carbon capture journal

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# CCS in Australia

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*Front cover: The CRC-1 wellhead at the Otway carbon dioxide storage demonstration project in Victoria, Australia - multiple injection and monitoring wells means the Otway Project is well placed for future collaborations*

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# CarbonNet full-chain CCS project advances

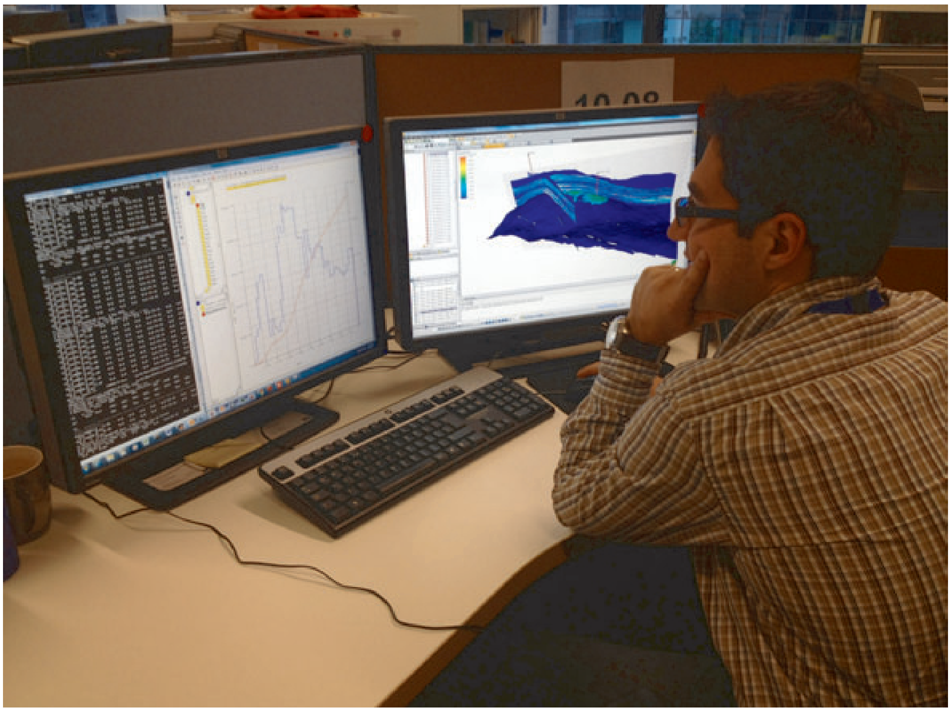
Australia's CarbonNet Project is well advanced in its investigation into the feasibility of a commercial-scale, multi-user CCS hub in the state of Victoria's Gippsland region.

**By the Department of State Development, Business and Innovation, Government of Victoria**

CarbonNet emerged out of a number of Australian and Victorian government initiatives, culminating in early 2012 with the project being awarded Australian Government CCS Flagship status along with $100 million in joint Australian and Victorian government funding to continue with detailed feasibility studies.

The project's multi-disciplined team has led a range of detailed studies investigating the whole CCS chain, including capture and pipeline options, commercial, environment, regulatory, planning, and social issues, and the geological assessment of storage sites in the Gippsland Basin.

The project anticipates the feasibility studies (including securing rights to its preferred offshore storage sites) will be concluded next year. This will inform a business case to support a decision to undertake field activities to assess the preferred storage site, such as seismic surveys and drilling.



*CarbonNet has shortlisted three potential offshore storage sites out of an initial 14 options, with one prioritised for field investigation*

## Storage site selection and DNV certification

CarbonNet's storage investigation programme built on earlier work by the Australian Government's Carbon Storage Taskforce, which identified the offshore Gippsland Basin as "Australia's most suitable storage basin"*, and the Victorian Government's geological research, which identified the near shore zone as presenting the best opportunities for storage in the short to medium term.

CarbonNet's team of geoscientists, modellers and reservoir engineers, supported by industry consultants, drew on a wealth of existing data from the oil and gas industry which has operated in the region for over 50 years, to identify sites with the potential for secure CO2 storage.

Initially, 14 storage site options were identified, each comprising two possible storage intervals (sections of the geological stratigraphy that is suitable for carbon dioxide (CO2) injection, with a sealing layer of cap rock). An extensive and methodical assessment and ranking process led to three offshore sites being identified for further analysis, with one prioritised for field investigation. The prioritised site has the capacity to store up to 125 million tonnes of CO2 in the main storage interval, with additional unquantified potential in other intervals.

CarbonNet's storage site analysis and assessment follows a robust process consistent with international best practice. The project's evaluation process and findings have been subjected to four international review processes involving experts and scientific peers. In addition, in November 2012, the project engaged global quality control and risk management services provider Det Norske Veritas (DNV) to assess its storage site selection process with reference to DNV's recommended practice (DNV-RP-J203). CarbonNet obtained the first stage of DNV certification for the portfolio of three offshore sites in January 2013.

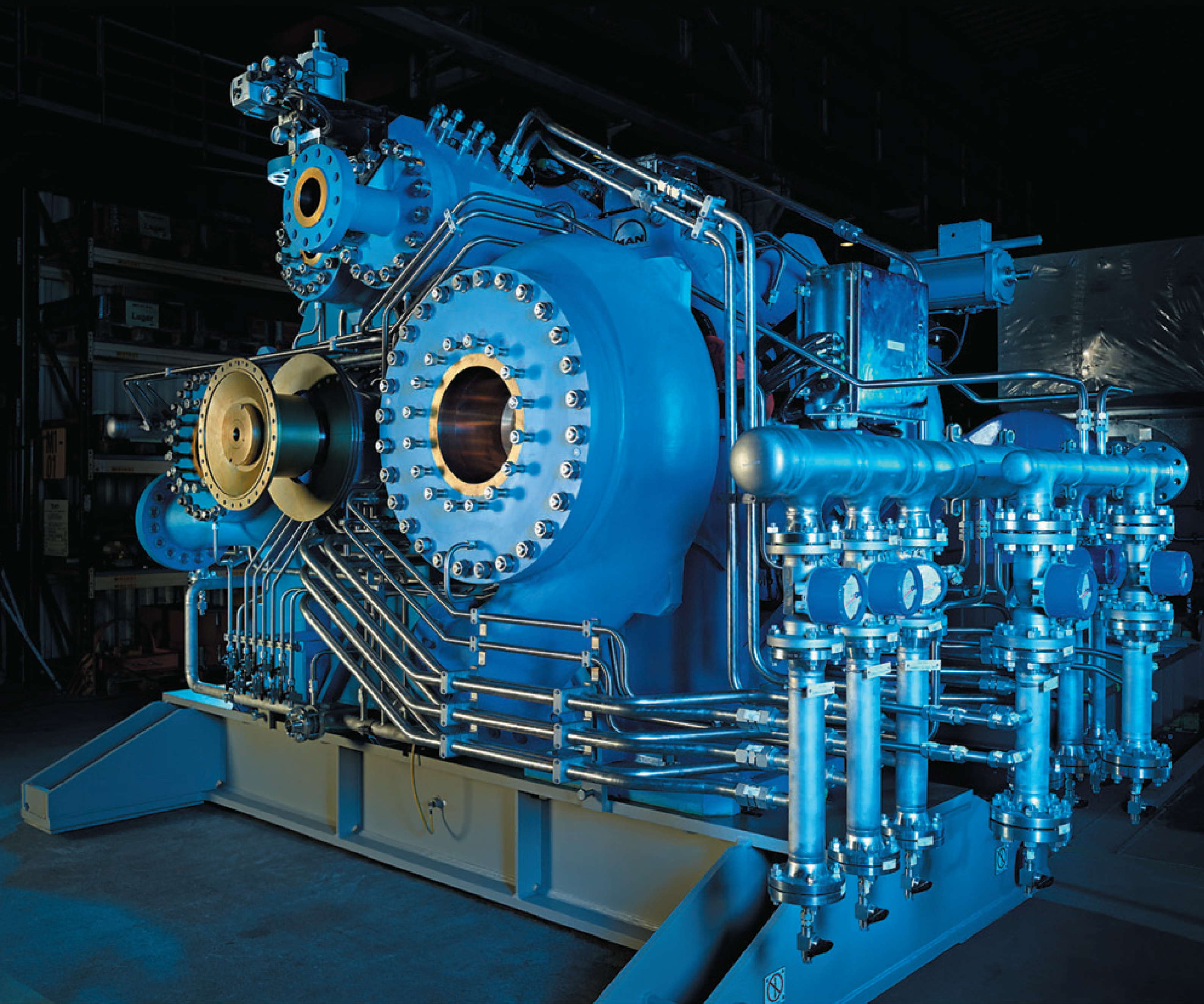
The project is currently seeking DNV verification for its appraisal plan, which outlines a range of potential field activities to acquire additional data for conformance with recommended practice, secure the necessary regulatory approvals, and to confirm CarbonNet's geological modelling of the prioritised offshore storage site. This process included a two day intensive workshop involving the CarbonNet team, its advisor Schlumberger Carbon Services, and a DNV panel of five technical specialists in key areas of geoscience and storage integrity, who meticulously scrutinised the proposed appraisal plan.

## Assessing technical feasibility – CO2 capture and transport

Supported by a range of professional consultancies including Parsons Brinckerhoff, GHD and AECOM, CarbonNet has undertaken a number of technical studies focused on CO2 capture and transport, including the related environment and planning aspects.

A whole of project basis-of-design has been prepared, which links together all elements of the CCS chain. The basis of design defines key parameters such as the CO2 specification which would represent the interface between industry and the CarbonNet network.

In a process similar to the project's



storage site assessment, potential pipeline corridors from the Latrobe Valley – where the region's vast brown coal resources are located – to the offshore storage site approximately 130 kilometres away, have been assessed and prioritised.

A transport economics model has also been constructed to allow scenarios to be tested for infrastructure capacity sizing and staging. This will allow decisions on the optimal size and timing of pipelines to be made, once volumes of CO2 to be captured have been confirmed with industry.

Further, CarbonNet has developed a regulatory approvals strategy for the transport and storage components of a commercial-scale, multi-user CCS hub in the Gippsland region. The project's environmental and regulatory team is now liaising with regulators at the state and Commonwealth level to understand requirements and build confidence around the application of the legislative and regulatory framework.

*Approximately 40 regulators participated in a workshop as part of the Victorian Government's deployment of the Global CCS Institute's Regulatory Test Toolkit*

## Australia's first deployment of the Global CCS Institute's Regulatory Test Toolkit

In August 2013, the Victorian Government, led by CarbonNet and supported by the Australian Government and the Global CCS Institute, deployed the Global CCS Institute's regulatory test toolkit. The regulatory test toolkit is an exercise designed to help governments establish whether their CCS legislative and regulatory frameworks are fit for purpose. This was the first time the toolkit had been deployed in Australia.

Approximately 40 key Commonwealth and Victorian regulators took part in a one day workshop, where the applicable legislation and regulations were tested in relation to a hypothetical CCS project, to identify any potential issues, gaps, overlaps and opportunities.

The workshop was successful in prompting robust discussion, increasing the regulators' understanding of CCS and how the regulatory framework applies, and identifying areas for further consideration. A steering committee will collaborate with policy makers and regulators to review and progress the recommendations arising from the workshop.

A report presenting the outcomes and recommendations of the workshop has been released and is available for download on CarbonNet's webpages – www.energyandresources.vic.gov.au/carbonnet-regulatory-toolkit.

## An attractive proposition for industry

Victoria's Latrobe Valley is home to one of the world's largest brown coal resources, which is adjacent to the offshore Gippsland Basin, which has been assessed as having the greatest capacity for CO2 storage of any basin along Australia's eastern seaboard. The offshore Gippsland was ranked as the highest technically and it also has the lowest transport and storage cost per tonne of CO2 avoided*.

This presents significant opportunities for companies interested in capitalising on the coal resource, including generators, coal-to-products and other industries. CarbonNet has undertaken an extensive national and international industry engagement process and received strong support from a wide cross section of industry, with many emphasising the importance of CCS as an enabler for investment.

A framework for developing a business model for a network-based CCS project has been prepared by CarbonNet's commercial team and advisers. The commercial framework provides a structured approach for comparing alternative commercial and financial arrangements for a hub project with public and private participants.

This framework was presented at Victoria's Low Rank Coal Symposium 2014 and will form part of an upcoming knowledge sharing report supported by the Global CCS Institute.

## What next?

CarbonNet takes a stage gated approach to development of the project. This means government will make key decisions on whether to progress to subsequent stages following the successful completion of the current stage. The business case will provide recommendations on a pathway forward, including field activities to assess the preferred storage site.

Following government's consideration of the business case, appraisal of the preferred storage site will commence, drawing on current existing and committed funding. Each major field activity conducted as part of appraisal will require regulatory approvals, and will involve extensive stakeholder consultation. Engaging communities will be a key focus as the project progresses with on-the-ground and planning activities.

CarbonNet looks forward to presenting on the project's achievements and status to a broad range of national and international stakeholders at Australia's National CCS Conference in August-September this year.

**Carbon Storage Taskforce 2009*

### More information

More information on the conference including registration can be found at www.nationalccsweek.com.

For more information on CarbonNet or to register to receive the project's e-newsletter visit : www.energyandresources.vic.gov.au/carbonnet or email: CarbonNet.Info@dsdbi.vic.gov.au

# Latest CO2CRC Otway project news

The CO2CRC Otway Project has been an important research facility for work on geological storage, from its initial stage of demonstrating safe storage of CO2 in a depleted gas field, to more recent experiments leading to improved assessment of storage efficiency.

**By Tony Steeper, Communications and Media Adviser, CO2CRC**

As large scale carbon capture and storage projects are being built around the world it becomes even more pressing to improve confidence in geological carbon storage for communities and regulators.

Over the years a wealth of information has been gathered, giving CO2CRC valuable baseline measurements, extensively characterised geology and over eight years of assurance monitoring data. Significantly, the project also has very positive relationships with the local community, including nearby landowners, and well developed channels for regulatory approvals.

Multiple injection, production and monitoring wells, plus a supply of naturally occurring CO2, mean that the infrastructure is in place for ongoing research for many years to come. CO2CRC welcomes approaches from international research groups interested in collaborative research at the site.

The next major experiment planned for the Otway Project will investigate innovative geophysical methods to tackle three major research questions:

• What is the smallest amount of CO2 detectable by seismic techniques?

• Can we use seismic techniques to design a cost-effective long term monitoring system?

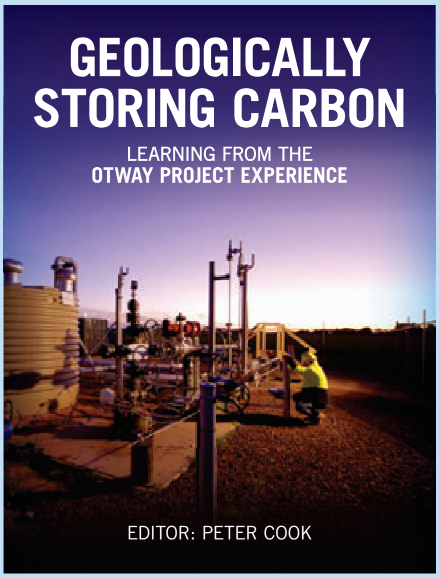
• Can these techniques be used to monitor the movement and eventual stabilisation of stored CO2?

The experiment, now underway, will see an injection of 10,000 – 30,000 tonnes of CO2 at a depth of about 1440 metres into the Paaratte formation. A number of geophysical methods will be used to monitor the gas in the saline formation, both from a new buried seismic array and from downhole sensors in existing wells.

The seismic array will consist of 1100 permanently installed geophones buried four metres underground, covering an area of one square kilometre. Research trials at the site have shown that burying the sensors significantly improves the resolution of the signals obtained.

The regulatory process has been rigorous but all the necessary approvals for the experiment have been obtained. CO2CRC has also worked closely with the landowners

## Geologically Storing Carbon: Learning from the Otway Project Experience




The CO2CRC Otway Project has been a major achievement, not only for CO2CRC but also for Australia. This collaborative, multidisciplinary project, involving an investment of over $70 million over nearly a decade, has established itself as one of the world's most significant sites for field-based research programs investigating geological storage of carbon dioxide, with research still underway.

Stage 1 of the project, the first trial of geological storage in Australia, broke new ground in several areas. The lessons learnt have informed legislation, government policy and the science and technology of reservoir modelling, geophysics, geochemistry, monitoring and verification, and community engagement. Stage 2 of the Project applied new techniques to better understand the trapping of CO2 in saline aquifers.

A record of this remarkable project has been in development for over two years and is now nearing completion, with the publication of the book Geologically Storing Carbon: Learning from the Otway Project Experience scheduled for mid-2014.

The book, edited by project conceiver Professor Peter Cook, comprises eighteen comprehensive chapters written by leading experts in the field. The book is concerned with outstanding science, but it is not a collection of scientific papers; it is about "learning by doing". For example it explains how the project was organised, managed, funded and constructed; and the approach taken to community issues, regulations and approvals. It describes how the team tackled understanding the site and addressed questions such as are the rocks mechanically suitable; will the CO2 leak; is there enough storage capacity; and, crucially, is monitoring effective?

The book will be of interest to geologists, engineers, regulators, project developers, industry, communities and anyone who wants to better understand how a carbon storage project really works. Available mid-2014, the book will be jointly published by CSIRO Publishing and Wiley.

## Sharing knowledge at National CCS Week

A diverse range of Australian and international experts from the resources sector, technology providers, government, academia and non-government organisations, including environmental NGOs, will come together at Australia's National CCS Conference to examine a range of climate change and CCS-related issues.

They will consider recent CCS research, technological advancements, including lessons learned through implementation, and effective community engagement strategies. They will explore strategies for addressing barriers to the global deployment of CCS technologies, including contemporary economic, social and policy issues. They will contemplate how CCS will evolve in the future energy mix and complement other low-emissions technologies. And key project proponents will provide updates on Australian and international CCS projects.

31 August - 3 September, Sydney, Australia

www.nationalccsweek.com.au

hosting the project to ensure the installation of the array, scheduled for later this year, disrupts farming operations as little as possible.

A program of seismic surveys, using both a surface source and a permanent source, will be run during injection and over several years following injection. The proposed injection zone is an eighteen metre thick reservoir with a permeability of several Darcies surrounded by impermeable layers. The gas plume is expected to be relatively thin and large in lateral extent. Therefore, the main challenge for the seismic method is to detect a thin plume on a background of noise.

Demonstrating CO2 plume stabilisation following injection will be a major outcome for research – something that has not been demonstrated before anywhere in the world. It will also be an important demonstration for the general public, showing that plume behaviour can be predicted by modelling and validated in field experiments. Demonstration of secure and permanent storage is critical if CCS is to be accepted by communities, regulators and governments.

The Otway Project has continued to prove itself to be an ideal facility for ongoing research and an excellent example of multidisciplinary collaboration across many organisations and countries, including the United States, the UK, Korea, Canada, Japan and New Zealand.


*The experiment will track the behaviour of injected CO2 in the subsurface over several years*

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 CO2CRC members.

**More information**

www.co2crc.com.au

# Callide oxyfuel project update

The $245 million Callide Oxyfuel Project in Central Queensland continues to lead the way in the demonstration and development of low emission coal-fired electricity generation, passing more than 6,000 hours of operation.

The project has been operating in oxy-firing mode at Callide A Power Station since December 2012, making it one of the most advanced carbon capture projects in the world.

Project Director Dr Chris Spero said the Callide Oxyfuel Project aimed to prove the suitability of oxyfuel technology for both new build and existing coal-fired power stations.

"The Callide Oxyfuel Project and other oxyfuel projects underway around the world are essential to the development of the technology and its future application at a commercial scale," Dr Spero said.

"We've been collaborating with R&D organisations and participants in other projects to carry out a number of tests at Callide A to help us optimise the technology and share knowledge. This will help progress the commercialisation and deployment of oxyfuel combustion with carbon capture."

Oxy-firing involves burning coal in a mixture of oxygen and recirculated exhaust gases, instead of air, and results in a concentrated stream of carbon dioxide (CO2) which is suitable for capture and storage.

The current demonstration phase follows the retrofit of Callide A with oxyfuel technology between 2009 and 2011 and the construction of a CO2 capture plant on the site.

The Callide Oxyfuel Project is also advancing the understanding of CO2 transport and storage options through its contributions to a number of feasibility studies and investigations.

*Callide Oxyfuel Project Director Dr Chris Spero does a test release of captured carbon dioxide at the project site*

The project is a joint venture between CS Energy, ACA Low Emissions Technologies (ACALET), Glencore, Schlumberger Carbon Services, and Japanese participants J-Power, Mitsui & Co., Ltd and IHI Corporation.

The project was awarded $63 million from the Australian Government under the Low Emissions Technology Demonstration Fund and has also received financial support from the Japanese and Queensland governments and technical support from JCOAL.

## Conclusions from the Callide project

(i) The principal driver for oxy-firing technology development has been CO2 capture, and secondarily reduction in other flue gas emissions. These drivers have been pursued through the 30 MWe Oxyfuel Boiler and 75 tonne per day CO2 capture plant at Callide A, commissioned in 2012.

(ii) Oxy-firing and CO2 capture at Callide A has demonstrated almost complete removal of all toxic gaseous emissions (such as SOx, NOx, particulates, and trace elements) from the flue gas stream, which are then disposed of via the waste ash/condensate streams of the process.

(iii) In the case of NOx, significant reduction in stack mass emission rates are observed under oxy-firing conditions due to the significant reduction in the amount of atmospheric Nitrogen (N2) normally associated with the comburent (O2) and hence reduction in Thermal NOx, and because of the re-burning effect on recycled flue gas in the furnace which reduces NOx back to N2.

(iv) Other benefits of oxy-firing that have been observed and measured are improved combustion efficiency measured as reduced Carbon-in-Ash, and a reduction in the tendency to produce furnace ash deposits.

(v) The Callide Oxyfuel Project has been complex for three principal reasons:

a. The Project required a large capital investment and being non-commercial required funding support from the Australian and Japanese Governments and the Coal Industry through COAL21, and equity from several Companies. The negotiation of the relevant Funding, Joint Venture and Project Agreements, required many considerations and issues to be resolved.

b. The demonstration project was a first-of-a-kind and therefore required very careful design and carried many perceived technical risks.

c. It was not possible to form a cost effective single Engineer Procure Construct (EPC) contract because of the complex and perceived technically-risky nature of the Project, so all the Capital Works had to be broken down into a large number of small contracts which were managed by Callide Oxyfuel Services Pty Ltd.

(vi) By the end of August 2013, the issues associated with running-in of new plant had been resolved, but not without a substantial effort and many learnings along the way by all concerned with design, construction, commissioning and subsequent operations and maintenance.

(vii) All phases of the Project have provided a great deal of knowledge and experience to inform future Oxyfuel technology development. It is very important to have the background from RD&D and pilot facilities and carefully considered design; but there will always be unforeseen issues in the plant.

(viii) Of particular note has been the learnings derived on the safety and environmental aspects of Oxyfuel combustion.

www.callideoxyfuel.com

# Australia's CCS Flagships Program

Dennis Van Puyvelde of Van Puyvelde Energy and CCS Research Consultants takes a look at how the recent Australian Budget affects funding for its CCS Flagships Program.

In 2009, the Australian Government allocated AUD2 billion to the Carbon Capture and Storage Flagships Program over a 9-year period[1]. The aim of this program was to support the development of industrial scale carbon capture and storage projects in Australia. The program included an allocation of AUD200 million towards research infrastructure through the Education Investment Fund (EIF).

The initial objective of the program was to facilitate commercial scale CCS within the 2015-17 timeframe, leveraging additional funding from industry and state governments. The first projects selected, and the Federal Government funding allocated, were:

- Zerogen in Queensland – $38.5m allocation[2]. The prefeasibility studies of this project were completed and it was decided not to proceed with the project.
- Wandoan/CTSCo in Queensland – $15.6m allocation. Prefeasibility studies were completed leading to the decision not to proceed with the project. An alternative project - the Surat Basin CCS Project - is under consideration[3].
- The South West Hub in Western Australia – allocation of $52m[4]. An in-principle commitment of $278m to the full commercial project was also made.
- The CarbonNet Project in Victoria – allocation of $ 70m[5]. The Victorian Government contributed an additional $30m towards the CarbonNet Project.

Two of these projects – South West Hub and CarbonNet - have proceeded beyond the initial phase and are currently focused on demonstrating the feasibility of geological storage and other preliminary studies for their project.

The EIF component has committed funding of $48.4 to the National Geosequestration Laboratory[6] linked to the South West Hub project and administered by CSIRO. $51.6 million has been allocated to the CCSNet[7] Project linked to CarbonNet and administered by CO2CRC.

In the six years since the announcement, AUD276.1m of the initial allocation has been committed towards projects. This represents a significant underspend compared to the initial funding profile of the program that aimed to have projects operational in the 2015/17 timeframe.

Unfortunately, the Federal Government has cut funding to the program in the last four Budgets:

- 2011/12 Budget[8] – a cut of $250m cut including $100m cut from the research infrastructure component (EIF). This money was used to contribute to the National Disaster Recover and Rebuilding program as a result of the major floods in Brisbane, Queensland at that time. Some of remaining money was postponed to later years as a result of underspending in the early years. A reallocation of $60.9m was also made for a National CO2 Infrastructure Plan. Overall, the 2011/12 Budget reduced the money available by over $300m and the available funds to the National CCS Flagships after this budget was $1.68 billion[9].
- 2013/14[10] – cuts to the program of $500m.
- Mid Year 2013/14 fiscal outlook[11]– additional cuts of $255.9m.
- 2014/15[12] – cuts to the program of $459.3m. After this budget, the total funding of $191.7m over seven years will remain available to existing projects.

The initial allocation of $2 billion towards industrial scale CCS projects was welcomed by the CCS industry in 2009/10. The subsequent cuts to the program have meant that only $484 million of the initial allocation is actually being directed towards industrial scale CCS deployment in Australia.

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www.budget.gov.au

# Demonstrating CO2 capture from industrial sectors in the UK

In November 2013, the UK Government commissioned a team led by Element Energy, and comprising Carbon Counts, PSE, Imperial College and the University of Sheffield, to carry out a study of industrial CO2 capture for storage or utilisation.

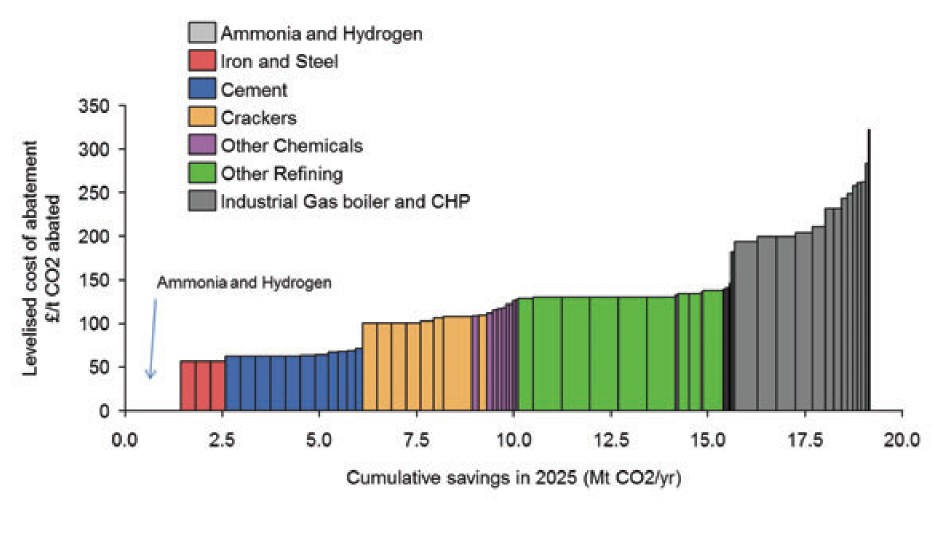
The primary focus of the study was assessing the technical potential and cost effectiveness for retrofit deployment of different CO2 capture technologies to the UK's existing largest (0.2-8 MtCO2/yr) sources of process CO2 emissions in the cement, chemicals, iron and steel, and oil refining sectors by 2025.

Techno-economic modelling was carried out to understand the cost effectiveness of deployment in different sectors and sensitivity to the main cost drivers. The analysis is based on current understanding of commercial-scale costs and performance of a number of capture technologies.

This is supplemented with process simulation-based analysis to provide, in a public and transparent format, detailed performance assessments, equipment requirements and cost estimates for plausible configurations for demonstration and commercial scale carbon capture projects at UK industrial sites. These assessments are combined with stakeholder interviews and literature reviews to provide overviews of barriers to uptake and current piloting and demonstration activities.

The technical and commercial maturity of CO2 capture for storage or utilisation varies between different source types. Globally maturity is highest for high purity CO2 sources and the upstream hydrocarbon processing industries, followed by coal and gas power.

Development of CCS in the other energy intensive sectors (cement, chemicals, iron and steel, and oil refining) lag several years behind these; there are no industrial retrofit CCS projects worldwide at the scale of UK industrial CO2 sources (ca. 0.1MtCO2/yr to a few MtCO2/yr) currently in operation in these sectors. This leads to significant barriers and uncertainties in feasibility, requirements, costs and performance.




*Marginal abatement cost curve for different subsectors for projects operational by 2025 in the pragmatic deployment scenario. Amongst the sectors analysed, the high purity sources represent the most cost effective capture opportunity, followed by the iron and steel and cement sectors*

## Technology and sector carbon capture potential in UK industry

Stakeholder interviews confirm that first-of-a-kind demonstration projects at the MtCO2/yr capture scale at UK sites in 2025 would need to take Final Investment Decision (FID) by 2020, and would seek to minimise risks by employing the most mature technologies with minimal integration challenges.

A number of capture technologies could be deployed in industrial retrofit demonstration scale projects in the period to 2025, including the following high technology readiness level (TRL) capture technologies:

- First generation amine solvents
- Physical solvents (greatest relevance for sources with high partial CO2 pressure)

as well as the following lower TRL capture technologies:

- Second generation chemical solvents (including advanced amines, amino acids and blends)
- Cryogenic technologies
- Solid looping technologies such as calcium looping

The analysis suggests that, in the absence of significant capture technology deployment in the period to 2020, capture technologies with a high TRL would deliver the highest abatement (in tCO2/yr abated) at a cost (based on £/tCO2 abated) competitive with lower TRL technologies.

With a strong technology push, leading to significant capture technology deployment in the period to 2020, currently lower TRL technologies could become significantly more cost effective (£/tCO2 abated) and their abatement potential (in tCO2/yr abated) significantly larger.

There are significant cost and performance uncertainties for both low and high TRL technologies, and site-specific interests and issues may dominate technology selection. Additionally there are other more novel capture technologies which are especially effective when integrated in the main process. This high level of integration is usually only feasible for new build facilities and would require significant process and facility redesign in retrofit applications.

The analysis indicates a 2025 abatement potential of 1.2 - 8.2 MtCO2/yr for marginal levelised costs of 22 - 74 £/tCO2 abated (excluding compression, transport and storage) by 2025 in the UK's 52 largest cement, chemicals, iron and steel and oil refining sites. However there is a significant variation in capture potential and cost effectiveness between sectors and between sites. In addition to the technology selection, the key factors affecting differences in cost effectiveness between projects in these sectors are:

1. CO2 concentration of source gas streams (cost increases with dilution).

2. Degree of contamination of the gas stream (additional gas clean up may be required; some capture technologies are more sensitive to impurities).

3. Mass flow rate of the source (where costs can reduce through economies of scale).

## Barriers to deployment of industrial carbon capture in the UK

For high purity CO2 sources small scale piloting is unlikely to add significant value, as CO2 can potentially be captured with limited further CO2 separation. However for other types of sources, the deployment scales of potential industrial CCS demonstration projects in the period to 2025 can be influenced by the number and scale of detailed engineering studies and pilot projects in the UK and worldwide in the period to 2020.

These engineering studies, pilots and demonstration projects can help reduce multiple barriers and uncertainties ahead of deployment at a commercially relevant scale. The analysis distinguishes between systemic barriers and barriers that can be addressed by pilot and demonstration projects. The most pertinent site level barriers which detailed engineering studies, pilots and demonstrations can reduce are:

- Increased operational complexity and risks (unavailability, process dependencies)
- Applications not proven at scale
- Plant integration risks (hidden costs of additional downtime, alternative product supplies, technology lock-in)
- High levels of uncertainty regarding costs

Further barriers that can be addressed by pilots include lack of staff familiarity and operating expertise, space availability, impact on product quality, effects of impurities, health, safety and environment (HSE) considerations, number of CO2 streams per site, and budgeting. The report also summarises the key systemic barriers and enablers for industrial capture deployment.

## Pilot and demonstrations of carbon capture in UK industry

Pilot and demonstration projects should be designed to remove barriers and reduce uncertainty, and achieve this in a manner that is safe, cost effective and minimises risks. Engineering studies and pilots will have increasing value the more closely the pilot conditions resemble those of the actual UK sites for which demonstration is planned.

Several UK industrial sites contacted during the course of this study, and covering all four industrial sectors, indicated a willingness-in-principle to participate in CO2 capture engineering studies, pilots and/or demonstrations. Work on capture should concentrate, at least initially, on those sites for which CO2 transport and storage infrastructure can be available in time for 2025.

For first generation amine solvents or physical solvents, there should be some opportunities to learn from CCS demonstration projects in the power sector, in the UK and internationally. In addition first generation amine solvent or physical solvent pilots of 0.1 Mt/yr in cement and up to 0.6 Mt/yr in oil refining in the period 2015-2020, would be valuable in advance of demonstration-scale projects. For second generation amine solvents and solid looping technologies, piloting will be necessary before industry would implement at a scale above 0.1 MtCO2/yr.

Potential timelines and project scales to achieve the DECC/BIS challenge of industrial CCS projects operational by 2025 vary between different subsectors:

- For the iron and steel sector, stakeholders confirmed that, with an ambition for a full scale project by 2030, a realistic demonstration project of 1-3 MtCO2/yr could be operational by 2025.
- To enable roll out at a scale of 0.9-1.5 MtCO2 in the oil refining sector by 2025, capture pilots at a scale of 0.1-0.7 MtCO2/yr could be implemented in the period to 2020, possibly tied to individual cracker units which are considered one of the likely first capture streams by industry experts.
- In the cement sector development of a project of 0.5 MtCO2/yr scale operating in 2025 could be achieved. It may be appropriate to start with one pilot at a scale close to 0.1 MtCO2/yr by 2020, and to actively ensure knowledge transfer from international pilots.
- The other chemicals, boilers, CHP and other refinery units typically have multiple, heterogeneous small CO2 streams, for which the feasibility and cost-effectiveness of CCS, relative to alternative abatement technologies are poorly understood. The next steps should mainly be focussed upon improving understanding of the individual CO2 streams, their conditions, and method and feasibility for capture.

## Carbon dioxide utilisation

In theory CO2 utilisation offers opportunities for improving the economics of capture or providing a use of CO2 for those sites that cannot access transport and storage infrastructure. A literature review reveals that utilisation options differ in terms of technology availability, market maturity, CO2 abatement potential, and relevance for large UK industrial sites.

A key challenge is that existing markets for CO2 are already competitively supplied with CO2 produced from existing industrial processes. A step change in CO2 utilisation could theoretically be achieved through the development of new markets and technologies.

However, the majority of emerging technologies are at too early a stage for deployment to reach the scale of 0.1-1 MtCO2/yr in 2025 that would be needed to support industrial capture, and the costs, performance and CO2 abatement potential of these are not yet well described in the literature.

Meaningful onshore CO2 utilisation levels are only possible with significant and carefully designed interventions to build markets and push technology development. Stranded industrial CO2 sources are unlikely to implement capture based on revenues from utilisation alone without additional policy support.

Annual revenues of £25-250million may be possible if some of the hurdles identified can be overcome. An upper limit for the potential for CO2 utilisation deployment in the UK by 2025 is estimated at 9 MtCO2/yr with annual revenues of up to £3 billion arising from the production of fuels, building products and chemicals based on CO2 feedstocks.

### More information

www.element-energy.com
www.carbon-counts.com
www.psenterprise.com
www.imperial.ac.uk
www.sheffield.ac.uk

# Alberta continues to support CCS

The Province of Alberta, Canada is continuing to invest in two carbon capture and storage projects: the Alberta Carbon Trunk Line and Quest Project.

**By the Government of Alberta**

*Minister of Energy Diana McQueen and Conservative MP Mike Lake tour the Quest Carbon Capture and Storage facility at Shell's Scotford plant near Fort Saskatchewan on April 17, 2014. The project is retrofitting the Scotford bitumen upgrader for carbon capture, designed for up to 1.2 million tonnes of carbon captured per year, piped 80 kilometres north and injected more than two kilometres below the Earth's surface. (Photo: Chris Schwarz/Government of Alberta)*

Alberta is a province with great energy resources, including sizable reserves of oil, natural gas, and coal. This presents both an opportunity and a challenge to the province. Alberta's carbon capture and storage program has taken some of the challenges inherent with the responsible development of its 168 billion barrels of oil sands resources and turned it into a carbon capture opportunity.

Almost all (99 per cent) of Alberta oil reserves are oil sands – a naturally occurring mixture of bitumen, sand, clay or other minerals and water. Buried under the province's northern forests, the development of the province's bitumen resource has been an extensive exercise in land use planning, environmental monitoring and developing the right technologies.

The Alberta government strives to develop its energy resources in the most environmentally responsible way possible. One of the ways it has done so is by establishing a single regulator as part of a larger integrated resource management system. The government has enhanced each piece of the previous regulatory system, including monitoring and reporting, and created a more efficient system to support continued growth and environmental management.

With large-scale bitumen upgrading underway, the province recognizes carbon capture and storage (CCS) is one way to significantly reduce greenhouse gasses. Other initiatives include developing the province's vast potential for renewable energy, including hydroelectricity, wind power and solar energy, and promoting energy efficiency. A

lberta's Energy Minister, Diana McQueen, is eager to share with global audiences the progress made on the province's carbon capture projects. "Our CCS program is doing what we want it to do, and that's making sure that as we grow our economy and become a global energy supplier we are doing it in a responsible way and reducing our emissions here in the province."

In 2009, the Alberta government began its CCS program by committing up to $2 billion for large-scale projects and making changes to legislation that enabled CCS. Through a competitive process $1.3 billion was committed to two large scale CCS projects over a 15-year period (2010 to 2025) – the Alberta Carbon Trunk Line / Sturgeon Refinery and Quest. The funding program has been designed in a way that the projects receive funding only when certain benchmarks have been achieved and verified. This provides assurance to provincial taxpayers that their money is well spent and that the projects are meeting specific targets.

To ensure success in the projects, the Alberta government undertook a Regulatory Framework Assessment, which looked at the rules for CCS in Alberta and best practices from around the world. Over 100 global experts on CCS, including representatives from industry, environmental groups, scholars and government worked on this review. The process, which began in 2011, released its report in August 2013, and produced 71 recommendations and conclusions on how to improve CCS in the province.

The final recommendations in the report will help strengthen all aspects of CCS within Alberta, including clearly defining the roles and responsibilities of the agencies that regulate CCS in Alberta and creating clear approval requirements; encouraging cooperation and fair development of CCS among operators; reviewing notification requirements for those living in the area where large scale carbon sequestration is underway; and ensuring access to sites for monitoring, measurement and verification activities. Another recommended action is to clarify the details of the Post-Closure Stewardship Fund, including obligations from operators to contribute to this fund. Alberta Energy, the government department responsible for energy development policy in the province, has committed to further examination and implementation of the recommendations over three years. This will ensure the appropriate policies and regulations are in place for when the CCS projects begin operation in 2015 and 2017.

Enhance Energy is building a 240-kilometre Alberta Carbon Trunk Line connecting a bitumen upgrader and fertilizer plant outside of Edmonton with enhanced oil recovery projects . The plant, better known as the Sturgeon Refinery, will be the first refinery in Canada with built-in carbon capture capacity.

The project is estimated to cost nearly $1.2 billion, with the company contributing $640 million, the Alberta government investing $495 million over 15 years, and the Government of Canada contributing $63.3 million. Development is well underway at the refinery site and it is expected to begin operation in 2017. Refinery aside, the partnership also continues to work on regulatory approvals and right of ways for its carbon pipeline.

The Quest project, a partnership of Shell, Chevron and Marathon Oil, involves retrofitting an existing bitumen upgrader outside of Edmonton for CCS and then piping the carbon dioxide 64 kilometres north where it will be permanently sequestered more than two kilometres below the surface. The project is estimated to cost $1.35 billion, with the Quest partners contributing $485 million, the Alberta government $745 million and the Government of Canada $120 million.

Currently, the Quest project is half constructed, with all major regulatory approvals granted in 2013. Construction is underway at the upgrader site, on the pipeline and at the sequestration site. Additionally, work on the baseline monitoring, measurement and verification is underway, including work on ground water and biosphere sampling. The Quest Project is on track for commissioning to begin at the end of 2014 and production in the second quarter of 2015.

McQueen sees the progress being made on the carbon capture units as important component in Alberta's approach to resource development. "Enhanced recovery is another positive impact of CCS projects. For Alberta this technology will allow for more efficient recovery of our resources and a greater return for citizens with less environmental impact. "

In addition to the benefit that CCS is bringing to Alberta and its energy industry, a fundamental part of Alberta's CCS program is sharing its learnings with other jurisdictions and stakeholders as they move forward with their own initiatives. Both projects are required to share technical information on their projects, and this information has been made available on the Alberta Energy website making it available to stakeholders from around the world. "We know that CCS is a powerful tool against climate change and the more jurisdictions taking advantage of this technology will be better for our planet and for future generations," said McQueen.

The knowledge sharing efforts are expected to lower the cost of future CCS projects, and capitalize on expertise from around the world to improve CCS in Alberta. One government in particular that is paying attention to what is going on in Alberta is China, where sharing information on CCS was included in a Memorandum of Agreement between China and the province of Alberta in October 2013. Delegations from around the world have been visiting Alberta to learn more about the projects underway and the policy work being done within government.

Alberta's commitment to CCS is unprecedented for a jurisdiction of 4 million people, and speaks to the importance the province places on responsible development of energy resources the world wants and needs.

**More information**

www.energy.alberta.ca

# CCS in the Netherlands - and the future of ROAD

**ROAD, the Dutch flagship CCS project, is currently "essentially mothballed" while the project team wait for financing. Speakers at the CATO conference discussed who should be doing more to get it moving – industry or government?**


*CATO research discussion – caption – A panel of CCS researchers from around the world were brought together at the CATO conference. From left to right: Professor Wei Wei, of Shanghai Advanced Research Institute (China); Jon Magne Johansen of Big CCS Centre in Trondheim (Norway); Stuart Haszeldine of the Scottish CCS Centre (UK); Jon Gibbins of the UK CCS Research Centre; Jan Brouwer of CATO (Netherlands); Robert Kleiburg of TKI Gas/ECN (Netherlands); and Isabelle Czernichowski-Lauriol of CO2GeoNet (France).*

The ROAD project, to capture CO2 from a new power plant located on the Maasvlakte, in the Port of Rotterdam, and store the CO2 in a depleted gas reservoir in the North Sea, just 25km away, is currently "essentially mothballed" while the project team wait for financing to be agreed, said capture director Andy Read.

He was speaking at the 7th Dutch CCS Symposium of Dutch research organisation CATO in Amsterdam on June 19-20.

CATO stands for CO2 Afvang, Transport en Opslag, or CO2 capture, transport and storage. ROAD stands for Rotterdam Opslag en Afvang Demonstratieproject or Rotterdam Capture and Storage Demonstration Project.

All the engineering for ROAD is complete, Mr Read said. So far the EU has committed Eur 180m to ROAD, the Dutch government 'up to' Eur 150m, and the Global Carbon Capture and Storage Institute (GCCSI) up to Eur 5m.

ROAD aims to capture CO2 from a new power plant located on the Maasvlakte, in the Port of Rotterdam, and store the CO2 in a depleted gas reservoir in the North Sea, just 25km away.

"It is one of the best CCS projects," Mr Read said. Being next to the sea, the capture plant doesn't need cooling water. There is a huge amount of industry adjacent to the North Sea [which could provide CO2]. Rotterdam already pumps CO2 to greenhouses to fertilise plants, and "this could be extended".

The ROAD project was launched in 2008, after E.ON agreed it could be connected to its new power plant. The project then became a key pillar of the Rotterdam Climate Initiative project.

Over the past six years the ROAD team has worked closely with CATO researchers on many aspects, including power plant integration, managing emissions, and flow assurance, he said.

For example there were concerns that the high pressure CO2 would freeze as it entered the low pressure (20 bar) reservoir and expand, and CATO did research to try to work out what would happen.

## Bert de Vries

Bert de Vries, Deputy Director-General, Department Energy and Sustainability Dutch Ministry of Economic Affairs, pointed out that ROAD is one of the biggest projects the Dutch government is considering altogether, comparable in size to major defence investments.

Mr de Vries said he would like to see more industry involvement in the project. "I'm a bit disappointed we in government are trying to find a solution, and there is not a big call from industry to join us," he said.

"If this [CCS] is not a strategic decision for industry, then we do have a problem. It cannot be that this is only government business."

From the government perspective, "CCS is a big challenge because it's new," he said. "You have competitors [for government funding] - solar and wind. I'm sure they will decrease enormously in price."

Mr de Vries said he expected to see rapid change in the energy industry in coming years. "There will still be centralised production, but there will be a lot of other producers," he said.

"10 years ago, you knew all the producers [companies producing electricity]," he said. "Today there are 125 different players producing electricity, producing it at very different moments. There will be more and more producers."

"In that world, CCS needs to have a place."

## Shell Nederland

Dick Benschop, president-director of Shell Netherlands and Vice-President Gas Market Development, and a former Dutch deputy Minister for foreign affairs, talked about the Barendrecht CCS project which Shell aimed to operate in the Netherlands in 2007-2010.

## Brad Page, GCCSI

Brad Page, CEO of the Global Carbon Capture and Storage Institute (GCCSI) said that for carbon capture and storage overall, "you have to say this is a North American story", with 19 large scale CCS projects at various stages of development in the US and 7 in Canada.

This compares with 4 in continental Europe, 13 in China, and 6 in the UK.

The European perspective is that UK and continental Europe "need to be treated differently, the trend is not in the same direction," he said.

The number of large scale projects in continental Europe (including Norway) has sadly reduced from 14 to 4 in the past 3 years, whilst the number of projects in the UK has dropped from 7 to 6.

The number of projects in the US and Canada has also declined in the past 3 years, from 25 to 19 in the US and from 9 to 7 in Canada.

However the number of projects in China has grown dramatically in the same period, from 6 to 13, he said. "This is what happens when you put CCS into a 5 year plan, you have a government deciding it wants to do something."

The first major power project with CCS should be Canada's Boundary Dam project at the end of September. "It puts to bed the argument that CCS doesn't work," he said.

"By early next year, the next major power project, Kemper County [Mississippi, USA] should come online, using its CO2 for EOR."

EOR is proving critical in making CCS work, he said. "You have to find these revenue sources."

So far, the only projects to store carbon capture in aquifers have been Norway's Snøvhit and Sleipner projects and Algeria's In Salah, all separating CO2 from natural gas wells (not from power stations). "Everything else has been EOR," he said.

Mr Page presented a chart showing all of the CCS projects developed in the past and planned for the future, with each project shown as a dot, with the dot blue for EOR projects and green for aquifer or 'dedicated geological' projects.

"Without EOR it would have been very hard to see green dots. EOR has held a big role in keeping CCS viable," he said.

Mr Page described developments around CCS in Europe as 'a mixed bag'. Europe is perhaps the region of the world most focussed on climate change, and has a big interest in energy security. "We see advanced CCS in Europe at Snøvhit and Sleipner," he said.

"But regulatory developments [in Europe] are disappointingly small. There's going to be some challenges making sure the next parliament comprehends the importance of CCS. We are not seeing CCS getting a specific policy focus except in the UK."

There are 3 components to the CCS business case: technology, policy and understanding he said. "The technology exists and it works. But it's a technology question to lower the cost. But getting projects operational is critical to gaining a positive perception, he said.

Mr Page included a quote from Fatih Birol, chief economist of the International Energy Agency, speaking to Wired Magazine for an article published in March 2014.

"Outsiders should be grateful that China is weighing in," Mr Birol was quoted as saying. "Somebody needs to figure out how to capture and store carbon dioxide on a massive scale before it's too late.

"I don't know of any other technology which is so critical for the health of the planet and at the same time for which we have almost no appetite. The only place it seems to be increasing is China."

Mr Page said he thought developing CO2 networks could be an important part of the solution of getting the costs down. "Hubs and networks are fast emerging," he said.

According to GCCSI's 2013 Global Status of CCS report, between 2008 and 2012, policy leader governments committed more than US$22billion in direct funding to large-scale CCS demonstration projects.

*Brad Page, CEO of the Global Carbon Capture and Storage Institute*

Barendrecht is a suburb of Rotterdam, and the project aimed to store carbon dioxide there.

Public campaigning led to the project being abandoned, despite intervention by Jacqueline Cramer, then Minister of Environment, and Maria van der Hoeven, then Minister of Economic Affairs.

Inhabitants feared the plan would endanger the town and lead to a fall in house prices.

"We all thought it was a great idea, it couldn't be better, but that was not the idea of the inhabitants," Mr Benschop said.

The story of how relations with local inhabitants was handled is now seen as "a story of how not to do it," he said.

As a result, "you'll probably see CCS going offshore for a while," he said. "But at some point in time we hope we would be able to come onshore.

"I think that would be difficult now."

Mr Benschop did not explain why Shell is not involved in ROAD.

Mr Benschop cited International Energy Agency figures from 2013 showing that "a global delay in CCS deployment would cause an increase in costs for power sector decarbonisation of $1 trillion".

He cited UK Energy Technology Institute data showing "without CCS the additional costs to run a decarbonised UK economy in 2050 will be £32bn per annum."

The best way to reduce CCS costs might simply be to build more CCS plant, he said. "You double [global] capacity and get 10 per cent cost off, and repeat a number of times," he said.

When it comes to finding the right financing arrangement, "UK is leading in Europe in terms of doing it with contracts for difference," he said.

Mr Benschop was asked if he thought there should be alternative approaches to the emissions trading scheme in achieving a low carbon society, on the basis that ETS has not been very successful so far.

"I find the UK example on the carbon floor price an interesting one," he said. There could also be "ETS reform, to get into a more meaningful CO2 price."

"If you look at transport, the cost of abatement is in triple figures [in terms of the money you have to spend to avoid a ton of

CO2 being emitted]. "So we are not able to live with a 30-40 euro CO2 price."

"There is one alternative, performance standards for the power sector," he said.

So when it comes to finding funding for CCS, as industry, "we don't lack objectives, we lack policy instruments," he said.

## Stan Dessens

Stan Dessens, conference chairman and a former Director General of the Energy Ministry of Economic Affairs for the Netherlands, noted that there are many companies who benefit from ETS being as low as it is, and many people who complain ETS is too low who would also like to see an alternative system.

Mr Dessens also noted that Chris Davies, a former Member of the European Parliament for North West England with the Liberal Democrat Party, had been the biggest advocate for Carbon Capture and Storage in the European Union. He lost his seat in the 2014 European Elections. He hopes that another MEP will replace Mr Davies as a CCS advocate.

The most important energy topic in Brussels at the moment is "security of supply," he said. "It would be quite easy in Brussels at the moment to get a billion euros for energy security."

## Ward Goldthorpe

Ward Goldthorpe, program manager for CCS and gas storage with the Crown Estate in the UK, noted that in the UK people no longer talk about 'demonstration', but talk about getting projects to the full scale.

Mr Goldthorpe also noted that the UK has managed to get CCS projects running by concentrating on getting large scale projects running and developing a suitable system for investors (contracts for difference), rather than spending money on research.

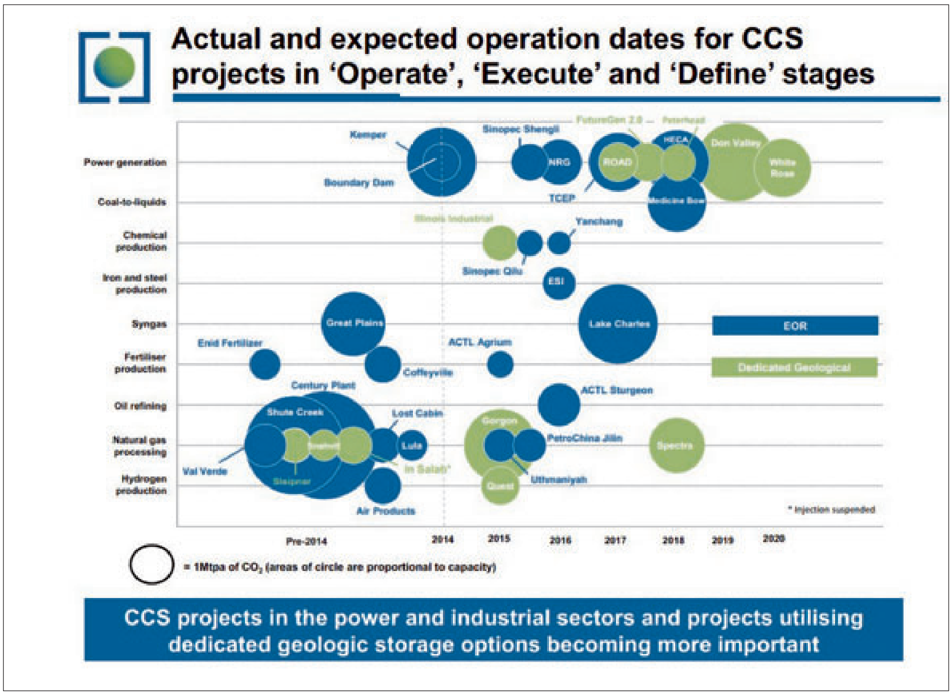
## Jon Gibbins, UKCCSRC

Jon Gibbins, Professor of Power Plant Engineering and Carbon Capture with the University of Edinburgh, said he thought it was time we saw a range of second and third generation CCS projects, building on the first generation projects done so far.

Most of the CCS projects still on the table are first generation projects, he said.

But it is also interesting to note that the two UK projects which are moving ahead, White Rose and Peterhead, are comparatively new projects, with discussions only starting about a year before the FEED funding was confirmed last year.

Mr Gibbins noted that CCS might take off earlier in developing countries, now organisations such as the World Bank and




*Mr Page presented a chart showing all of the CCS projects developed in the past and planned for the future (see box text opposite)*

Asian Development Bank (ADB) are refusing to fund new coal power plants which don't have CCS.

When it comes to who pays for CCS, Mr Gibbins thought it was the wrong question, since ultimately "it is the customers who pay."

## Stuart Haszeldine, University of Edinburgh

Stuart Haszeldine, professor of carbon capture and storage at the School of Geosciences, University of Edinburgh, said that in his view, there is still not enough public or political demand for carbon capture, so it is not rising high enough up the political agenda.

"The public don't understand that we've got to make choices," he said.

Carbon capture and storage "has to be something which feels inevitable," he said. "The politicians have to believe it is possible and can be done now. "Public perception feeds the government."

"If the Dutch government wanted ROAD they'd find EUR 250m by the end of the week," he said.

Because politicians don't think the public thinks there is a problem, they are not giving a signal to industry that it should be investing in CCS.

"Companies will do it when they have to," he said.

On the plus side, the industry has public 'permission' to store offshore, and the regulatory framework is there, he said.

Having a "demonstration project will prove it can work," he said.

We need more understanding of how CO2 + EOR works, and we also have to develop a legal infrastructure for cross border CO2 transport, he said.

It would be possible to start doing carbon capture in the North Sea now by using gas tankers, he said, rather than wait for the pipelines and offshore infrastructure to be developed.

One audience member questioned whether the carbon capture industry should be attacking the wind sector harder, since it is winning all the government attention. "We [CCS people] have had a policy of not attacking renewables, but I think we're going to have to erode that false hope [in wind power]", the audience member said.

"I think it is tricky to attack renewables, you end up in the lap of the devil," Mr Haszeldine replied.

"You can just point out, renewables supply 4 per cent of energy. We love renewables but we need more. Do we want to live with 4 per cent of our energy?"

## More information

You can download presentations from the CATO conference at:
http://bit.ly/CATO2014

# MPs urge the Government to 'fast track' CCS

MPs in the UK have urged the Government to fast-track final funding decisions on two pilot Carbon capture and storage projects at Peterhead and Drax by early 2015.

The UK Energy and Climate Change (ECC) Committee report examines the progress of CCS in the UK as well as setting out a number of recommendations on how to overcome barriers to deployment. In particular, the ECC Committee recommends that the Government should "commit to a realistic but ambitious timeline for awarding support to projects both inside and outside its CCS commercialisation competition".

"Fitting power stations with technology to capture and store carbon is absolutely vital if we are to avoid dangerously destabilizing the climate," said Energy and Climate Change Committee Chair, Tim Yeo MP. "After nearly a decade of delay DECC has finally got near to delivering two pilot Carbon Capture and Storage projects in the UK. It must now fast-track these projects and reach final investment decisions before the election to ensure this technology can start delivering carbon savings by the 2020s."

"These two demonstration projects will not be enough to kick-start the industry or have a significant impact on our carbon budgets, however. Ministers must also ensure that viable CCS projects not involved in the competition are able to apply for guaranteed-price contracts alongside other low-carbon energy schemes."

## Comments

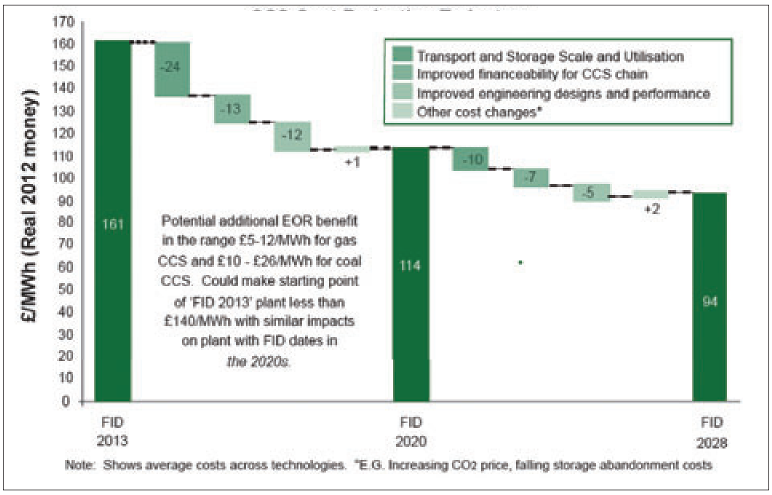
**The Carbon Capture and Storage Association (CCSA)** welcomed the report, Luke Warren, Chief Executive of the CCSA, commented:

"The ECC Committee's report on CCS and its recommendations is extremely timely – and we very much share their concerns and frustrations on the substantial delay to the development of CCS in the UK.

We strongly support the recommendations of the Committee, particularly in relation to the need for speed on projects both within and outside of the CCS competition.

As well as highlighting the importance of successfully concluding the current competition we are extremely pleased to see that the Committee has identified the need for clarity surrounding the availability of CfDs for non-competition projects. There is a very real risk that, without a strong signal that these projects can access a CfD in parallel with the competition, these projects will be shelved.

There is no credible scenario for cost-effectively tackling climate change without CCS. The sooner we build the first projects, the sooner we will be on the path towards meeting this goal whilst delivering the significant benefits that a mature CCS industry can offer."




*CCS Cost Reduction Task Force's cost reduction trajectory (Source: Carbon Capture and Storage Association)*

**Scottish Carbon Capture and Storage (SCCS)** said that everybody was agreed CCS is essential for the future of UK low-carbon electricity.

The UK is uniquely positioned for developing CCS, said SCCS. It has inventive manufacturers to develop CO2 capture equipment, industries to engineer equipment and pipelines, and a world-leading offshore hydrocarbon industry to undertake safe and secure CO2 storage. The Committee states that the UK should concentrate on developing its massive, and potentially profitable, offshore storage in depleted oilfields and saltwater aquifers – hundreds of years' worth. And it points out that the UK Government should better inform its public about the benefits.

The UK has an outstanding civil service, which has delivered the correct legislation, regulation and electricity market reform rapidly and to the highest quality. Two full-chain CCS commercialisation projects (Peterhead, Aberdeenshire; and White Rose, Yorkshire) are also being examined, but they will not begin operating until 2018 at the earliest.

Why is the UK so slow at developing this technology, which the Committee says will reduce wholesale electricity costs in 2030 by 20% – and will halve the extra cost of low-carbon power by 2050, according to the Energy Technologies Institute? The delivery of CCS takes time to build the necessary equipment. If we are to meet these milestones, the UK must have another five projects under construction by 2020.

Professor Stuart Haszeldine, SCCS Director, said: "We all want a secure future, which includes low-carbon energy. Developing five CCS projects now will cost each UK household around £30 per year. The UK needs more than 30 of these to start building before 2025. To avoid extra costs later, we must develop our CO2 storage now. That is a good insurance premium against the 100% certainty of future carbon taxes and future global change. Avoiding CCS investment may look cheap today, but is storing up high-cost trouble for later."

Ironically, three fully commercial projects await the UK Government's use of market powers, which already exist, to kickstart development. Summit Power's CCS proposal at Grangemouth could create 5,000 construction jobs from 2015, 2Co Energy's Don Valley CCS Project in Yorkshire was once a leading European project, and Teesside Low Carbon could decarbonise a large part of the UK chemical industry. All are withering due to a lack of government attention. All could pipe CO2 offshore to produce additional oil recovery from depleted fields, which would more than pay for their costs through oil tax revenue."

### More information

www.parliament.uk

# Policy, projects and regulation news

## IEA report confirms CCS critical but too slow

www.iea.org

**The International Energy Agency (IEA) has published the fourth volume of its Energy Technology Perspectives report, which concludes that business-as-usual is not an option if we are to transition to a sustainable energy future.**

The report underlines that Carbon Capture and Storage has a critical role to play in decarbonizing the power sector and energy intensive industries as well as supporting energy efficiency.

Speaking after the publication of the report, Dr. Graeme Sweeney, ZEP Chairman, said, “We commend the IEA for this comprehensive report that reiterates the value of CCS in the mitigation of CO2 emissions. The report’s conclusions come at a crucial time in EU energy policy discussions on ensuring security of supply for Europe, while staying in line with our emission reduction objectives. Following recent political developments in its eastern neighbourhood, the EU faces an uncertain energy future. It is clear that we must increasingly look towards our indigenous energy sources – CCS plays an essential role in enabling this.”

“The IEA has made clear that CCS is crucial for decarbonizing large-scale fossil fuel use for power generation and in energy-intensive industry. The agency previously concluded that in principle this technology can reduce full life-cycle CO2 emissions from fossil-fuel combustion at power stations and industrial sites by 65-85%. Moreover, by providing flexible back-up power, CCS is an essential complement to renewables and energy efficiency,” Sweeney added.

Yet, the IEA has confirmed, as ZEP has often pointed out, that the deployment of CCS is occurring too slowly due to high costs and a lack of political and financial commitment. Increased progress in CCS research, development and demonstration is needed to ensure cost-competitiveness and timely deployment.

“Based on ZEP’s own analysis, if we act now, with the right investment framework and support measures, CCS can become commercially available post 2030. The next step is to scale up to large, integrated projects, which have a huge potential to drive down costs. This is achievable through the introduction of transitional support measures and the creation of a level playing field with other low carbon technologies. Ultimately, the EU must embed CCS in its energy security strategy and 2030 energy and climate framework,” Dr. Sweeney concluded.

*Tampa Electric Company’s Polk Power Plant will host an IGCC carbon capture pilot project*

## DOE recovery act project begins

www.rti.org

**The project at Polk Power Plant will demonstrate warm syngas desulfurization and CO2 capture.**

The Department of Energy, RTI International and Tampa Electric Company (TECO) have completed the successful startup of a pilot project to demonstrate carbon capture technology in a coal gasification unit at the Polk Power Plant Unit-1 in Tampa, Florida.

The gasification process converts carbon-based materials such as coal, petroleum coke and biomass into syngas, which requires cleanup and conditioning steps before being used for the production of electrical power or industrial products such as chemicals, fertilizers, fuels, or hydrogen.

RTI's technology removes contaminants such as sulfur and heavy metals at warm process temperatures, eliminating the need for substantial syngas cooling and expensive heat recovery systems. This would significantly increase the thermal efficiency and reduce the capital and operating costs of new gasification-based systems when compared to conventional process technologies.

The newly installed pre-commercial demonstration facility will use about 20 percent of the raw syngas from Tampa Electric’s existing 250 megawatt electric Polk 1 coal- and petcoke-fueled integrated gasification combined cycle (IGCC) plant as its input feed stream. It will remove more than 99.9 percent of the sulfur contaminants from the raw syngas at gasifier pressure and warm process temperature.

In addition to demonstrating warm syngas desulfurization, the RTI system also includes a water-gas-shift reactor to enrich the hydrogen content of the cleaned syngas and will demonstrate an advanced activated amine process for capture of more than 90 percent of the carbon dioxide from the syngas stream. Following cleanup, the hydrogen-enriched syngas will be re-introduced to the Polk 1 plant and combusted in the existing syngas turbine.

The Department of Energy has a long history of collaboration with TECO at the Polk Power Station, starting more than 20 years ago when DOE helped fund construction of the plant.

Gas cleaning at power plants to remove contaminates like carbon dioxide, mercury, and sulfur is typically done at low temperatures. IGCC technology, or warm gas cleanup, has posed a technical challenge to scientists for more than 30 years. It has the potential to improve the energy efficiency of removing pollutants from coal power plant emissions, reducing the overall cost of capturing carbon dioxide and other contaminant emissions from power plants while also increasing reliability.

IGCC also has the potential for local economic benefits. The technology increases the possibility that the captured carbon dioxide can be turned into a new revenue stream for operators by converting it into other uses, like fertilizer and enhanced oil recovery. The project, which is approximately $3 million under budget, included $168 million American Recovery and Reinvestment Act funding.

## DOE awards $100M for innovative energy research

science.energy.gov/bes/efrc

**The money will fund 32 projects at Energy Frontier Research Centers (EFRCs) across the U.S. including several on CCS.**

The 32 projects were competitively selected from more than 200 proposals. Ten of these projects are new while the rest received renewed funding based both on their achievements to date and the quality of their proposals for future research.

Twenty-three of the projects receiving funding are headed by universities, eight are led by the Energy Department's National Laboratories and one project is run by a non-profit organization.

Awards range from $2 million to $4 million per year per center for up to four fiscal years, subject to a progress review in year two. DOE plans to open the EFRC program to new applications every two years.

Those realting to carbon capture and storage include:

- Lawrence Berkeley National Laboratory - Produce robust predictive models that will greatly improve confidence in subsurface carbon dioxide storage systems by characterizing and understanding carbon dioxide trapping processes at the nano, meso, and macro scales.
- University of California, Berkeley - Create new synthesis strategies, combined with novel characterization and computational methods, for tailoring materials for the efficient separation of gases, such as natural gas, hydrocarbons, and carbon dioxide.
- The University of Texas at Austin - Understand and control emergent behavior arising from coupled physics and chemistry in heterogeneous geomaterials, particularly during the time and length scales for geologic carbon dioxide storage

Since their establishment by the Department's Office of Science, the EFRCs have produced 5,400 peer-reviewed scientific publications and hundreds of inventions at various stages of the patent process. EFRC research has also benefited a number of large and small firms, including start-up companies.

## UKCCSRC allocates £2.75M for research

ukccsrc.ac.uk

**The UK Carbon Capture and Storage Research Centre (UKCCSRC) has today announced the allocation of £2.57 million from its research budget to support 14 new CCS research projects.**

The projects include 7 on CO2 capture (£1,128,000), 5 on CO2 cross-cutting issues (£1,040,000), and 2 on CO2 storage (£399,000) and have attracted a total of £2 million in additional co-funding and support from a broad range of industrial partners from the UK and overseas.

Prof Jon Gibbins, Director, UKCCSRC said, "It is great to have the UKCCSRC's own research portfolio now fully under way. Our big tasks for the next three years of the Centre's life will be to see these projects executed successfully and to link them, and all the academic research supported by the Research Councils, DECC and other funders, to maximise their value for supporting future CCS delivery."

The projects funded in this call are fundamental and multidisciplinary CCS research projects that address research needs identified by the Advanced Power Generation Technology Forum (APGTF) and the DECC CCS Roadmap for Innovation and R&D.

This call builds upon the £2.2million allocated in 2012 for 13 projects in the UKCCSRC's first call. The 14 projects in the second call will involve 9 different UK universities in the delivery of the research.

Two of the projects include significant academic collaboration with Australia and China. The Quantifying Residual and Dissolution Trapping at the CO2CRC Otway Project Injection Site, excitingly involves collaboration with the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) in Australia.

The UK Minister of State for Energy and Business, Michael Fallon, announced the funding during a visit to the Knowledge Transfer Centre at the Advanced Manufacturing Research Centre in South Yorkshire after he formally opened the UKCCSRC's Pilot-Scale Advanced CO2-Capture Technology (PACT) facilities in Beighton.

## Scottish projects win research funding

www.sccs.org.uk

**Scientists from the Scottish Carbon Capture and Storage (SCCS) research partnership have competitively won a 20% share of the £2.57 million funding.**

Three out of 14 new CCS research projects, selected by the UK CCS Research Centre (UKCCSRC) as part of its second funding call, will be led by academics based at Heriot-Watt University and the University of Edinburgh. The three projects will yield crucial results that will feed into each stage of the CCS chain, from capturing CO2 within flexible power generation systems to monitoring its transport in liquid state and ensuring safe and permanent storage deep below ground. A further two projects will involve researchers from within the SCCS partnership as co-investigators.

UKCCSRC has provided funding to nine research institutes across the UK for a total of 14 project collaborations. Seven projects will focus on CO2 capture, five will tackle cross-cutting issues and two will involve CO2 storage. The winning bids have attracted an additional £2m in co-funding and support from industry partners.

Professor Stuart Haszeldine, SCCS Director, said, "The diversity and quality of expertise within the SCCS partnership has enabled us to secure an improved share of funding for research that will support the growing CCS industry in the UK. The knowledge gained will also be applicable to CCS projects worldwide, as many countries begin to assemble the elements of a low-carbon economy. It is essential that academia, industry and government continue working together to refine our knowledge and progress to commercial-scale deployment of CCS technology."

## CO2 Capture Project annual report published

www.co2captureproject.org

**The 2103 annual report details the work of the group to advance the technologies that will underpin the deployment of industrial-scale CO2 capture and storage.**

In 2013 a number of significant projects were brought to conclusion with two of the largest projects ever undertaken by CCP – an OTSG oxy-firing capture demonstration and a storage contingencies study – reaching important milestones during the year.

The CO2 Capture Project (CCP) is an award-winning partnership of major energy companies, working to advance the technologies that will underpin the deployment of industrial-scale CO2 capture and storage.

Since its formation in 2000, the CCP has undertaken more than 150 projects to increase understanding of the science, economics and engineering applications of CCS. The group has been working closely with government organizations — including the US Department of Energy, the European Commission and more than 60 academic bodies and global research institutes.

Phase Three (CCP3) members are: BP, Chevron, Eni, Petrobras, Shell and Suncor.

# Optimisation of oxygen-based CFB technology with CO2 capture

CIUDEN is working on the FP7 European O2GEN project, which focuses on one of the most important recommendations of the Zero Emission Platform´s (ZEP) report for the deployment of CCS in the European Union: the use of higher O2 concentrations in oxyfuel combustion reducing the flue gas recirculation and energy penalty.

Coordinated by Centro de Investigación de Recursos y Consumos Energéticos (CIRCE), operational experience will be gained through demonstrating the technology at CIUDEN Technology Development Centre for CO2 Capture (NW Spain).

The project objective is to demonstrate the concept of second generation oxyfuel combustion to reduce significantly the overall efficiency penalty of CO2 capture into power plants, from approximately 12 to 6 efficiency points. The improvement in the overall efficiency of power plants with CO2 capture requires the development and demonstration of overhauled processes and components throughout the whole system to obtain an optimized combustion with high oxygen levels (30-50% v/v basis).

The second generation oxyfuel concept will consist of integrated high-efficiency optimised systems for oxygen production, steam generation (boiler) and CO2 compression and purification, process integration and application of conclusions to large power plant designs.

The O2GEN project will draw conclusions that will be included in future large scale oxy-fuel power plants with Circulating Fluidized Bed (CFB) technology and CIUDEN Technology Development Centre for CO2 Capture is considered as an optimum demonstration scale unit to carry out the O2GEN project experimental campaigns and to obtain complementary knowledge.

The following systems from CIUDEN Technology Development Centre for CO2 Capture are within the O2GEN project scope:

- Oxygen supply
- Fuel and sorbent feeding
- Combustor
- Cyclone, flue gas cooling and filter unit
- Ash discharge systems
- Flue gas recirculation system (RFG)
- Compression and Purification unit (CPU)

During the period late 2011-2013 an extensive amount of information (operational as well data analysis) under different European funded projects was acquired. In this article the main problems faced and solutions developed over the past two years are summarized. The lessons learned will serve as improvements for the second generation oxy-fuel power plants with CFB technology. They are set as a first input for the O2GEN project.

The installations have been improved when problems arose. From those activities, there has been some learning which can be applied to second generation oxy-fuel commercial power plants. Some of the problems overcome are common to conventional power plants too. It must be kept in mind that most of the improvements stated here have a qualitative nature and have been concluded at a maximum value of 28% volume oxygen content in the oxidant.

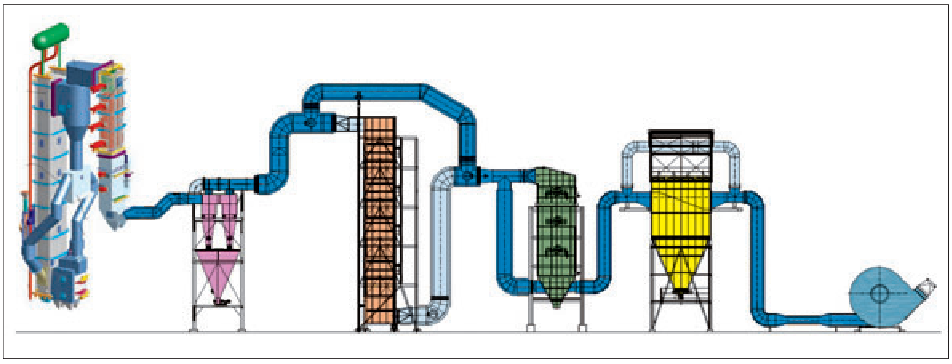


*Figure 1 - Flue gas circuit*

## Solids handling

Flue gas moisture content is higher in oxy-combustion than in air combustion, implying new challenges in case these gases are used for solids handling. There are two important recirculated flue gases (RFG) critical temperatures:

- Acid dew point temperature, when acid gases in the RFG start condensing at temperatures on the range of 130°C - 150°C.
- Water dew point temperature, when water starts condensing at temperatures on the range of 100°C - 80°C.

Humidity by itself becomes a problem when it reaches water dew point and condenses. During oxy-fuel, RFG are sent to the fly ash silo to pneumatically transport the fly ash to the furnace, for reburning. Blocking problems appeared in these transport lines. Water condensation was seen as the cause of this issue. As a consequence two different measures were adopted:

- Isolation was proposed in order to avoid water condensation.
- A new commercial CO2 connection to the main rotatory valve was set in order to increase pneumatic transport. It is expected for the near future to use recirculated dry CO2 from the compression and purification unit (CPU) as an auxiliary service to avoid condensation problems.The problem described is enhanced by the high moisture content in the fuel. Unlike in air-firing operation, under oxy-fuel combustion, gas for solids transport (RFG) has higher humidity content and lower oxygen concentration. This consideration is important depending on the type of fuel being used:
- For high volatile fuels, high oxygen concentration in the solids transport fluid lines may be an issue since combustion may occur before entering the combustion chamber.
- For sticky fuels, high humidity in the pneumatic solids transport lines becomes


*Figure 2 - Impact of effect of air leakage*

a problem and additional measures to avoid blockages or unplug them are necessary.

Proper design (pneumatically-sizing, isolation by heat tracing, purge lines, etc.) and the potential use of dried CO2 from the CPU should be considered for solids transportation.

## Air infiltration

Under real conditions it may not be practically feasible to seal the boiler and the flue gas duct completely. Air ingress dilutes the flue gas considerably and causes a loss of sensible heat. There is additional compression consumption for rotating equipment too and in the CPU there are limiting values below which some units could not operate. All these considerations imply a reduction in CO2 capture efficiency, defined as the ratio between the energy consumed per unit of CO2 captured.

In CIUDEN corrective actions were implemented such as the replacement of textile expansion joints and bolted connections in flange unions by metallic expansion joints and welded flange unions respectively. After intensive works to reduce air infiltration, a consistent CO2 concentration of more than 80% v/v (dry basis) has been achieved in the flue gases.

## Leakages

The characteristics of the RFG with high water content and some chemical species like SO3, SO2, NOx, may cause any leakage from the pressurized section (from the induced draft fan to boiler) to condensate immediately into acid deposition when cooling down, even affecting health and safety conditions at site. Figure 2 shows some examples.

Welded flanged unions, leak-proof equipment, and metallic expansion joints with pipe ends made of stainless steel, or anti-corrosive coatings were installed in CIUDEN. It is important to mention that fully-tight on closing instrumentation (valves, gates) as well as dedicated purge is advisable in order to have proper isolation. Dynamic seals in fans have been used with multi-part and self-adjusting seal rings and in other places CO2 has been the sealing element.

## Temperature losses

Sections and parts not properly isolated and cold points such as gates, valves, hangers and expansion joints facilitate the acid corrosion appearance in internal components of heat exchangers, valves, fans, pipes, etc. In Figure 3 some pictures are shown with such corrosion aspects.

Removable insulation that facilitates inspection and maintenance activities is a potential solution. It is important to avoid dead points in the piping that could lead to cold areas (parts where net fluid velocity becomes near zero, because of sharp change of direction, or closed valves section) as well as good construction integration between the different units. Purge lines in case of condensation formation are recommended.

## Operation aspects

Several operation aspects are summarised below:

- For certain conditions agglomerates were formed in different parts of the CFB unit. It is still not clear whether the cause lies on the chemistry of the particulate matter and fluidization atmosphere, or if it is a consequence of the oxy-fuel operation. Agglomerates formation greatly affects plant availability. This issue needs further study.
- Oxygen is mixed with primary and secondary oxidant streams after the force draft fans. For high pressure lines in a commercial plant, the fans should be after the oxygen is mixed with RFG in order to avoid fluctuations in the oxidant stream.
- The feeding-water flue gas heat recovery accumulates fly ash and needs a very often shoot-blowing with steam during oxy-fuel operation. Such shoot-blowing affects the stability of the boiler. This is an important aspect to pay attention to in future flexible oxy-fuel configurations since fly ash elutriation will be higher under high oxygen content in the oxidant stream.
- The refractory material initially installed inside the CFB was damaged due to corrosion and abrasion. Refractory materials with higher resistance to corrosion and abrasion are required in oxy-fuel CFB boilers.

## Compression and Purification unit

The CPU has been capable of accepting the boiler flue gas and reaching specified CO2 purity. The following CPU items are considered to require further development:

- Location capacity and connection to the stack of the CPU vents must be improved.
- Cooling and steam demands for heat integration within the overall system.
- Dried CO2 from the CPU, can be used as inertization, sealing and transport fluid in the plant with no need to use commercial CO2.
- Cross interference identification. Conventional analysis techniques are used to measure components concentration along the CPU. Reliability of measurements must be validated for

each analytical method. Cross interferences must be examined if accurate and precise results are to be obtained.

## Process Integration

### Energy recovery and heat integration

In a commercial scale oxy-fuel CFB power plant the integration between the Air Separation Unit (ASU), the CFB boiler, the steam cycle and the CPU will be a major concern in order to increase plant efficiency. Simulation studies within the O2GEN project will deal with these integration aspects, in order to optimize future second generation oxy-fuel configurations.

### Emissions optimization

Emissions control takes place firstly in the CFB boiler by means of limestone addition and then ammonia solution entering the CPU for further purification. CIUDEN's experience shows that no additional cleaning is needed, apart from the particulate removal system.

Even though sulphur capture efficiency by limestone addition is high, the presence of calcined limestone may cause re-carbonation problems in the solids recirculation loop (loop-seal and intrex areas) giving place to fluidization deficiencies or agglomeration. In order to minimize limestone addition other sulphur capture strategies could be considered in the future such as wet or oxidative desulfurization units. Furthermore, higher efficiency in the SOx polishing unit in the CPU could be needed.

The consequences of the ammonia injection system in the boiler performance has not been yet evaluated and activities within the O2GEN project will develop new knowledge.

### Control philosophy

The control philosophy avoids malfunctions or perturbances and foresees the response of the installation to unexpected behaviours. One of the main variables of the control philosophy is the pressure balance of the system which has been tested in the following cases:

- Stationary and transient periods (air to oxy mode or vice versa).
- Boiler and CPU trips.
- Soot-blowing process. Note that in CIUDEN's CFB boiler, designed in an industrial size, the soot-blowing effect is higher compared with the one of a commercial plant.

The control of RFG to adequately adapt to the different oxidant composition requirements, so as to the CPU capacity must be carefully addressed.

## Plant performance at a glance

### Combustion performance

In the test runs with anthracite and high O2 in the primary and secondary streams, unburnt carbon shows higher values than in conventional combustion. This is not a definitive conclusion and needs further study, since numerous factors are influencing these results, such as fluidization performance, limestone calcination-sulfation reactions, secondary oxidant composition or fuel moisture content.

### Sulphur capture

Sulphur capture efficiency was higher in oxy-combustion compared to air-combustion due to flue gas recirculation even though it is known that sulphur capture efficiency in oxy-fuel conditions is lower at conventional CFB temperatures, due to changes in sulfation mechanisms. The optimum temperature for sulphur capture was found to be around 890-910°C under oxy-combustion conditions and for anthracite coal with limestone used as sorbent.

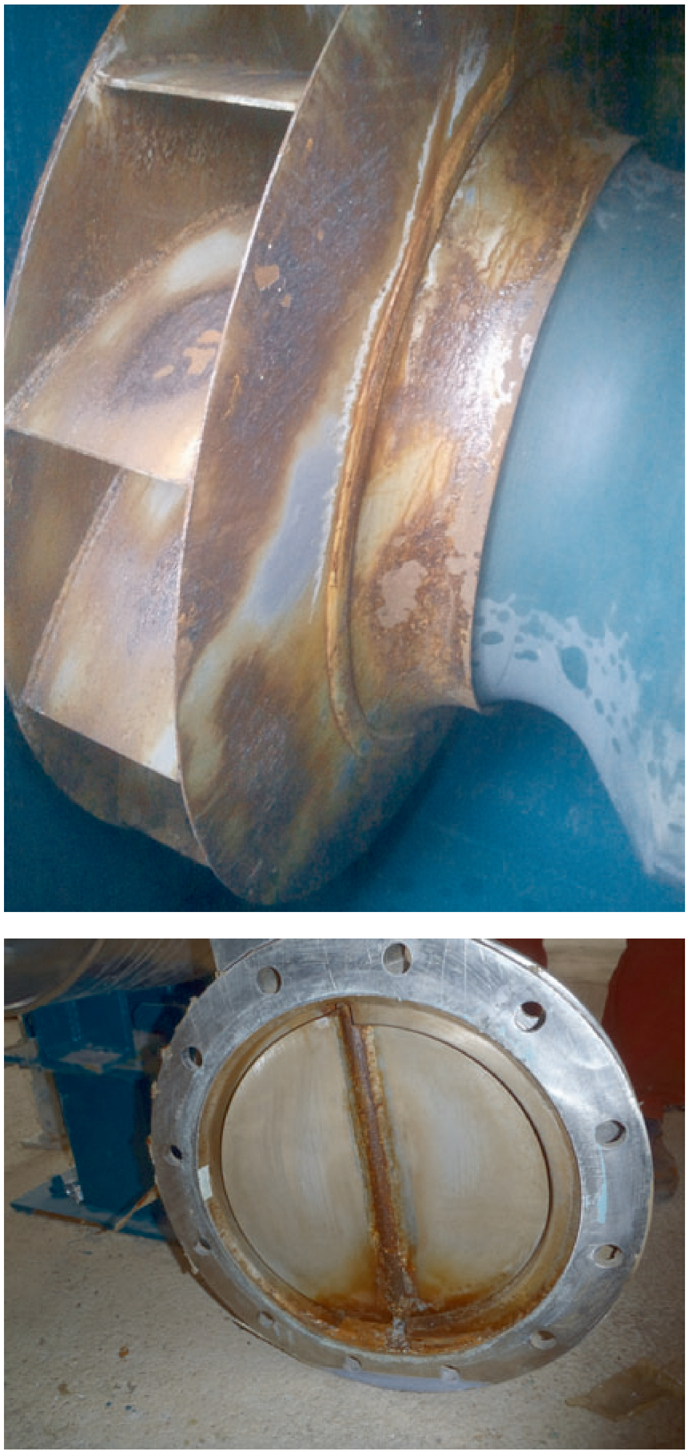


*Figure 3 - Impact of corrosion*

### Other components

Mercury-related issues are of essential importance in oxy-fuel operations. Mercury can corrode aluminium-alloys forming amalgams.

The information available on Hg emissions under oxy-fuel conditions is limited and much of this information is not public. O2GEN will address this issue in the CPU. Control of acid gases, SO3, HCl and HF in oxy-fuel needs also further development. Available data on pollutant emissions/formation during oxy-fuel combustion is limited and mostly resulted from small and laboratory scale plants.

In spite of the extensive experience gained during CIUDEN oxy-fuel operation, further research and experimentation is needed at this industrial scale, in order to bring the CCS deployment closer to the commercial scale, with the confidence given by a deep knowledge of the operation, safety, environmental and efficiency needed in the second generation oxy-fuel power plants.

### More information

www.o2genproject.eu
www.ciuden.es

# Lafarge's new process for CO2 mineralization

Lafarge has developed a novel atmospheric-pressure process for the capture of CO2 from flue gases, using conventional industrial equipment and avoiding the energy-intensive CO2 purification and compression steps typical of current CCS approaches.

**By Ellis Gartner, Lafarge Centre de Recherche, Saint Quentin Fallavier, Isere, France**

## Why should a cement maker be interested in CO2 capture?

Global Portland-based cement production exceeds 3.5 Gt/year and its direct CO2 emissions now probably constitute well over 5% of total anthropogenic CO2.[1] Cement is used as the binder in concrete for the construction of buildings and the infrastructure. While concrete is inherently a very low-energy, low-carbon material, vast quantities are needed - roughly 10 cubic kilometres per year - especially in the developing world.

Cement is a fine powder made by grinding "Portland Cement Clinker" (PCC) with other mineral-based ingredients. PCC is made in large rotary kilns by burning a finely ground mixture of limestone with clays and other minerals. It is comprised principally of "alite" (tricalcium silicate, Ca3SiO5). Limestone, which is globally abundant and well distributed, is usually the main source of the calcium. But limestone contains "fossil" CO2 which is emitted during the process (see equation (1) in Fig.1)

Energy use and CO2 emissions are major issues for the cement industry, so it has adopted multiple approaches to minimizing them, most of which are industry-specific. Energy consumption has been minimized by optimized kiln design, and significant proportions of waste fuels are already being used. PCC is now being replaced to a significant extent by "supplementary cementitious materials" (SCM), usually industrial by-products such as slags or fly ashes. Alternative clinker chemistries have also been developed to permit even lower kiln CO2 emissions.[1]

However, all of the above approaches have their practical limits. So, if the industry aims ultimately to achieve near-zero CO2 emissions, some kind of CO2 capture technology will also be required.1 But "conventional" CCS (capture, transport and underground storage) is not a viable approach everywhere.

This led us, in 2009, to begin to investigate mineral capture as an alternative long-term approach. By the time our project terminated in 2012 we had made good progress on the research aspects but had not progressed very far towards actual industrial development. The remainder of this article attempts to summarize our new approach, which, we believe, is potentially applicable to almost any industrial point source of CO2 and thus deserves wider attention. Details are contained in a recent conference paper.[2]

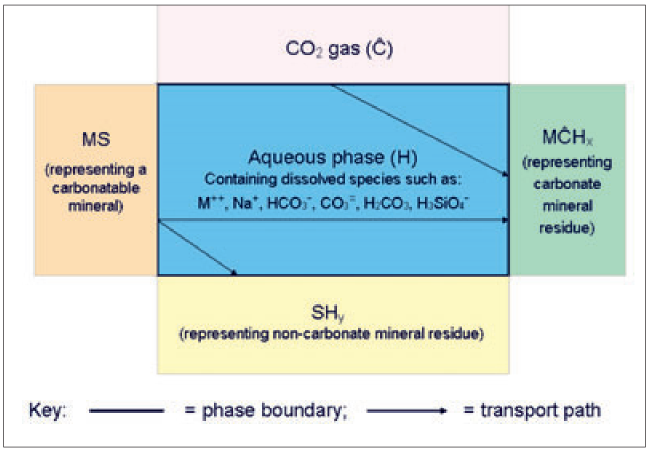



*Fig. 2: Diagrammatic representation of water-mediated carbonation of an alkaline-earth silicate (M = Mg or Ca; MS = MO•SiO2; MĈ = MO•CO2; SHy = hydrated amorphous silica)*

## What raw materials might be carbonated on an industrial scale?

A review of the literature showed that the only widely available "carbonatable" raw materials are silicates of magnesium or calcium with the general formula n(MO)•SiO2•QO, where M represents Ca or Mg, and QO represents other oxides (i.e. impurities). Their CO2 capture potentials increase in proportion to the basicity (n), since the desired end product of carbonation is the simple carbonate MO•CO2. Water catalyses carbonation effectively at near-ambient temperatures. Fig.(2) shows the main features of the reaction, and fig. (3) shows how we proposed to make the process more efficient by use of an alkali carbonate plus a catalyst[3]

Calcium silicates tend to carbonate rapidly even at very low CO2 partial pressures (e.g. in ambient air), but magnesium silicates carbonate far more slowly, so calcium silicates would constitute the ideal raw materials were it not for the fact that they are relatively rare at the Earth's surface, (presumably, because they weather too quickly.)

The most readily accessible sources turn out to be man-made wastes, e.g. slags from metal extraction processes, etc., of which there are significant stockpiles. They thus have the advantage that their reclamation provides additional local environmental benefits. In comparison, natural magnesium silicates, which weather far more slowly, are very abundant but not very well-distributed (fig. 4).

We thus began our study by looking into carbonating common calcium-rich industrial by-products. However, we were soon able to show that developing a special carbonation process for such materials made lit-

eq.(1) $$3CaCO_3 + SiO_2 \rightarrow Ca_3SiO_5 + 3CO_2\uparrow$$

eq.(2) $$n(MgO)\cdot SiO_2\cdot QO + Na_2CO_3 \rightarrow (n-1)MgO + Na_2MgSiO_4 + QO + CO_2\uparrow$$

eq.(3) $$(n-1)MgO + Na_2MgSiO_4 + QO + (n+1)CO_2 \rightarrow nMgCO_3 + Na_2CO_3 + QO + SiO_2$$

*1: Key chemical equations referred to in the text*

1. Barcelo, L., Kline, J., Walenta, G., Gartner, E., 'Cement and carbon emission' Materials and Structures, Springer Press, electronic publication doi: 10.1617/s11527-013-0114-5 (2013)
2. Gartner, E., Gimenez, M., Meyer, V., Pisch, A., 'A Novel Atmospheric Pressure Approach to the Mineral Capture of CO2 from Industrial Point Sources,' paper #105, CCUS 2014, Pittsburgh, USA, April 30, 2014
3. Gartner, E., Gimenez, M. and Paliard, M., US patent 8617500, (2013)

tle sense for a cement maker, because we had a much better way to use them: simply incorporate them into the "kiln feed" used for making PCC! Since PCC comprises basic calcium silicates, aluminates and ferrites, most calcium-silicate-rich raw materials are acceptable.

The fraction of any such materials that can be substituted in any given cement plant of course depends on the actual local compositions and can be quite low in some cases, but this approach is always very favourable both in terms of energy consumption (less limestone decarbonation is required in the cement kiln, which reduces kiln fuel needs,) capital cost (no new equipment is needed,) and of course in terms of ultimate disposal (the product is a commercial cement).

Needless to say, it is already being done in many locations and its implementation is usually simply a question of local economics, logistics and environmental regulations. But because available calcium silicate resources would in any case clearly never be sufficient to make a large impact on total cement industry CO2 emissions, we soon stopped research on that approach to focus exclusively on magnesium silicates.

## Carbonation of Magnesium Silicates:

Olivines {(Mg,Fe)2SiO4} are ultra-basic minerals directly derived from rocks originating in the Earth's mantle. They convert to serpentine {Mg3Si2O5(OH)4} and other less basic minerals as a result of hydrothermal or weathering processes near the Earth's surface. Global resources of Mg-rich olivines and serpentines are estimated to be sufficient for permanently stocking all conceivable anthropogenic CO2 emissions. The problem is, however, that both olivines and serpentines only carbonate very slowly.

The carbonation of basic magnesium silicates had been studied intensively over the past few decades,[4] and the prior art suggested that the only way to directly carbonate such minerals rapidly was to use high pressure CO2 plus heat - typically, pressures of around 100-150 atmospheres and temperatures of ≈150-200°C.

The minerals also first had to be finely ground. Such processes were clearly very energy-demanding, partly because of the need to first capture and concentrate the CO2, just as for CCS. Thus, they looked unlikely to be net CO2-negative unless powered by nuclear or renewable electrical energy sources. They were also very capital intensive.

Several different "catalytic" approaches had been proposed in the literature to help alleviate this problem, but these essentially all used some form of initial acid attack to dissolve the magnesium silicates.

This causes two additional problems: firstly, the acid anion must be recaptured and effectively recycled, since any losses tend to significantly increase operating costs; and secondly, the intermediate magnesium salt solutions are also difficult to carbonate.

So, all-in-all, none of the catalytic cycles proposed in the literature appeared to meet our requirements. This forced us to look for a novel approach.

It was well known that magnesium silicates would dissolve in an excess of molten sodium carbonate – this was the approach traditionally used to dissolve such rocks for chemical analysis. So we wondered whether or not it might be possible to use a similar approach but with much smaller proportions of sodium carbonate. We found[5] that reaction (2) was rapid and almost stoichiometric for powdered Mg-olivine or serpentine-rich rocks at about 900°C.

The advantage of this reaction was evident to a cement maker: it could be done in a variety of relatively standard "sintering" kiln systems, at atmospheric pressure. Fig. (5) shows one possibility, which requires pre-pelletizing a mixture of sodium (or potassium) carbonate with powdered magnesium-silicate rock in proportions typically designed to give an alkali-metal/silicon atom ratio of about 2.

The pellets are fed into the kiln, which can burn any conventional fuel. Kiln gases run counter-current to the flow of the solids, thus ensuring efficient heat exchange for both feed preheating and product cooling. It is equally possible to use a carbon-rich solid fuel premixed into the feed pellets, and this may have some advantages, especially if it is desirable to avoid strongly oxidizing con-

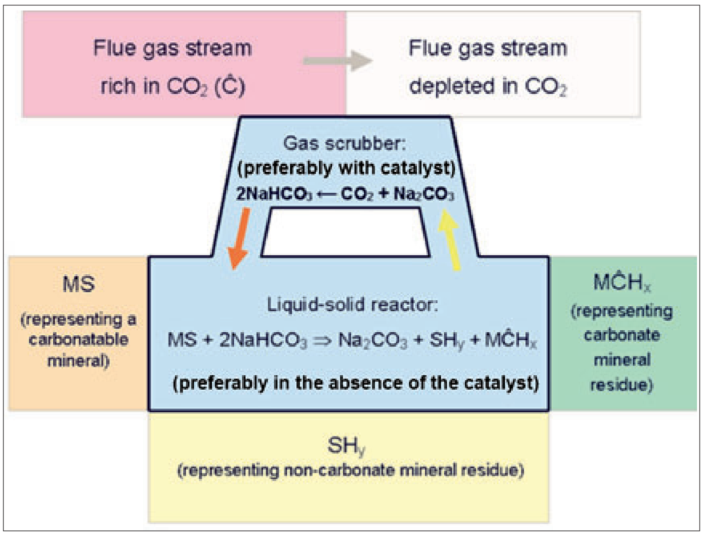



*Fig. 3: The scrubbing of CO2 from flue gases can be made more efficient by a two-step process of the type shown here, which allows the gas-liquid reaction and liquid-solid reactions to be conducted in separate reactors with optimized volumes and residence times. An additional catalyst is also useful in accelerating the gas-liquid reaction (see reference (3)).*

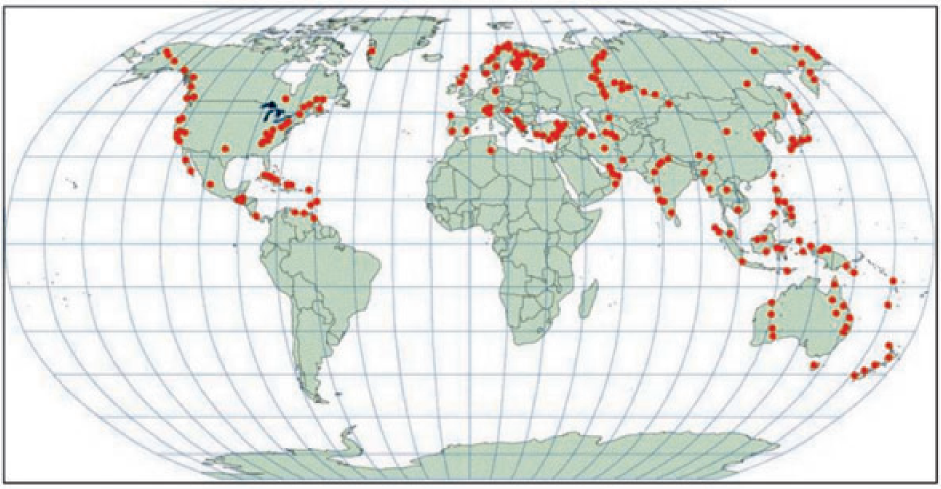


*Fig. 4: Global distribution of identified magnesium silicate resources (taken from Zevenhoven and Kohlmann, Second Nordic Minisymposium on Carbon Dioxide Capture and Storage, Göteborg, October 26, 2001).*

4. See, for example, Sipilä, J., Teir, S. and Zevenhoven, R., "Carbon dioxide sequestration by mineral carbonation Literature review update 2005–2007," Åbo Akademi University Faculty of Technology Heat Engineering Laboratory report VT 2008-1 (2008)
6. Gartner, E. and Pisch, A., world patent application WO2012168176 (2012)

ditions in the hot zone.

Such an approach is also well-adapted to the use of a simple vertical-shaft-kiln process, which has the added advantages of low energy losses and low capital costs. The risk of melting due to local excesses of fuel in the feed pellets is very limited because all of the reaction products (other than the $CO_2$, which escapes with the exhaust gases) are solid at temperatures well above the proposed reaction temperature.

The product of reaction (2) is a "clinker" (i.e. hard nodules) comprising MgO (periclase), $Na_2MgSiO_4$ and various impurities symbolized by "QO." We found that this product, when wet, is very easy to carbonate with conventional flue gases. It could be ground with water to make an aqueous slurry which could then be used in a conventional gas-scrubber.5 The ideal reaction is shown in Eq. (3). Note that we can potentially recover all of the sodium carbonate used in the sintering process and also recapture all of the "chemical $CO_2$" emitted by that reaction, plus n additional moles of $CO_2$.

The overall process effectively constitutes a catalytic cycle for the direct atmospheric-pressure carbonation of basic magnesium silicates by industrial flue gases. However, the ideal cycle, shown in figure 6, ignores several complexities, especially relating to reaction (3), that can in practice significantly reduce the overall efficiency of the process. These are listed below:

1. The magnesium carbonate produced may well not be the ideal form shown (magnesite, $MgCO_3$). In practice, we usually get hydromagnesite ($4MgCO_3 \cdot Mg(OH)_2 \cdot 4H_2O$), which contains 20% less $CO_2$ per Mg atom. In addition to reducing the amount of $CO_2$ captured, this product also removes water from the cycle.

2. The silica-rich product may not be pure silica. It is more usually a magnesium silicate hydrate "gel," written as "M-S-H" to signify a variable composition. The higher the Mg/Si ratio of the M-S-H, the lower will be the overall $CO_2$-capture-efficiency of the process.

3. The alkali metal carbonate formed is very soluble and can be separated from the other products by leaching. However, an efficient washing cycle is needed to ensure that very little of it is lost with the other products. The dissolved alkali metal carbonate must then be concentrated, crystallized and dried if it is to be re-used in the sintering process. All of these processes could require a lot of energy.

4. "QO" in the equations represents a wide range of possible impurities in the raw materials, each of which could have a different effect on both reactions (2) and (3). Such effects clearly need to be taken into account in optimizing the overall process.

5. The cycle as shown does not take into account the fuel-derived $CO_2$ from the sintering process. This can be estimated from the enthalpy change of reaction (2), which is found from thermodynamic data to be about 3.4 GJ per tonne of "chemical" $CO_2$ released. By comparison with similar industrial sintering processes, we estimate that this will increase the amount of $CO_2$ in the flue gases from the sintering kiln by about 40% relative to the "chemical" $CO_2$. This clearly reduces the $CO_2$-capture-efficiency of the overall process.

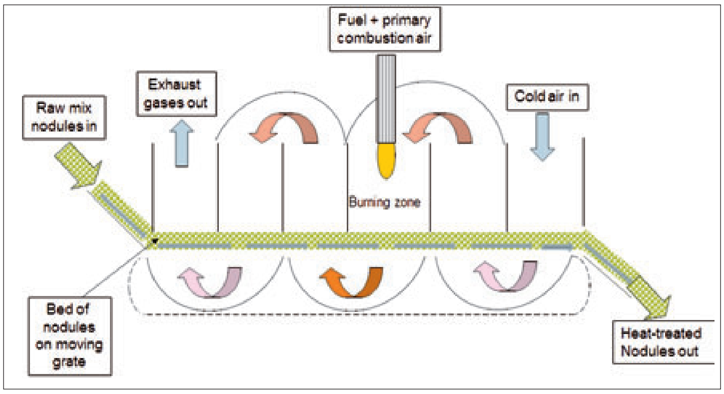



*Fig. 5. One possible industrial process suitable for reaction (2) – a "sintergrate" kiln*

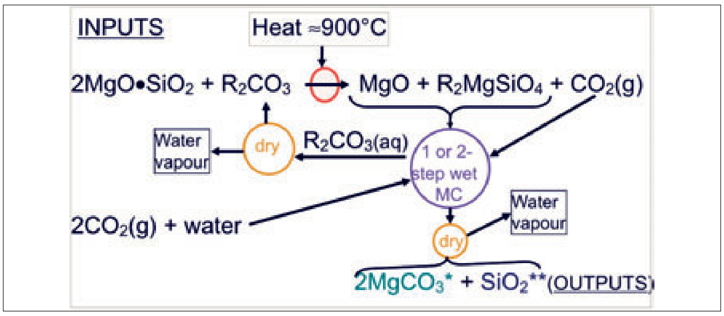



*Fig. 6: Idealized cycle for the $CO_2$ capture process using a pure magnesium olivine. (R represents Na or K; MC represents the mineral carbonation process; and the asterisks are intended to indicate that other products may form in practice)*

We have proposed technical approaches to tackling the most important of the above problems2 and we believe that the cycle could be further refined to give an acceptable net level of $CO_2$ capture efficiency; but there is also the issue of mass flows. Net mineralization of one ton of $CO_2$ by our process could ideally require as little as 2 tons of raw materials, but in reality this figure will probably be much higher because of lower Mg contents of most raw materials, as well as lower capture efficiency. And the main products do not have much value in the large volumes that would be produced.

They could be used to make precast products, such as blocks, etc., but it is likely that large amounts would also have to be land-filled. So we consider that this process is only likely to be used in locations near to suitable deposits of ultrabasic rocks and where there might also be additional value created by secondary benefits, such as remediation of asbestos-containing mine wastes, or extraction of valuable elements (e.g. chromium and nickel) which are often present at significant levels in such rocks.

## Concluding remarks

We have invented a novel atmospheric-pressure process for the capture of $CO_2$ from flue gases, using basic magnesium silicate rocks as the main raw material and producing stable magnesium carbonate products. This process uses very conventional industrial equipment and avoids the energy-intensive $CO_2$ purification and compression steps typical of current CCS approaches.

However, more work needs to be done to maximize the overall efficiency of the process so as to increase its industrial viability. In view of the long-term need to reduce global $CO_2$ emissions, we believe that further investment in such R&D is justified.

## More information

Lafarge is a world leader in building materials, with 64000 employees in 62 countries and 1,636 production sites

The Lafarge Research Center (LCR) gathers 250 researchers on a single site near Lyon, France.

`@lafargegroup` on Twitter
`Lafarge` on Facebook
`www.lafarge.com`

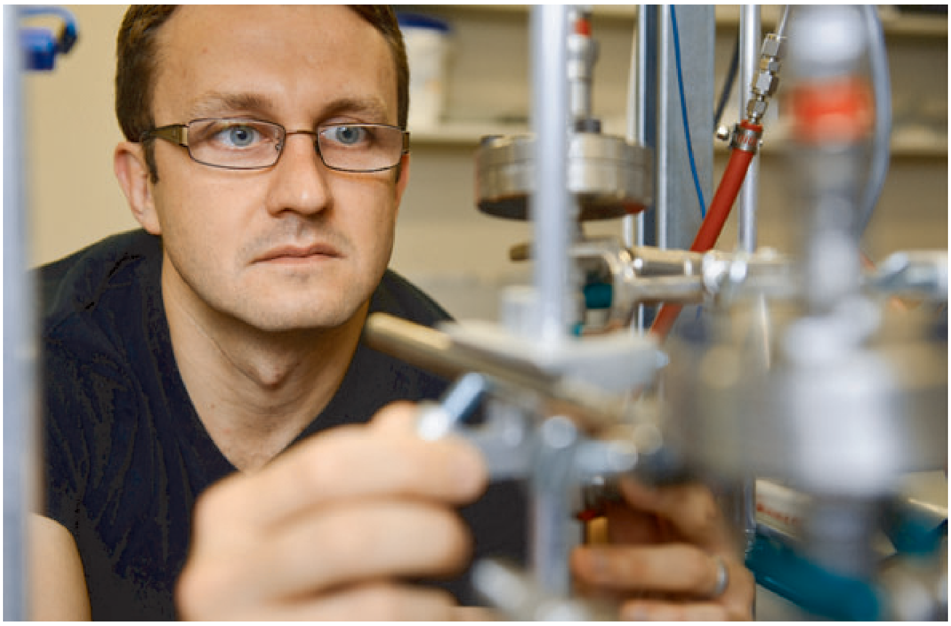
# Capture and utilisation news

## UA professor patents further carbon capture technology

www.ua.edu

Less than a year after patenting a process that could improve stripping greenhouse gasses from industrial emissions, a University of Alabama engineering professor was recently granted another patent that uses a different solvent to accomplish the same goal.

The newest method, patented by UA and Dr. Jason E. Bara, assistant professor of chemical and biological engineering, uses a form of liquid salt that could be swapped with chemicals currently used to scrub harmful emissions, such as carbon dioxide, or CO2, from industrial emissions. In a different patent granted in August 2013, Bara proposed switching currently used chemicals with a class of low volatility organic molecules. It is all part of his research focus of showing different, and possibly better, ways to capture harmful emissions.



*Research led by Dr. Jason E. Bara shows a more efficient and cheaper method for capturing harmful emissions*

"We pursue this work with novel solvents to hopefully achieve the greatest energy efficiency for CO2 capture," Bara said. "It's the magnitude of the problem and the impact on the global economy that makes it extremely important that capture processes be highly optimized when they are rolled out at full scale."

Nearly all commercially-available efforts at scrubbing greenhouse gasses, GHG's, from emissions use a liquid solution of water and amine, derived from ammonia, that contacts the stream, removing CO2 or other unwanted gases. The system patented by Bara would replace much of the water in the aqueous amine solutions with imido-acid salts, a negatively-charged group of organic solvents with almost no vapor pressure, or boiling point.

The patent, granted in March to UA, claims the chemical make-up of the imido-acid salts for use in capturing CO2 and other gases from natural gas and post-combustion emissions such as those from coal-fired power plants.

There are global efforts to reduce the man-made emission of GHG's that likely contribute to global warming by trapping the sun's heat inside the atmosphere, including emission standards and financial penalties on excess emissions. The most common and most studied method is introducing monoethanolamine, or MEA, into natural gas or post-combustion emissions, a process that can capture about 90 percent of CO2 from flue gas.

The use of MEA to scrub flue gas is energy intensive since recycling the solution requires boiling it to desorb, or rid, the CO2 before recycle of the MEA solution back into contact with the flue gas. The cost of the energy needed to use MEA in power plants, for example, would likely be passed onto consumers, Bara said.

Bara's work shows that swapping most of the water in the process for other chemical solvents saves energy since the solvent can be regenerated without boiling large amounts of water, a cost and energy-intensive process. Bara's research shows the solvent system can capture the same or more CO2 than MEA.

The imido-acid salts are a version of the organic molecules patented by Bara and UA in August 2013 to perform the same function as imidazoles, but with an anionic, meaning negatively charged, group tethered to them. The anionic group suppresses the vapor pressure to zero, which means the salts do not vaporize during the CO2 absorption process.

The cost of building and operating a CO2 capture process to treat 90 percent of a plant's emissions is a major reason the energy industry has been reluctant to embrace carbon capture on a large scale, Bara said.

"Solvent-based processes are leading contenders to be the first deployed in carbon capture, so it's crucial that research consider a wide variety of solvents before making a decision on what's 'best'," he said. "This latest patent offers a new solvent composition that eliminates organic vapor losses since it contains a salt."

This technology has been licensed to the clean tech company ION Engineering in Boulder, Colo., with the hope of further developing this technology for carbon dioxide capture. Bara helped found ION Engineering, and continues as a science adviser with the company.

The patent also covers use of the imido-acid salts as potential building blocks for pharmaceuticals or in polymer materials..

Bara's research is funded by the U.S. Department of Energy, the National Science Foundation and the American Chemical Society Petroleum Research Fund.

U.S. Patent Designated No. 8,673,956 was granted March 18.

## DOE and Southern Company research coal CCS

energy.gov

**The U.S. Department of Energy (DOE) has signed a new 5-year cooperative agreement with Southern Company to evaluate advanced carbon capture and gasification technologies at the National Carbon Capture Center (NCCC) in Alabama.**

Under the agreement, which will be managed by the National Energy Technology Laboratory, Southern Company will test both pre- and post-combustion carbon-capture technologies, as well as materials and processes that support advanced fossil-fuel conversion systems, primarily coal gasification. The agreement supports national efforts to mitigate climate change through more efficient, lower-cost coal conversion and carbon capture and storage.

Southern Company's cost-shared project proposal, "Post-Combustion and Pre-Combustion Carbon Dioxide Capture and Gasification Technologies Testing," was selected in January 2014 following a funding opportunity announcement issued in August 2013. The cooperative agreement for work to be completed was executed earlier this month.

Through this agreement, efforts at the NCCC will include:

Demonstrating integrated coal-based energy technology for plants with clean coal technology, including carbon capture.

Developing technologies that will subsequently be scaled directly to commercial-sized equipment and/or integrated with commercial projects, including those under DOE's Clean Coal Power Initiative.

Advancing lower-cost technologies to capture carbon dioxide while enabling affordable, reliable, and clean coal-based power generation for years to come.

The NCCC has been operating since 2009, when it was established by Southern Company at the Power Systems Development Facility under an earlier cooperative agreement with DOE. The NCCC is equipped to test multiple slipstreams from diverse fuel sources simultaneously under commercial conditions. At the NCCC, Southern Company will identify and test promising technologies from third-party developers from around the world, including government entities, industry, and universities.

The new cooperative agreement gives the NCCC the means to provide services and infrastructure that will enable it to become a cornerstone for U.S. leadership in advanced clean coal technology development. Technologies tested and demonstrated at the NCCC will accelerate the development and improve the performance of cost-effective carbon-capture and gasification technologies.

The total award value is $187 million. DOE will contribute $150 million, with Southern Company adding $37 million in cost-sharing.

## UK and Canada strengthen their collaboration on biochar research

www.biocharforcarboncapture.com

**Current collaboration between the UK and Canada in the area of biochar as an effective way to capture CO2 has been strengthened by the signing of an Memorandum of Understanding.**

The MoU was signed between Professor Raffaella Ocone at Heriot-Watt University (UK) and BioFuelNet Canada (BNF) and Bio-Char Network (Bio-Char) in Canada.

Raffaella Ocone leads the Leverhulme Trust UK-Canada Network on Biochar which started in 2012 involving Heriot-Watt University and the University of Edinburgh in the UK and Western University, McGill University and the University of Saskatchewan in Canada.

Biochar, a co-product of thermal processes for the production of renewable fuels and chemicals, offers a viable way to reduce CO2 concentration in the atmosphere and presents an economical alternative to CO2 capture and storage. Multidisciplinary research in the sustainable production and use of biochar as a long-term storage for CO2 is still in its infancy: some of the questions which are still unresolved are, for instance, the selection of the sources of suitable biomass, the processing conditions for the production of biochar, and its effects on the soil properties and on plants and microbial species.

The fundamental questions on biochar production and usage are still to be exploited at an industrial scale; consequently, despite being potentially the most effective way of capturing CO2, basic research on biochar still needs to be undertaken by assembling a multidisciplinary network of scientists and engineers capable of tackling these complex scientific issues. The Network investigates the potential of biochar as a technically and economically effective method of capturing carbon in a stabilised form while, simultaneously, increasing soil quality and thus adaptability of agriculture to climate change.

The new MoU aims at partnership in responding to calls for work relating to biochar in the EU and North America; at joint research and activities; at planning activities for repurposing of industrial facilities.

## Skyonic secures $12.5M to develop SkyCycle technology

www.skyonic.com

**Skyonic Corporation has secured an additional $12.5 million in funding from existing investor ConocoPhillips and new investor Enbridge.**

The funding will provide for the continued development of Skyonic's SkyCycle technology toward commercialization.

While current industry estimates place the cost of carbon capture between $150 and $450 per ton, SkyCycle uses a thermolytic chemical reaction to capture carbon dioxide emissions at costs estimated to be between $16 and $25 per ton, significantly lower than industry averages.

The process converts the CO2 emissions into a wide variety of products, including hydrochloric acid and calcium carbonate, also known as limestone, which can be used to make glass, paper, cement, paint, PVC pipe and other products.

This current funding joins the recently announced $500,000 CAD grant from the Climate Change and Emissions Management Corporation to bring the SkyCycle to pilot scale at the Capitol SkyMine San Antonio site by late 2015.

## CO2 Solutions partners with Neumann Systems for pilot

www.co2solutions.com

**CO2 Solutions and Neumann Systems Group will demonstrate a combination of their two proprietary technologies at pilot scale.**

CO2 Solutions has entered into a Collaboration Agreement with Colorado-based Neumann Systems Group (NSG), an established emissions control solutions provider.

The pilot combines CO2 Solutions' enzyme-based technology with NSG's high mass transfer gas-liquid contactor technology, known as NeuStream®. NSG's technology has a significantly smaller footprint than current technologies, with development to date demonstrating the potential to reduce CO2 capture equipment capital costs by up to 50 per cent.

Following this pilot, the companies anticipate co-marketing a combined solution for profitable application in enhanced oil recovery (EOR) and other existing and new CO2 sequestration and reuse markets.

"This project with Neumann Systems has the potential to significantly accelerate the commercialization of both our companies' carbon capture technologies," said Evan Price, President and CEO of CO2 Solutions. "Successful completion of the pilot will enable us to jointly pursue commercial opportunities both companies have identified. This is also a timely start to a relationship between CO2 Solutions and a U.S. partner given the June 2, 2014 landmark announcement by the Obama administration of carbon emissions regulations for the U.S. power sector."

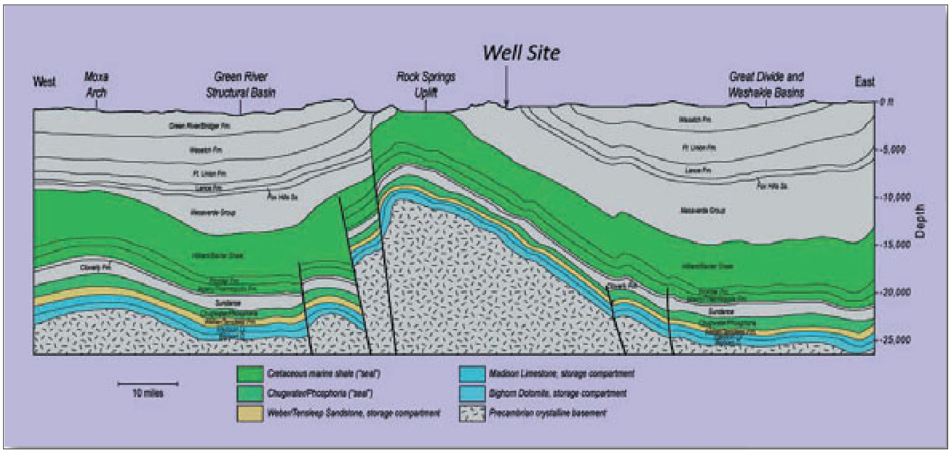
CO2 Solutions has demonstrated that, using conventional CO2 capture equipment, its enzyme-based solution can generate cost savings in excess of 30 per cent compared to conventional solvent-based processes. Additionally, the Corporation's solution enables the use of low-grade, nil-value heat from industrial sources, dramatically reducing process energy costs.

# Carbon storage potential in Wyoming

A geological feature in Wyoming could store up to 300 years of the region's CO2 emissions, a study finds.

The Wyoming Rock Springs Uplift could potentially store 14 to 17 billion metric tons of carbon dioxide (CO2), according to results from a Department of Energy-sponsored study. This is equal to 250 to 300 years' worth of CO2 emissions produced by Wyoming's coal-fired power plants and other large regional anthropogenic CO2 sources at current emission levels.

The project team – led by the University of Wyoming's Carbon Management Institute and sponsored by the Office of Fossil Energy's National Energy Technology Laboratory – gathered geologic, hydrologic and geochemical data from a 12,810-foot-deep stratigraphic test well drilled to evaluate the area's potential as a long-term, high-volume storage site for CO2.




*Cross-section of Moxa Arch-Rock Springs Uplift in Southwest Wyoming*

The Rock Springs Uplift (RSU), a geologic feature in southwestern Wyoming, was found to have the sought-after combination of ideal geological characteristics for carbon storage, and proximity to some of Wyoming's largest sources of anthropogenic CO2 emissions.

To evaluate the site's potential for CO2 storage, the project team performed digital imaging of a core sample to learn about the formation's grain size, mineralogy, facies distribution, and porosity. In addition, the team studied a comprehensive set of geophysical data from the test well, focusing on two potential CO2 storage reservoirs — the Madison Limestone and the Weber/Tensleep Sandstone — and the overlying formations that would trap the CO2 at depth.

The researchers discovered that, along with the promise of a prime CO2 storage space, the deep saline waters of the Rock Springs Uplift contain high, commercially viable concentrations of lithium: ~190 parts per million for the Weber/Tensleep Sandstone, and ~130 parts per million for the Madison Limestone.

For every 1 million metric tons of CO2 stored, approximately 250 metric tons of lithium carbonate, with an approximate market value of $1.6 million, could be recovered from processed brine. Lithium, which is used in batteries and other electronics applications, has become vital as many nations transition to greener technologies. The recovered lithium could generate revenue to offset the cost of CO2 storage and help reduce the need for lithium import.

In addition to the testing completed within the characterization well, and on samples removed from it, the project team performed a three-dimensional seismic survey of a 25-square-mile area around the test site. The seismic data allowed the researchers to extrapolate the geologic properties measured in the well — such as porosity, permeability, and fluid saturation — to the rocks throughout the two storage reservoirs and confining formations.

This made it possible to build realistic three-dimensional geologic models of these formations. Combining this with information gathered in the lab from the core samples, the researchers developed realistic assessments of how injected CO2 would behave in the storage reservoirs, which in turn yielded greatly improved CO2 storage capacity estimates.

## Project activity

The overall project goal is to characterize the RSU and Moxa Arch deep saline reservoirs for potential commercial development. The University of Wyoming and partners are accomplishing this through:

- Acquiring new geophysical data from the RSU to complement existing Moxa Arch data.
- Drilling and installing a 12,000 foot deep stratigraphic test well in the RSU. The drilling site is located near PacifiCorp's 2,200 megawatt Jim Bridger coal-fired power plant.
- Acquiring wireline logs, core, cuttings, fluid samples, and a baseline microseismic signature from the RSU well.
- Performing microfrac tests of the primary seal (Dinwoody Shale) and two target storage reservoirs.
- Conducting a 3-D seismic survey and an electromagnetic survey over a 25-square mile area surrounding the characterization well site.
- Developing a geologic model and performing numerical simulations of different CO2 injection/storage scenarios in the Madison Limestone formation to predict reservoir pressures and the displacement of formation saline fluids.
- Designing a complete management and treatment facility for displaced water to maintain acceptable reservoir pressures, obtain usable water, and extract valuable minerals (including lithium) from formation fluids.

## More information

www.netl.doe.gov/research

# Big Sky Carbon Sequestration Partnership drilling progress

The BSCSP field team has made substantial progress on the monitoring well since drilling began in May.

The Kevin Dome Carbon Storage project reached an important milestone on Tuesday, April 29, as ground was broken at the location where the first production well will be drilled, near the town of Oilmont in north-central Montana.

The production well will be used to extract naturally-occurring carbon dioxide (CO2) from underground. It will be ~3,800 feet deep and take approximately 3 weeks to drill. The team will also be logging and coring this well. Researchers will test the CO2 for its chemical composition and to measure its "producibility" (for example, how much is available and can it be consistently extracted).

Over five days, the team drilled the main hole down to a depth of 3,661 feet, the target destination for extracting the first core samples.

The "coring" process involves extracting long cylinders of rock, which are studied for their geologic properties. The first core was a 30 foot sample from the Potlatch Formation, which consists of dense, anhydrite rock. This layer will serve as a secondary layer of cap rock above the CO2 injection zone.

From there, the team drilled ahead approximately 200 feet to reach another section targeted for more extensive coring. Starting at a depth of 3,904 feet, the team cored a continuous section of 240 feet. The process, which took three full days to complete, was conducted by extracting four samples, each in 60 foot core barrels.

By capturing samples from such a long segment of the well, researchers will be able to carefully analyze the complex geology of the carbon dioxide (CO2) injection zone, which includes layers of cap rock as well as zones of high porosity and permeability. This will help BSCSP pinpoint the optimal for injection and monitoring activities.

When the coring was complete, the team continued drilling approximately 550 feet, reaching the total, final depth of 4,700 feet on May 28. With the primary drilling finished, the next tasks on this well will include logging (a measurement process), lining the hole with pipe, and cementing the well surfaces.

## Drilling the monitoring well

On the weekend of May 17-18, the drilling rig was moved to a new site, to begin work on drilling the second well of the project. This well will be used for geochemical monitoring throughout the project. Located near the proposed carbon dioxide (CO2) injection area, the well will allow scientists to take samples and conduct testing in order to track the underground movement of CO2.

On the morning of Monday, May 19, the drilling team "spudded" or began drilling the well. By the end of the day, they had drilled and set surface casing of the surface hole, which has a depth of 272 feet.

This well will take approximately two weeks to drill and have a total depth of 4,700 feet. The team will also be logging and coring this well.

Before the CO2 injection process begins, the team will install additional monitoring wells in the project area to facilitate comprehensive monitoring.

## Logging the monitoring well

After the drilling of the main hole for the monitoring well was finished, the team began the logging process, which allows them to collect a wide range of geologic measurements and data from the underground layers exposed by the open hole.

Logging involves lowering advanced measurement tools to the bottom of the well. The tools collect the measurements and data as they are pulled up slowly through the length of the well hole. The team monitors the logging process and the incoming data in real time from a large vehicle at the well site, which is equipped as a mobile laboratory.

Through a suite of logs, the team can collect valuable information such as the depth and lithology (rock type) of each formation, the porosity of rocks that are filled with gas or liquid, the size and connectivity of rock pores, the existence of fractures, and other geologic properties, all of which will guide drilling, injection and monitoring activities throughout the life of the project.

To collect all the data of interest, the team completed three logging "passes" – trips in and out of the hole with the equipment. The process was conducted over a 24 hour period on May 28th and 29th. The data has been synthesized into well logs – long, color coded graphs that display all the collected readings and measurements, correlated to the well depths.

When the logging was complete, the drill team cased the well by inserting and connecting pipe (one joint at a time) down the length of the hole. The well was then cemented through a two-stage cement process, first cementing the lower section (from 4,700 feet deep to 2,390 feet), followed by the upper section (from 2,390 feet to the surface). Work on the monitoring well was wrapped up successfully on the evening of May 30th, and the drilling rig was moved off the site.

## Background Water Sampling

The BSCSP Surface Water Monitoring Team returned to the Kevin Dome project site recently to conduct a second round of fieldwork. The team – led by Laura Dobeck (Montana State University), Travis McLing (Idaho National Lab), and Martin Stute (Barnard College, Columbia University) – collected surface water and groundwater samples from sites across the project area, including ponds, reservoirs, and shallow water wells.

Similar to the first round of fieldwork in the fall of 2013, these water samples will undergo laboratory analysis and provide a critical set of baseline data on the current chemical composition and general water quality of shallow subsurface and surface waters in the project area.

This baseline information will be compared to future water samples collected during and after the carbon dioxide (CO2) injection phase of the project. These comparisons will allow BSCSP scientists to provide assurance that water resources in the area are not being damaged.

### More information

www.bigskyco2.org

# Transport and storage news

## ETI to develop CCS marine monitoring system

www.eti.co.uk

**The Energy Technologies Institute (ETI) is developing a monitoring system using marine robotics to provide assurance that carbon dioxide stored deep below the seabed in CCS sites is secure.**

The project will be commissioned and funded by the ETI and will seek to develop a monitoring system which could be deployed using static monitoring equipment and marine robotics such as autonomous underwater vehicles (AUVs).

The project will be led by Fugro GEOS in collaboration with Sonardyne, the National Oceanography Centre (NOC) and the British Geological Survey (both part of NERC), Plymouth Marine Laboratory and the University of Southampton. The ETI is to invest £1m in the first phase of the project.

The ETI is to invest £1m in the first phase of the project. The first 12 months will see the economic and technological plans for the monitoring system developed.

Although there are existing technology components which can detect CO2 in a marine environment, there are no integrated, cost-effective and commercially available systems which can currently reliably record and report anomalies in the level of CO2 in the sea above a large store. The need to introduce capability for the robust monitoring of underground CO2 storage sites is in response to legislation such as the European Union's directive on CO2 storage. This states that any storage operator must monitor for potential leaks and examine whether any leak is damaging to the environment or human health.

Current research and evidence shows that leakage is highly unlikely. However if CO2 did escape, it would be difficult to predict with certainty exactly where it would reach the seabed. This is where mobile autonomous robots are very useful, patrolling over large areas at relatively low cost.

Robotics and Autonomous Systems was identified last year by the Minister for Universities and Science, David Willetts, as one of the 'Eight Great Technologies' that will propel the UK to future growth, and received a funding boost to bring the research base and industry together.

Den Gammer, ETI Strategy Manager for CCS added: "Progress on the development of a cost-effective, reliable monitoring system for the marine environment above CO2 storage complexes is another key step in the process of building confidence in a new CCS industry in the UK."

## Scottish and Cypriot scientists join to study CO2 storage in Mediterranean

www.sccs.org.uk

**Scientists from Scotland and Cyprus have formed a research partnership that could open up a new frontier for the storage of CO2 in the eastern Mediterranean.**

The agreement between the University of Nicosia's Centre for Green Development and Energy Policy (CGD) and Scottish Carbon Capture & Storage (SCCS) will seek funding for researchers from the far reaches of the European Union to work together to identify likely geological CO2 storage sites beneath the Mediterranean Sea to the south of Cyprus.

Using methodology developed in previous SCCS projects to assess CO2 storage capacity in the North Sea, the scientists will study seismic data and other information to build a picture of storage sites – including depleted oil and gas reservoirs and saline aquifers – which could boost Cyprus's capacity for tackling carbon emissions.

SCCS Director, Professor Stuart Haszeldine, announced the Memorandum of Understanding between SCCS and CGD at the All-Energy 2014 conference in Aberdeen.

Prof Haszeldine said: "Our research agreement with the University of Nicosia's Centre for Green Development is an exciting development for SCCS. It brings together expertise from both research groups for the shared goal of opening up new opportunities for CO2 storage, as a fledgling hydrocarbons industry in Cyprus plans its future. It will also provide excellent training opportunities for staff and students."

## Study shows Scotland ready for CCS hub

www.element-energy.co.uk

**A study by Element Energy has shown that all the components are either in place, or can be readily developed, for Scotland to become a CCS hub.**

Element Energy Ltd, working with partners SCCS, AMEC, and Dundas Consultants, recently completed the analysis into the development of CCS in the UK on behalf of Scottish Enterprise.

The report examines a wide range of scenarios for how CCS might develop and uses these to develop blueprints and detailed business plans for how to deliver CCS at least cost, least risk, and with maximum flexibility.

The report details how the combination of Carbon Capture and Storage with Enhanced Oil Recovery in the Central North Sea provides an excellent platform to achieve multiple benefits:

- Support the decarbonisation of the economy in Scotland, the UK and North West Europe, with potential for storing up to 1,700 million tonnes of UK and European CO2 over the period to 2050, helping us to meet the challenge of climate change.

- This can be accompanied by the economic production of up to 1.4 billion additional barrels of oil in the North Sea, extending the life of the oil industry in the UK, Norway and Denmark, and bringing in £10 bn in discounted revenue, and associated benefits in balance of trade, jobs, and energy security.

- Boost the economy - the potential gross value added to the Scottish economy from supporting infrastructure alone would be up to ca. £7 billion over the period to 2050.

- Reduce the costs of storage directly, leave a legacy infrastructure that could support decades of CCS activity, and generate tax revenues that could offset the costs of direct and indirect subsidies for CCS.

- Create cumulatively 44,000 person-years of employment in Scotland in the period to 2050.

The study has illustrated that all the components are either in place, or can be readily developed, for Scotland to become a CCS hub, supporting UK and European CCS deployment.

The CNS has by far the UK's largest variety of stakeholder interests, legacy facilities (pipelines, platforms and wells), potential physical and commercial / regulatory configurations for CCS development. This leads to a wealth of opportunity for established North Sea operators as well as new entrants. That demands leadership and flexibility, which Scotland is ready and willing to deliver.

The report provides a series of recommendations for Scotland if it wishes to be a European leader in CCS. Efforts to champion CCS projects, and develop infrastructure for EOR, power and industry in the UK and Europe should be stepped up immediately and continue during the 2010s on the following themes:

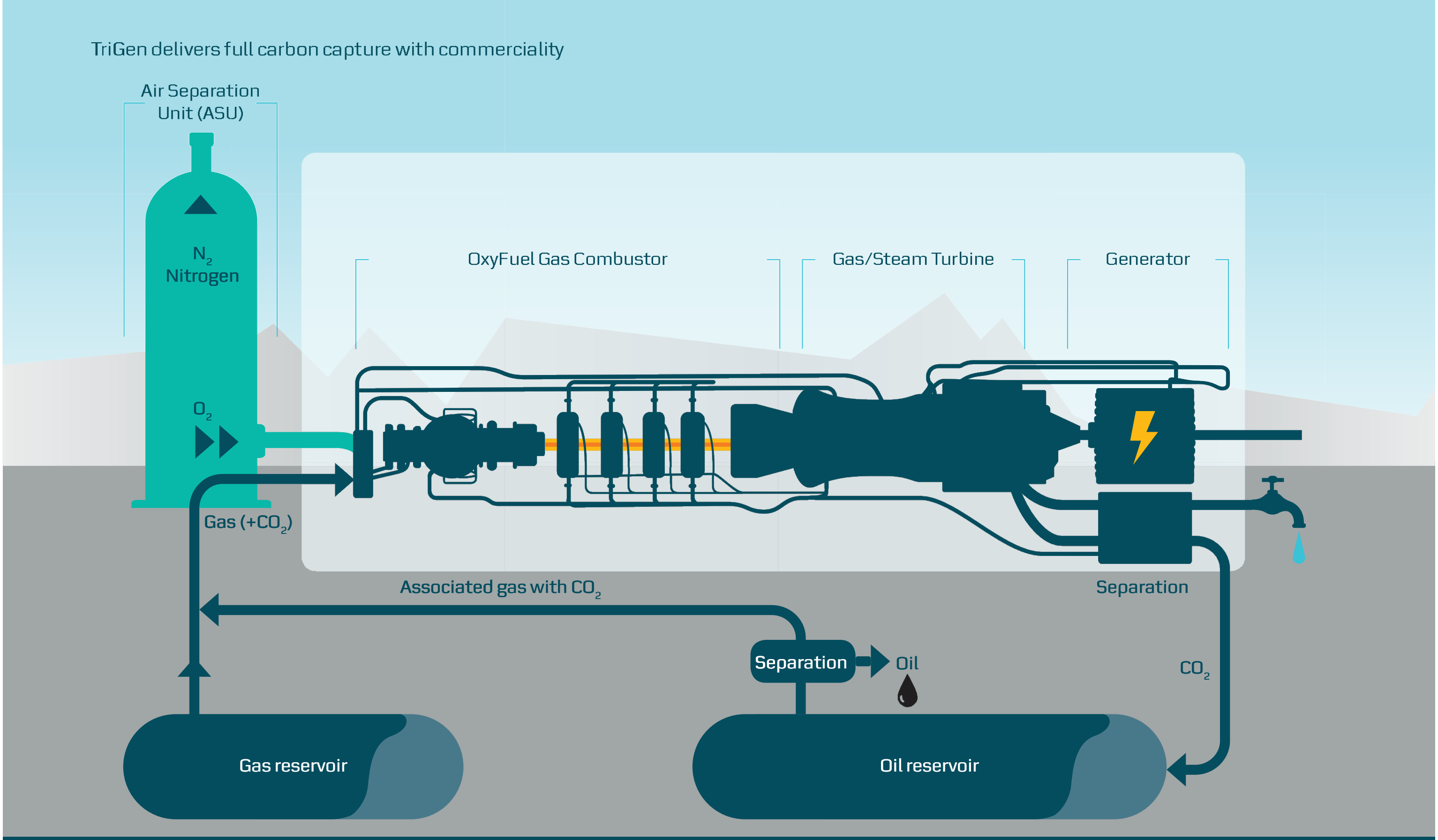
- Support for early CCS demonstration in Scotland

- Maximising the UK and European market for CCS in the 2010s and 2020s

- Supporting infrastructure that targets the CNS

- Improving CCS readiness and optimising infrastructure

- Improving the commercial attractiveness of CO2 transport, storage and EOR




# The TriGen™ Oxycombustion Process by Maersk Oil

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Maximize oil recovery
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As all of the TriGen products are useful, it enables zero emission energy from fossil fuels. Maersk Oil is working on developing commercial scale power projects that enable $CO_2$ EOR projects and is available to discuss potential collaboration opportunities globally. A single train TriGen plant can deliver:

- Up to 200 MW clean electricity net
- 500,000 gallons/day pure water
- Up to 45 mmscfd 'reservoir ready' $CO_2$ which can then produce ca. 7000 bbls/d incremental oil via Enhanced Oil Recovery (EOR)

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