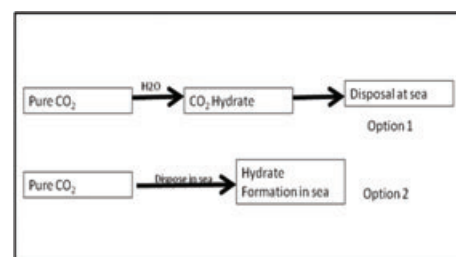


Fig. 2 - The schematic of the two options proposed to dispose CO2 using Hydrate Technology

Mole Ratio	Volume % of Hydrate Formed
1:1	34.53
2:1	57.00
3:1	72.30
4:1	83.62
5:1	92.27
5.5:1	95.87
5.9:1	98.47
6:1	100.00
6.1:1	100.00

Table 1 – Volume % of hydrate formed for varying

In the hydrate formation process, water and CO<sub>2</sub> gas is fed into a reactor. This produces CO<sub>2</sub> hydrate and water which then passes through a separator where excess wa-

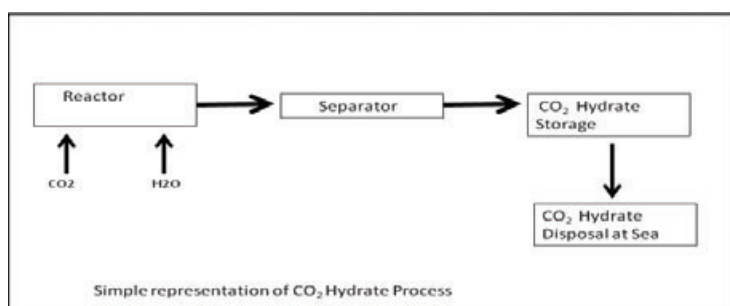


Fig.3 - Simple diagram of the CO<sub>2</sub> Hydrate Process

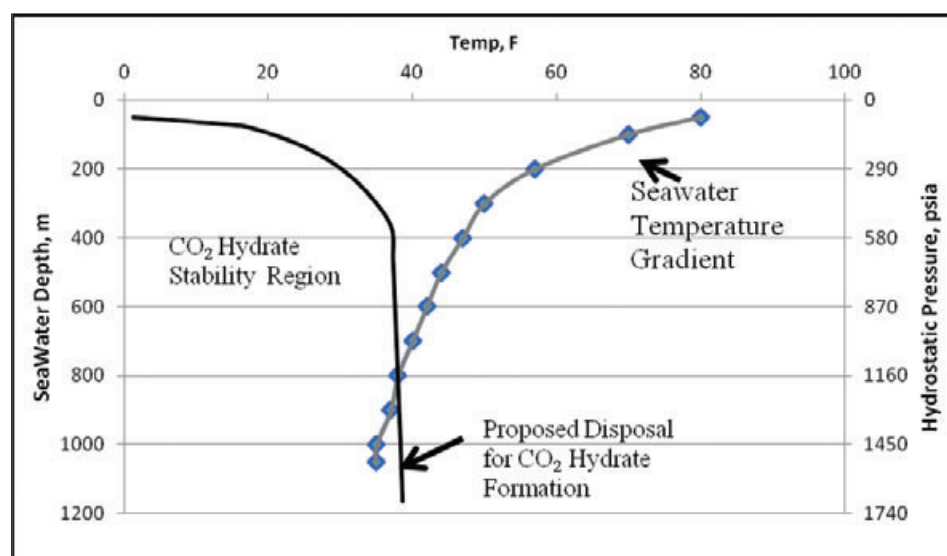


Fig.4 - Seawater Temperature Gradient with pure CO<sub>2</sub> hydrate equilibrium line with corresponding Depth and Hydrostatic Pressure

ter is removed and the hydrate stored for transportation. This simplified representation of the process is shown in Fig.3.

## CO<sub>2</sub> Disposal

Two options are examined for transporting and disposing CO<sub>2</sub> at depths (800 to 1000 m) in the ocean. In one case, CO<sub>2</sub> or CO<sub>2</sub> hydrate can be pumped from a land-based center through long pipelines laid on the ocean floor. The other case considered oceanic tanker transport of CO<sub>2</sub> or CO<sub>2</sub> hydrate to an offshore floating structure or fixed structure for vertical injection to the ocean floor.

The possible depth range for CO<sub>2</sub> disposal is 800 to 1000 m. Fig 4 shows the CO<sub>2</sub> hydrate equilibrium line with the seawater temperature gradient. The point where seawater gradient crosses the equilibrium line indicates the region of hydrate formation or hydrate disposal in seawater. This region starts at about 800 m and corresponds to about 1160 psia and 35 oF.

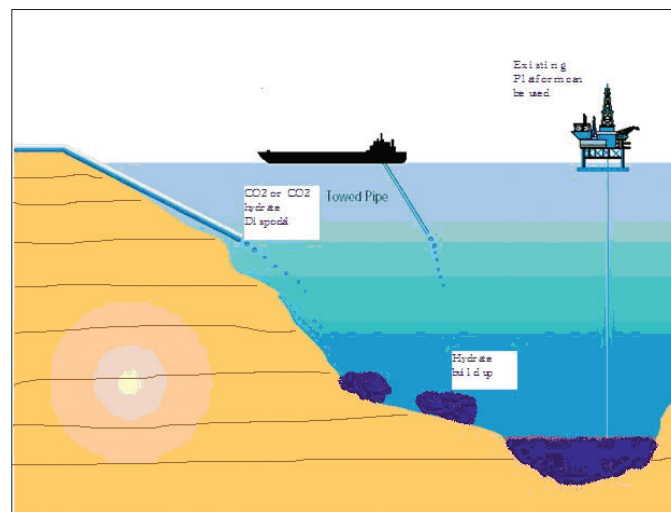


Fig. 5 - Disposal Options for CO<sub>2</sub> and CO<sub>2</sub> hydrate (Modified from Omerod et al, 2002)

for CO<sub>2</sub> and CO<sub>2</sub> hydrate disposal. There are several possibilities of disposing both CO<sub>2</sub> to form hydrate and CO<sub>2</sub> hydrate. This can be done using a subsea pipeline, ship or tanker and existing fixed platform. Disposal using a ship gives the option of moving to different disposal sites.

## Pipeline

Pipeline technology is sufficiently advanced that the oil and gas industry already constructs vertical risers in deep water and places seabed pipelines in depths down to 1.6 km to transport oil and gas. Overland pipelines for CO<sub>2</sub> have been operating in the USA for many years, over distances of up to 800 km; this is CO<sub>2</sub> which is used for enhanced oil recovery schemes but very similar principles would apply to disposal of CO<sub>2</sub>. If the desired release depth cannot be reached by an offshore pipeline, discharge of CO<sub>2</sub> from a ship or fixed platform could be considered. (Omerod et al., 2002)

## Ships or Tankers

CO<sub>2</sub> transportation by ship is similar to liquefied petroleum gas transportation by ship. The capacity, service speed, number of ships and shipping schedule could be planned considering the capture rate of CO<sub>2</sub>, transport distance, social and technical restrictions. The use of ships for transporting CO<sub>2</sub> across the sea is today in an embryonic stage. A CO<sub>2</sub> cargo tank should therefore be the pressure type or the semi-refrigerated type to keep CO<sub>2</sub> in the transported phase (Coleman et al, 2005).

## Fixed Platform

An existing platform may also be useful in CO<sub>2</sub> and CO<sub>2</sub> hydrate disposal. The vertical pipeline for disposal must be attached to the

platform and should be strong and thick walled to withstand its weight and strong waves. The pipeline may be anchored to the sea to assist in stability.

## Basic Heat Transfer Considerations

Basic heat transfer was estimated for the vertical pipe to 1000 m. This was done as a simple estimation of the heat loss or gain.

## CO2 Disposal and CO2 Hydrate Disposal

Figs 8 and 9 show the seawater temperature gradient with proposed pipeline length for CO2 disposal to form the hydrate and CO2 hydrate disposal.

The heat transfer between systems was estimated from:

$$Q = \alpha A \Delta t$$

The 1000m vertical pipeline was split into 200 m segments for this analysis. The temperature rise or fall for each section of the pipeline was evaluated for a particular pipeline diameter and flow rate. The average temperature for each section was used in the computation. The assumption here is that the temperature in each segment is uniform. This is seen in Figs 8 and 9.

The disposal of CO2 at 1000m to form hydrate, results in a heat loss and associated temperature fall. The disposal of CO2 hydrate results in a heat gain and a temperature rise.

The results show that when disposing CO2 only at any flow rate, the cumulative temperature change is relatively small (0.4 to 1.8 0F) and therefore CO2 may not be sufficiently cooled to form the hydrate. There is a temperature difference of 50 0F when CO2 enters the sea and therefore it would take a longer time to move into the hydrate formation region (Fig. 4). Hence, there is need for further cooling of CO2 before disposing into the sea.

The heat transfer calculations for disposing CO2 hydrate shows that at the lowest flow rate, the temperature rise is highest (3.16 0F cumulative) and may result in CO2 hydrate dissociation, moving outside the region of hydrate stability (Fig. 4). However, for the higher flow rates the cumulative temperature rise ranges between 0.73 to 1.26 0F, and may ensure that CO2 hydrate remain in the hydrate stability region (Fig. 4).

## Discussion

The ecological impact of CO2 hydrate is a factor that needs to be carefully assessed and monitored with pilot projects. Disposal of CO2 in the form of hydrates in the sea is a great potential as the ocean is vast and occupies 70% of the earth's surface. Numerous power plants and petrochemical plants are

located near the coast-line and hence there is easy access to the ocean. The CO2 hydrate formation with impurities should further be investigated as this method offers significant savings in CO2 disposal because of minimal cost of CO2 capture.

## Conclusions

Based on the seawater temperature gradient used in this analysis, CO2 can be disposed at a depth of 1000m to form hydrate.

The options for CO2 and CO2 hydrate disposal may be possible using ocean pipeline and ocean ships.

The pipeline diameters for different flow rates for CO2 and CO2 hydrate disposal are similar.

Formation of CO2 hydrate on land requires the use of large quantities of water.

More CO2 is disposed per day when CO2 hydrate is formed in the ocean rather than CO2 hydrate pumped in the ocean

Transportation of CO2 or CO2 hydrate by ships gives the option of moving to different disposal sites.

This analysis shows that transporting CO2 by pipelines to form hydrate in ocean is the most cost effective method of disposal.

Disposing CO2 only into the sea will require some additional cooling to ensure hydrate formation

CO2 hydrate disposal at a higher flow rate is most effective.

Current technology exists that can be used in CO2 and CO2 hydrate disposal.

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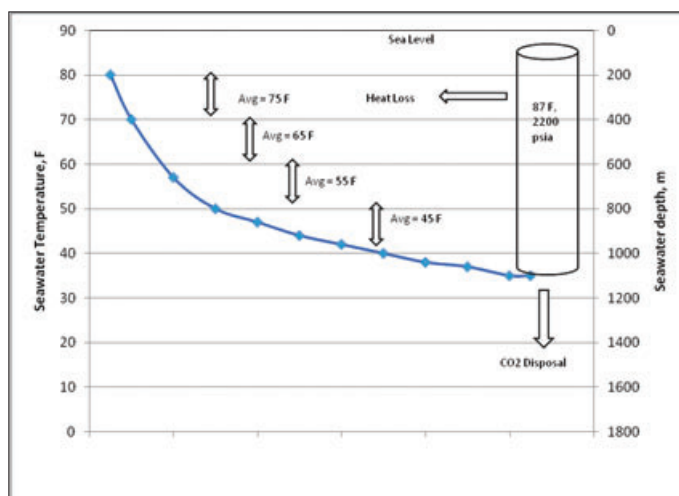


Fig. 8 - Sea temperature gradient to 1000m for disposal of CO2 to form the hydrate in the ocean

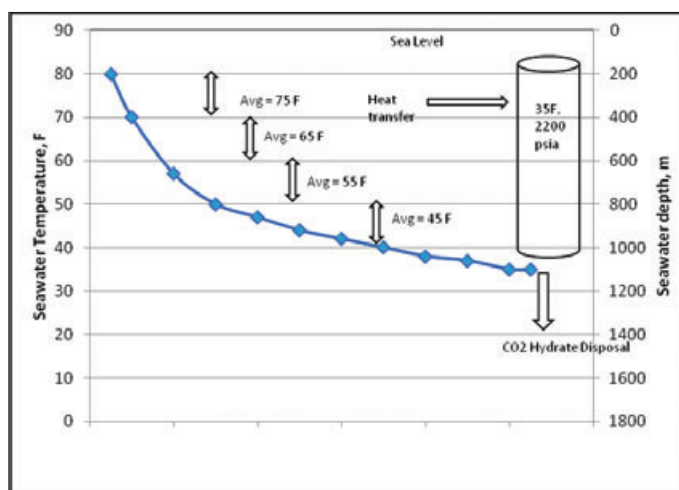


Fig. 9 - Sea temperature gradient to 1000m for disposal of CO2 hydrate

Software.

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## Transport and storage news

### Midwest Regional Carbon Sequestration Partnership field test results suggest potential to store hundreds of years of CO<sub>2</sub> emissions

Injection field tests conducted by the Midwest Regional Carbon Sequestration Partnership (MRCSP) suggest that geologic capacity exists to permanently store hundreds of years of regional CO<sub>2</sub> emissions in nine American states.

MRCSP's just-released Phase II final report indicates the region has likely total storage of 245.5 billion metric tons of CO<sub>2</sub>, mostly in deep saline rock formations, a large capacity compared to present day emissions. While distributed sources such as agriculture, transportation, and home heating account for a significant amount of CO<sub>2</sub> emissions in the MRCSP area, over half of the emissions come from large, stationary sources such as power and industrial plants. These units account for nearly 700 million metric tons annually.

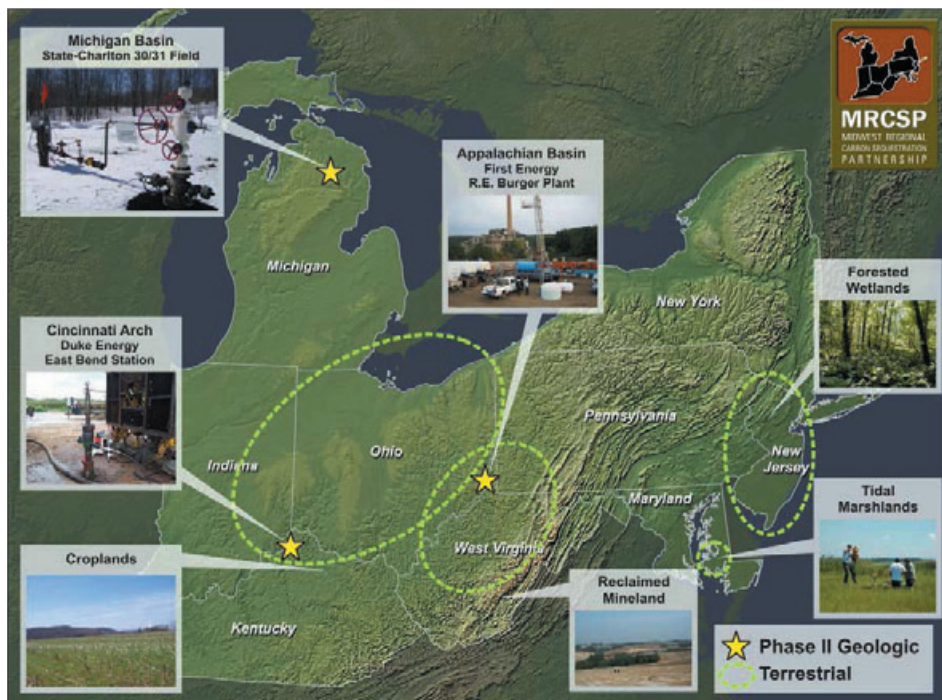
MRCSP is one of seven Regional Carbon Sequestration Partnerships (RCSPs) established by the U.S. Department of Energy's (DOE) Office of Fossil Energy (FE) to determine the best geologic and terrestrial storage approaches and apply technologies to safely and permanently store CO<sub>2</sub> for each partnership's specific region.

MRCSP's Phase II small-scale geologic field tests used less than 60,000 metric tons of CO<sub>2</sub> injection into selected deep saline formations to validate data from earlier Phase I, or characterization, research. Deep saline formation injection is a storage type that represents the most significant geologic storage potential for the United States. These latest results turn earlier information into practical, real-world knowledge for the most promising carbon storage technologies.

Phase I projects characterized large point sources of CO<sub>2</sub> and potential geological and terrestrial storage options for the region, which comprises Indiana, Kentucky, Maryland, Michigan, New Jersey, New York, Ohio, Pennsylvania, and West Virginia. In all, seven small-scale field validation tests were conducted in Phase II:

Three geologic injection tests, one in each of the three major geologic provinces of the region: the Michigan Basin, Appalachian Basin, and Cincinnati Arch, and hosted by major power companies in the region.

Four terrestrial field tests in land types characteristic of the region's diversity: croplands, reclaimed minelands, reclaimed marshlands, and forested wetlands.



*Locations of the Various Field Tests Conducted in MRCSP Phase II*

Phase II terrestrial field tests showed that the MRCSP region can potentially store about 15 percent of the region's annual CO<sub>2</sub> emissions from large point sources, such as power plants. In particular, Phase II confirmed that no-till agriculture is a valuable carbon storage strategy with the added benefit of improved soil quality and agronomic productivity.

MRCSP Phase II field tests also determined that oil-and-gas fields have a high potential for enhanced oil and gas production associated with CO<sub>2</sub> storage. In addition, using CO<sub>2</sub> for enhanced coalbed methane recovery also shows potential for storing CO<sub>2</sub>. The MRCSP estimates that by using CO<sub>2</sub> for EOR, approximately 1.2 billion barrels of oil could be recovered from existing oil fields in their region helping to offset the cost of deploying CCS technologies.

Managed by FE's National Energy Technology Laboratory, the seven RCSPs, which includes the MRCSP, focus on CCS opportunities within their specific regions, developing a regional carbon management plan to identify the most suitable storage strategies and technologies, aid in regulatory development, and propose appropriate infrastructure for CCS commercialization.

The MRCSP project, led by Battelle, included a public-private collaboration with nearly 40 members from government, industry, state geological surveys, and universities across the nine member states.

### Illinois CO<sub>2</sub> injection test commences

[www.fossil.energy.gov](http://www.fossil.energy.gov)

The Midwest Geological Sequestration Consortium (MGSC), one of seven regional partnerships created by the U.S. Department of Energy to advance carbon storage technologies nationwide, has begun injecting CO<sub>2</sub> for their large-scale CO<sub>2</sub> injection test in Decatur, Illinois.

The test is part of the development phase of the Regional Carbon Sequestration Partnerships program, an Office of Fossil Energy initiative launched in 2003 to determine the best approaches for capturing and permanently storing gases that can contribute to global climate change.

The CO<sub>2</sub> is being captured from the Archer Daniels Midland (ADM) Ethanol Production Facility in Decatur, Illinois. A processing plant built for this project removes water from the CO<sub>2</sub> stream and then compresses the dry CO<sub>2</sub> to a liquid-like "supercritical" dense phase. The compressed CO<sub>2</sub> then travels through a mile-long pipeline to the wellhead where it is injected into a deep saline formation more than a mile underground.

Up to 1 million metric tons of CO<sub>2</sub> will be injected into the Mt. Simon Sandstone at a depth of about 7,000 feet over a 3-year period. The Mt. Simon Sandstone is the thickest and most widespread saline reservoir in the Illinois Basin, with an estimated CO<sub>2</sub> storage capacity of 11 to 151 billion metric

tons. Analysis of data collected during the characterization phase of the project indicated that the lower Mt. Simon formation has the necessary geological characteristics to be a good injection target.

In October, the Illinois Environmental Protection Agency completed its review of the injection facilities' specifications and approved injection operations as per the terms of the Underground Injection Control Permit which was finalized in March 2011. This marks the first time a large-scale CO<sub>2</sub> injection test in a saline formation has been approved for operation in the United States.

Baseline environmental data collection has been underway for more than a year. During and following injection, a comprehensive monitoring program will ensure that the injected CO<sub>2</sub> is safely and permanently stored. The position of the underground CO<sub>2</sub> plume will be tracked, and deep subsurface water, groundwater, and surface water will continually be monitored around the injection site. The monitoring program will be evaluated yearly and modified as needed.

## U.S. DOE awards University of Kansas \$11.5m to test CO<sub>2</sub> storage

[www.kgs.ku.edu](http://www.kgs.ku.edu)

**The Kansas Geological Survey (KGS) at the University of Kansas (KU) has received a \$11.5 million award from the U.S. Department of Energy to test the safety and efficacy of storing CO<sub>2</sub>, captured from an industrial source, underground in south-central Kansas.**

A collaborative effort between government and industry, the four-year project includes scientists from the KGS, the KU and Kansas State departments of Geology, Wichita-based BEREXCO Inc., Lawrence Berkeley National Laboratories and Sandia Technologies.

The injection well is within the boundaries of the Wellington oil field south of Wichita in Sumner County, and the CO<sub>2</sub> will be transported from the Abengoa Bioenergy Corporation plant near Colwich.

It is planned that at least 40,000 metric tons of CO<sub>2</sub> emitted by the plant will be compressed and injected more than 5,000 feet underground into the lower portion of the Arbuckle aquifer, which is about 1,350 feet beneath the Wellington field's Mississippian producing zone.

In addition to the CO<sub>2</sub> introduced into the Arbuckle, approximately 30,000 metric tons will be injected into the shallower oil-producing Mississippian formation as part of an enhanced oil recovery pilot program.

Besides injecting CO<sub>2</sub> at the Wellington site, the researchers will use observation wells and state-of-the-art monitoring tech-



*Aerial view of the Otway project in Victoria, Australia*

niques to track the CO<sub>2</sub> plume and measure seismic and fluid properties.

The \$11.5 million cooperative agreement is from DOE's National Energy Technology Laboratory (NETL). Total DOE funding of the KGS's CO<sub>2</sub> sequestration research is approximately \$23 million.

Beyond the \$11.5 million DOE funding, the KGS and its partners — Kansas State University, BEREXCO Inc., Lawrence Berkeley National Laboratories and Sandia Technology — are providing nearly \$3.2 million in cost-share contributions, such as drilling and engineering personnel, equipment, facilities and discounted services.

## Otway project findings support geological CO<sub>2</sub> storage

[www.co2crc.com.au](http://www.co2crc.com.au)

**The CO<sub>2</sub>CRC Otway Project at Nirranda South in southwest Victoria, Australia, has provided verification of the underlying science of geological CO<sub>2</sub> storage.**

The journal paper 'Safe storage and effective monitoring of CO<sub>2</sub> in depleted gas fields', published this week in the Proceedings of the National Academy of Sciences of the USA, provides an overview of the science behind the project, led by the Cooperative Research Centre for Greenhouse Gas Technologies (CO<sub>2</sub>CRC).

"The Otway Project has confirmed that storage in depleted gas fields can be safe and effective, and that these structures could store globally significant amounts of carbon dioxide," said Dr Charles Jenkins from CSIRO, lead author of the paper and monitoring program manager.

"Since April 2008, CO<sub>2</sub>CRC re-

searchers used a natural source of carbon dioxide at the site to inject, store and monitor over 65,000 tonnes of CO<sub>2</sub>-rich gas, two kilometres underground in a depleted natural gas reservoir."

"The work has been a major scientific and logistical exercise covering risk assessment, monitoring and verification, reservoir modelling, regulation and community relations and has produced a huge amount of scientific and practical information on CO<sub>2</sub> storage and monitoring."

"The research included the world's first measurement of storage efficiency for CO<sub>2</sub> storage, lending weight to the conclusion that depleted gas fields have enough storage capacity to make a significant contribution to reducing global CO<sub>2</sub> emissions."

Monitoring of the stored CO<sub>2</sub> has been a major part of the project, allowing researchers to finetune a wide range of monitoring and verification procedures, including air, water, soil and sophisticated subsurface monitoring and sampling techniques. These showed that large-scale geological storage can be monitored to ensure safety, to confirm the stored CO<sub>2</sub> does not escape gradually back to the atmosphere and to underpin CO<sub>2</sub> trading mechanisms.

The CO<sub>2</sub>CRC Otway Project involves researchers from Australian universities and research organisations as well as researchers from the United States, Korea, Canada and New Zealand. The Project has been financially supported by the Australian Federal Government, through the Cooperative Research Centre Program, the Victorian State Government and the US Department of Energy, as well as CO<sub>2</sub>CRC members.



# Status of CCS project database

## The status of 78 large-scale integrated projects data courtesy of the Global CCS Institute

For the full list, with the latest data as it becomes available, please see the pdf version online at [www.carboncapturejournal.com](http://www.carboncapturejournal.com) or download a spreadsheet at [www.globalccsinstitute.com/resources/data](http://www.globalccsinstitute.com/resources/data)

Asset Lifecycle Stage	Project Name	Description	Country
Operate	<b>Century Plant (formerly Occidental Gas Processing Plant)</b>	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.	UNITED STATES
Operate	<b>Enid Fertilizer</b>	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.	UNITED STATES
Operate	<b>Great Plains Synfuel Plant and Weyburn-Midale Project</b>	About 3 million tonnes per annum 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 and Midale Oil Fields.	CANADA
Operate	<b>In Salah CO2 Storage</b>	In Salah is a fully operational onshore gas field in Algeria. Since 2004, 1 million tonnes per annum of carbon dioxide are separated from produced gas and reinjected into the producing hydrocarbon reservoir zones for storage in a deep saline formation.	ALGERIA
Operate	<b>Shute Creek Gas Processing Facility</b>	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.	UNITED STATES
Operate	<b>Sleipner CO2 Injection</b>	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.	NORWAY
Operate	<b>Snøhvit CO2 Injection</b>	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.	NORWAY
Operate	<b>Val Verde Natural Gas Plants (formerly Sharon Ridge)</b>	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.	UNITED STATES
Execute	<b>ADM Illinois Industrial Carbon Capture and Sequestration Project</b>	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.	UNITED STATES
Execute	<b>Agrium CO2 Capture with ACTL</b>	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.	CANADA
Execute	<b>Air Products Steam Methane Reformer EOR Project</b>	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.	UNITED STATES
Execute	<b>Boundary Dam Integrated Carbon Capture and Sequestration Demonstration Project</b>	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.	CANADA
Execute	<b>Gorgon Carbon Dioxide Injection Project</b>	This component of a larger gas production and LNG processing project will inject 3.4 to 4 million tonnes of carbon dioxide per annum into a deep saline formation. Construction is under way after a final investment decision was made in September 2009.	AUSTRALIA
Execute	<b>Kemper County IGCC Project (formerly Plant Ratcliffe)</b>	Mississippi Power (Southern Company) is constructing an air-blown 582 MW 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.	UNITED STATES
Execute	<b>Lost Cabin Gas Plant</b>	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.	UNITED STATES



# Status of CCS project database

State / District	Volume CO <sub>2</sub>	Operation Date	Facility Details	Capture Type	Transport Length	Transport Type	Storage Type	Project URL
Texas	8.5 Mtpa	2010	Natural Gas Processing	Pre-Combustion	256 km	Onshore to onshore pipeline	Enhanced Oil Recovery	<a href="http://www.oxy.com/">http://www.oxy.com/</a>
Oklahoma	0.68 Mtpa	1982	Fertiliser Production	Pre-Combustion	192 km	Onshore to onshore pipeline	Enhanced Oil Recovery	<a href="http://www.kochfertilizer.com/">http://www.kochfertilizer.com/</a>
Saskatchewan	3 Mtpa	2000	Synthetic Natural Gas	Pre-Combustion	315 km	Onshore to onshore pipeline	Enhanced Oil Recovery	<a href="http://www.cenovus.com/">http://www.cenovus.com/</a>
Wilaya de Ouargla	1 Mtpa	2004	Natural Gas Processing	Pre-Combustion	14 km	Onshore to onshore pipeline	Onshore Saline Formations	<a href="http://www.insalahco2.com/">http://www.insalahco2.com/</a>
Wyoming	7 Mtpa	1986	Natural Gas Processing	Pre-Combustion	190 km	Onshore to onshore pipeline	Enhanced Oil Recovery	<a href="http://www.exxonmobil.com">http://www.exxonmobil.com</a>
North Sea	1 Mtpa + 0.7 Mtpa in construction	1996	Natural Gas Processing	Pre-Combustion	0 km	Offshore to offshore pipeline	Offshore Saline Formations	<a href="http://www.statoil.com/en/">http://www.statoil.com/en/</a>
Barents Sea	0.7 Mtpa	2008	Natural Gas Processing	Pre-Combustion	150 km	Onshore to offshore pipeline	Offshore Saline Formations	<a href="http://www.statoil.com/en/">http://www.statoil.com/en/</a>
Texas	0.4 - 1.3 Mtpa	1972	Natural Gas Processing	Pre-Combustion	132 km	Onshore to onshore pipeline	Enhanced Oil Recovery	<a href="http://www.exxonmobil.com/">http://www.exxonmobil.com/</a>
Illinois	Up to 1 Mtpa	2013	Chemical Production	Industrial Separation	1.6 km	Onshore to onshore pipeline	Onshore Saline Formations	<a href="http://www.adm.com/">http://www.adm.com/</a>
Alberta	0.585 Mtpa	2014	Fertiliser Production	Pre-Combustion	234 km	Onshore to onshore pipeline	Enhanced Oil Recovery	<a href="http://www.agrium.com/">http://www.agrium.com/</a>
Texas	1 Mtpa	2012	Hydrogen Production	Pre-Combustion	Not specified	Onshore to onshore pipeline	Enhanced Oil Recovery	<a href="http://www.airproducts.com/">http://www.airproducts.com/</a>
Saskatchewan	1 Mtpa	2014	Power Generation	Post-Combustion	100 km	Onshore to onshore pipeline	Enhanced Oil Recovery	<a href="http://www.saskpower.com/">http://www.saskpower.com/</a>
Western Australia	3.4 - 4 Mtpa	2015	Natural Gas Processing	Pre-Combustion	10 km	Onshore to onshore pipeline	Onshore Saline Formations	<a href="http://www.chevronaustralia.com/">http://www.chevronaustralia.com/</a>
Mississippi	3.5 Mtpa	2014	Power Generation	Pre-Combustion	75 km	Onshore to onshore pipeline	Enhanced Oil Recovery	<a href="http://www.mississippipower.com/">http://www.mississippipower.com/</a>
Wyoming	1 Mtpa	2012	Natural Gas Processing	Pre-Combustion	370 km	Onshore to onshore pipeline	Enhanced Oil Recovery	<a href="http://www.conocophillips.com/">http://www.conocophillips.com/</a>



# ROSS OFFSHORE

## FOCUS ON CO<sub>2</sub> FOR EOR



Photo: Statoil

### CAPTURE, TRANSPORT AND STORAGE

Ross Offshore utilizes the Oil and Gas Business experience in the challenge to evaluate safe storage reservoirs for CO<sub>2</sub>, suitable subsea systems, well designs and CO<sub>2</sub> for EOR. With carbon capture, evaluation and selection of the most appropriate capture technology and plant design to match the industrial plant is vital. Transportation addresses alternative pipeline routes, designs, as well as conducting flow assurance.

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**Our experience  
– Your success**

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