# carbon capture journal

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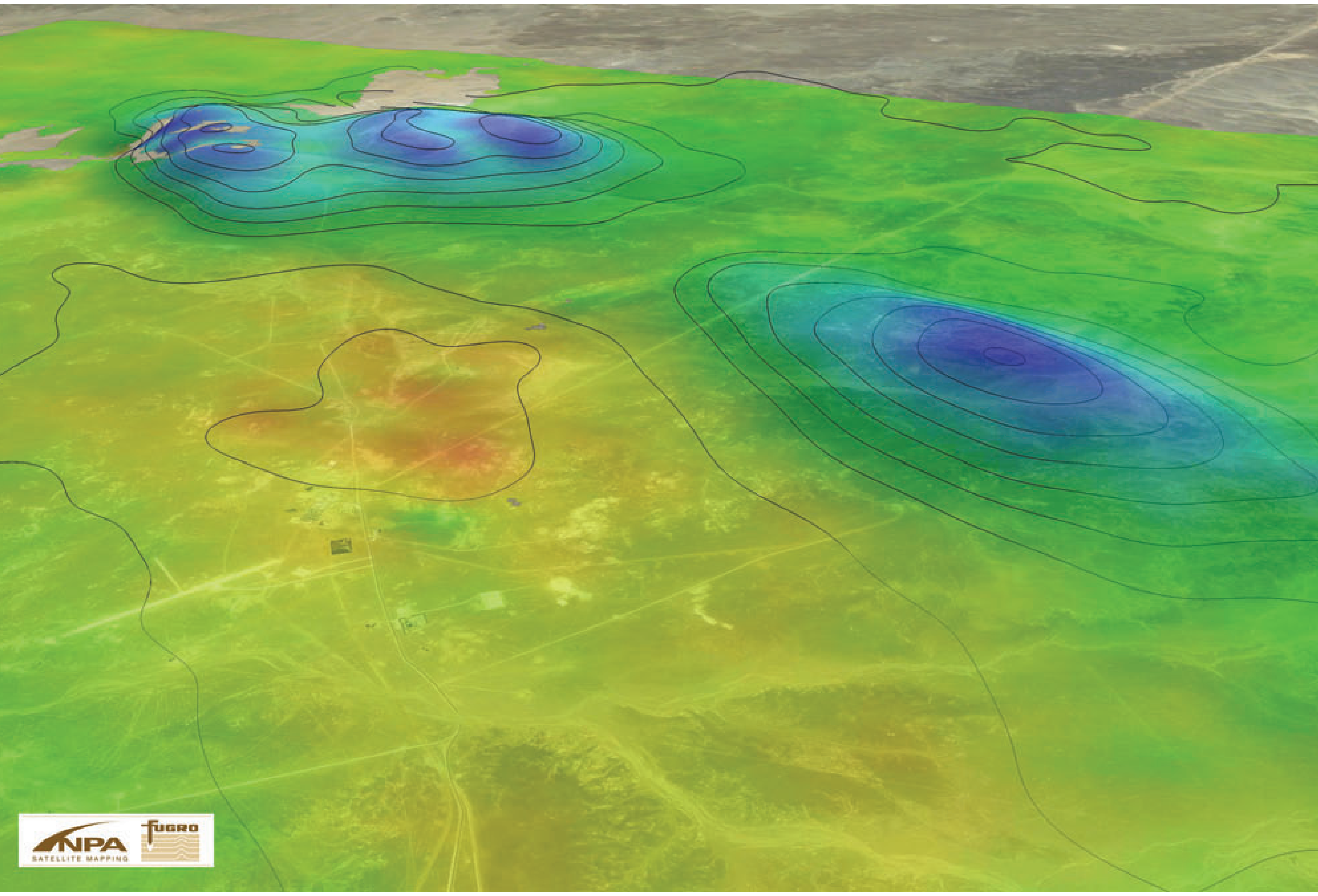
## The role of Earth Observation in CCS

## Air Liquide's air separation technology

## Clean Development Mechanism as a real option for CCS



GCCSI reports - industrial reuse of CO2 and CCS with bio-energy

Clean Energy Ministerial agrees steps to speed up CCS deployment

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CCS demonstration in developing countries

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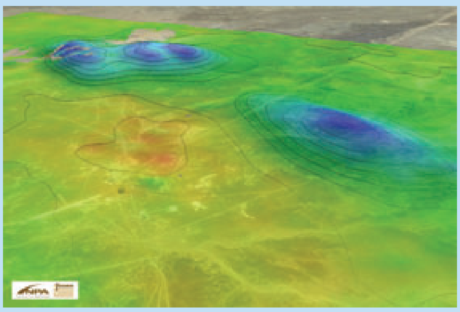
*Front cover:*
*Surface deformation across In Salah, Algeria, derived from Persistent Scatterer Interferometry spanning 2003 - 2010. Image © Fugro NPA 2011, SAR Data © European Space Agency 2003-2010, Background image © CNES/Spot Image*



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# The role of Earth Observation in CCS

**Over the last two years the European Space Agency (ESA) has been funding a project aiming to establish a 'service concept' based upon satellite Earth Observation (EO) technologies that could be applied to monitoring of CO2 capture and storage facilities. By Adam Thomas and Ren Capes, Fugro NPA**

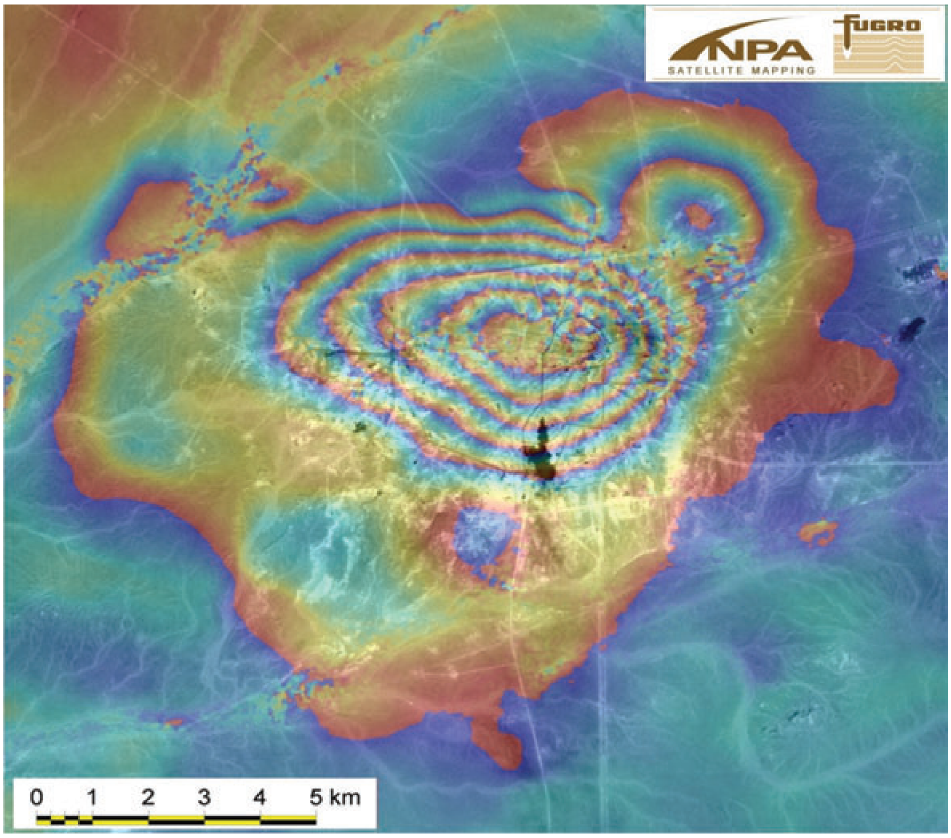


*Figure 1 - Monitoring the magnitude and extent of subsidence associated with oil production across an onshore oil field using differential SAR interferometry – Oman, Middle East. Two radar images dated 24th April 1992 and 27th May 1996 from ESA's ERS-1 satellite were processed to reveal six, 2.8cm interferometric fringes (motion contours), equalling an approximate total of nearly 17cm Line-of-Sight deformation.*
*Image © Fugro NPA Ltd 2009. Image data © ESA 1992, 1996.*

One of the biggest challenges facing the CCS industry is demonstrating that CO2 capture and storage is safe, effective and can be achieved at industrial scale at a competitive cost.

The establishment of test sites in the Netherlands, the United Kingdom and elsewhere indicates a growing need to address the lack of existing infrastructure currently in place to capture CO2 from industrial and power generation plants and store it in underground reservoirs available in the form of previously exploited oil and gas fields or other alternative storage sites/technologies.

Over the last two years the European Space Agency (ESA) has been funding a project aiming to establish a 'service concept' based upon satellite Earth Observation (EO) technologies that could be applied to industry and government, and that would support the establishment and monitoring of CO2 capture and storage facilities as part of future emissions-reduction and carbon-trading initiatives.

Project participants included: SciSys UK (lead), a company which has worked in all aspects of the space industry for many years from ground stations to on-board satellite software, Fugro NPA Ltd (UK), an acknowledged world leader in EO and specifically terrain-motion mapping from space, TNO, the largest fully independent research, development and consultancy organisation in the Netherlands, the British Geological Survey who are actively involved in the monitoring of many of the CCS sites, and AEA Technology, whose role was to provide user consultants and expose service concepts to key stakeholders within the industry.

## Current Capabilities in EO

A wide range of EO application services were considered in the project, including terrain-motion measurement, geological modelling, gravimetry, pipeline monitoring, land cover and ecosystem monitoring, vessel-tracking, sea-state forecasting, intelligent in situ sensor webs, real-time telemetry and monitoring of complex systems.

Conventional EO-based geological mapping is regarded as a routine tool used by most oil and gas producers when exploring for new reserves, planning surveys and establishing baselines for the monitoring of sites. However its wider application to CCS may not be relevant as most if not all CO2 to be stored is envisaged as filling existing, commercially depleted reservoirs where the geology has been largely determined during the discovery phase.

Ecosystem analysis to detect indications of vegetation stress linked to gas seepage and other factors is reasonably well developed using EO techniques and data sources available today, although not necessarily at resolutions always applicable to specific CCS sites.

One of the research areas of CO2GeoNet (a non-profit association joining together 13 partners spanning 7 European countries(www.co2geonet.com) is that of testing remote sensing monitoring technologies for potential CO2 leaks.

Work has been carried out in an area near the town of Latera in Lazio, Italy. This geothermal area, in a collapsed volcanic caldera, has long been known to have natural gas leaks and as such acts as a natural analogue to a leaking geological store of CO2. Since 2005 the indirect detection of CO2 via its effect on vegetation health has been studied using airborne multispectral and hyperspectral sensors in the visible, near and thermal infrared regions of the electromagnetic spectrum (Bateson, et al 2008). Methodologies developed have been extrapolated to the lower spatial resolution of satellite based sensors to investigate their use.

Pipeline routing and monitoring are well established remote sensing techniques but are normally aircraft and/or GPS-based. Pipeline monitoring can be accomplished using time-sequence aerial photography. Analysis of temporal change in the vicinity of the pipeline can provide information on nearby hazards such as landslides.

## Terrain-motion

Many potential storage sites are depleted oil or gas reservoirs which implicitly have already been mapped in minute detail, the project concluded that monitoring applications were of most interest, and the most relevant of these was terrain-motion mapping using Synthetic Aperture Radar Interferometry, or InSAR for


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short. The rest of this article, therefore, focuses on applications of InSAR for CCS.

InSAR technology is already widely used in the oil and gas industry to measure the integrity and optimise the productivity of onshore reservoirs. Depending on target characteristics and the temporal distribution of SAR data used, relative accuracies of better than 1mm displacement can routinely be achieved. When this accuracy is combined with the wide-area coverage that characterises satellite EO, a unique and valuable tool is provided with many applications, one of which can be the monitoring of terrain-motions related to CCS life-cycle, e.g.

**1. CCS site characterisation, i.e. tectonic setting:** InSAR can represent a useful tool in the provision of synoptic maps of crustal deformation relating to tectonics, e.g. fault-mapping and dynamics, of obvious concern to those positioning permanent subterranean reservoirs of potentially hazardous gases.

**2. Transportation, i.e. pipeline routing and integrity monitoring:** Besides monitoring general terrain-deformation, the main use for InSAR in this area is landslide mapping where potential slides might mean a re-routing of a proposed new pipeline, or for the risk management of slopes carrying an existing infrastructure.

**3. Analyses of plume migration as a surface expression:** In some circumstances, InSAR can be used to map $CO_2$ migration through the reservoir as an expression of surface terrain deformation.

**4. CCS-injection-facility integrity monitoring:** InSAR can be used to access the general, relative stability of a CCS pumping facility, e.g. effects of differential subsidence could lead to leaks and blowouts.

Note that appropriate SAR data availability for ongoing monitoring is assured by several different missions, not least ESA's Sentinel 1a and 1b radar satellites, due for launch next year as part of Europe's Global Monitoring for Environment and Security initiative (www.gmes.info), which will provide continuity to the invaluable SAR data archive already established since 1991.

*ESA's Envisat satellite*

## Satellite InSAR

Since 1991, European Space Agency satellites (ERS-1, ERS-2 and Envisat) carrying Synthetic Aperture Radar (SAR) instruments have been consistently acquiring data across the world, establishing an archive of over 1.5 million images. These systems have since been augmented by a number of other SAR satellites operated by a other agencies (in particular the Canadian, German, Italian and Japanese space agencies), providing yet further opportunity for analyses.

SAR images contain information about the position of the terrain at the time of image acquisition. As subsequent images are acquired over the same location they can be compared and used to map relative terrain-motion. This principal forms the basis of InSAR.

A range of InSAR techniques have been developed to extract optimal information from SAR imagery. Of particular importance for the CCS industry is a hybrid technique known as Persistent Scatterer InSAR (PSI). PSI allows relative sub-millimetric measurements to be made against individual, radar-reflective terrain-features that provide a persistent response in each SAR image. These 'persistent scatterers' (or 'virtual GPS points') generally correspond to parts of man-made structures, though they can also include bare rocks and outcrops.

They act as persistent scatterers because of their serendipitous geometry, surface-roughness and electrical conductivity. The exact location of persistent scatterers cannot, therefore, be accurately predicted in advance of processing, but over urban areas their densities are usually measured in the hundreds per square kilometre (thousands with the latest high-resolution SAR imagery).

The unique products derived from PSI include average annual motion maps and the motion history of individual scatterers, both covering the time-span of the dataset used, e.g. 1992 to the present day. The capability of PSI allows users to uniquely interrogate historical information (although PSI can also be used for up-to-date monitoring campaigns), an ability not possible with conventional surveying methods. The PSI technique was rigorously validated during a specific campaign over sites in the Netherlands during Stage 2 of the ESA Global Monitoring for Environment & Security (GMES) project Terrafirma, and is now widely used by dozens of national geoscience organisations across Europe.

The idea of using InSAR for the monitoring of CCS reservoirs first evolved from results obtained monitoring the inverse, i.e. gas and oil production where depletion of certain reservoirs cause a surface expression of subsidence. Such measurements proved to be of use to practitioners in understanding 'compaction-drive' and fluid dynamics.

It was a natural progression to apply similar techniques to the reverse, to the injection of fluids into reservoirs, where the natural elasticity of the cap rock would heave in sympathy with increased reservoir pressure.

## Case study: In Salah CCS Project, Algeria

In Salah is a world leading industrial scale CCS project located in central Algeria. The project, a joint venture initiative between BP, Sonatrach and Statoil, has been in operation since 2004. CO2 is separated from natural gas produced from three fields of Krechba, Reg, and Teguentour (Onumaa & Ohkawa 2008) and is re-injected into the Krechba Carboniferous Sandstone reservoir via three long (1,500m) horizontal wells at a depth of around 1,900m.

In 2005 a Joint Industry Project was set up to monitor the CO2 storage process using a variety of geochemical, geophysical and production techniques over an initial 5 year period (Mathieson, Midgely, Wright, Saoula & Ringrose 2010). InSAR has been used to better understand the impact of gas production and CO2 injection on the terrain, and provide a deeper understanding of reservoir characteristics.

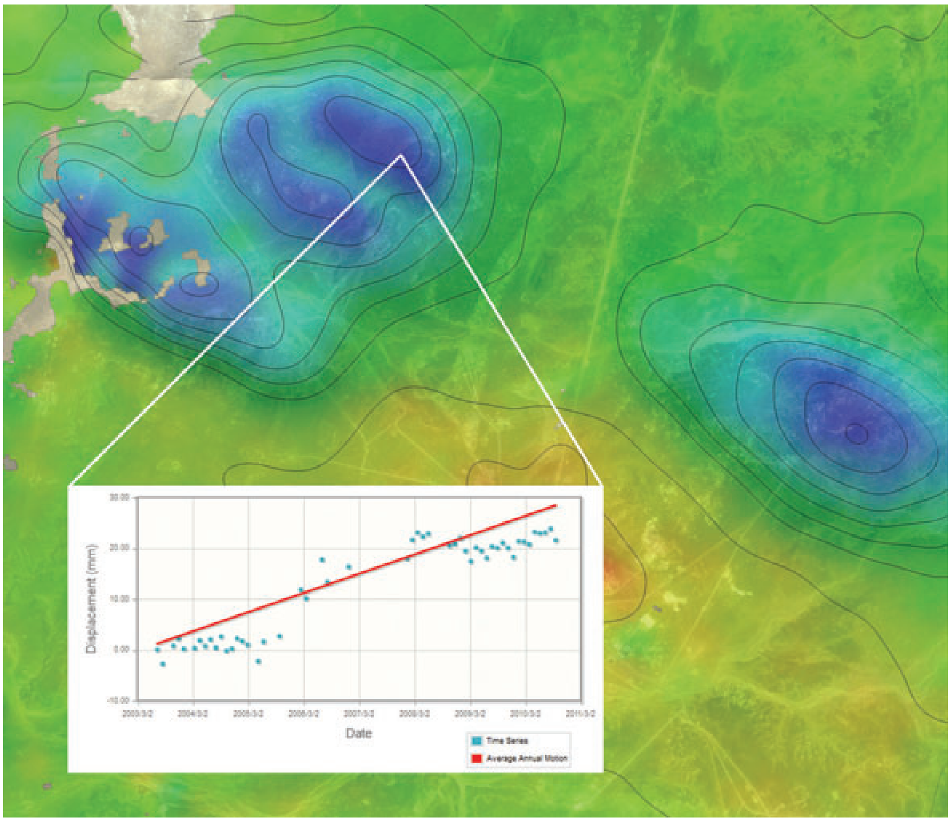
Fugro NPA Ltd have carried out a proprietary study of the impact of In Salah production/storage activities on the regional terrain using PSI. The quantity of satellite SAR imagery archived and available across the Krechba field, as well as the local ground cover conditions (dry, vegetation-free rocky desert) were key prerequisites for the application of PSI to this area.

PSI was undertaken using 50 archived SAR images (acquired by ESA's Envisat satellite), spanning a 7 year period (July 2003 to September 2010). High densities of measurement points, 406 per km2, were observed across the reservoir. PSI was successful in identifying four domains of terrain motion.

Mapping these features against well locations highlights a correlation, along a northwest axis, with natural gas production (subsidence), enveloped to the north and east by three smaller domains of motion that relate to CO2 injection (heave). Subsidence rates along the axis KB-CA/CB/CC/CE approximate -2.9 mm/year, as opposed to +4.7mm/year at heave locations KB-501/502/503.

The match between terrain deformation and evidence from subsurface data for the movement of CO2in the reservoir is intriguing. If PSI data can be calibrated against aspects of the injection dynamics, then the opportunity exists in certain circumstances for the remote monitoring of CO2 movement in the subsurface (Mathieson, Wright, Roberts & Ringrose 2008).

Elsewhere, PSI has been used to measure terrain heave associated with a gas storage facility located in the western region of Berlin, Germany. PSI was used to enhance measurements derived from ground levelling campaigns which, although highly accurate, only provide readings over a coarse network of measurements and are inherently time consuming and costly.




*Surface deformation across In Salah, Algeria, derived from Persistent Scatterer Interferometry spanning 2003 - 2010. Time-series shows millimetric uplift signal associated with injection. Result & Image © Fugro NPA 2011, SAR Data © European Space Agency 2003-2010, Background image © CNES/Spot Image.*

PSI was integrated into the study with great success; movement correlated well with an increase in borehole head pressures resulting from gas injection. It was determined that PSI can be used effectively to monitor the initial phases of gas storage operations (Kuehn, Hoth, Stark, Burren & Hole 2009).

## Conclusions

This article has provided a brief snapshot of the work done in a European Space Agency project looking at the potential for satellite EO technologies in application to CCS. A wide array of EO technologies were considered and although many might ultimately prove useful, the main potential is thought to be offered by satellite SAR interferometry where terrain-motion-measuring techniques can be applied to all stages of the CCS life-cycle.

It is also clear, however, given the prevailing public scepticism and suspicions of CCS as a concept, particularly if sited onshore and near populations, that the current focus is more on public relations than the analysis of state-of-the-art monitoring technologies. It is good to know, though, that, if and when required, satellite EO can offer cost-effective, non-invasive tools that match the cutting-edge nature of CCS.

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## Authors and links

Adam Thomas and Ren Capes. PSI processing by Harry McCormack and Alex Fairbarns (Fugro NPA Ltd).

www.fugro-npa.com
www.esa.int
Europe's Global Monitoring for Environment and Security initiative
www.gmes.info

# Air separation units for coal power plants

For over twenty years, Air Liquide has been a world leader in the development of air separation units (ASU) for the Integrated Gasification Combined Cycle (IGCC). For almost ten years, the Group has contributed to the development oxy-combustion coal power plants with CO2 capture, and it continues to improve and customize its air separation process for coal-fired power plants. This article summarizes what has recently been achieved and what could be expected in the next decade from these ASU developments in order to significantly improve the oxy-combustion and IGCC processes.

**By Jean-Pierre Tranier, Nicolas Perrin, Richard Dubettier, Air Liquide**

There are three ways to capture CO2 from coal power plants:

Post-combustion capture is essentially N2/CO2 separation, and it does not require an oxygen production plant.

With oxy-combustion, oxygen is used in the form of a high-purity oxidant stream. This enables combustion in a nitrogen-depleted atmosphere. This process results in the production of a flue gas that is highly concentrated in CO2, thus simplifying the CO2 capture process. An oxygen production plant is necessary.

The third way to capture CO2 from a coal power plant is by IGCC with pre-combustion capture. This method also requires an oxygen production plant. During pre-combustion, coal is partially oxidized in a gasifier, and a syngas containing mainly CO, CO2, and H2 undergoes a shift in which CO is converted into CO2 and H2 in the presence of water. Finally, the CO2 is captured (typically by absorption) and the H2 is burnt in a gas turbine.

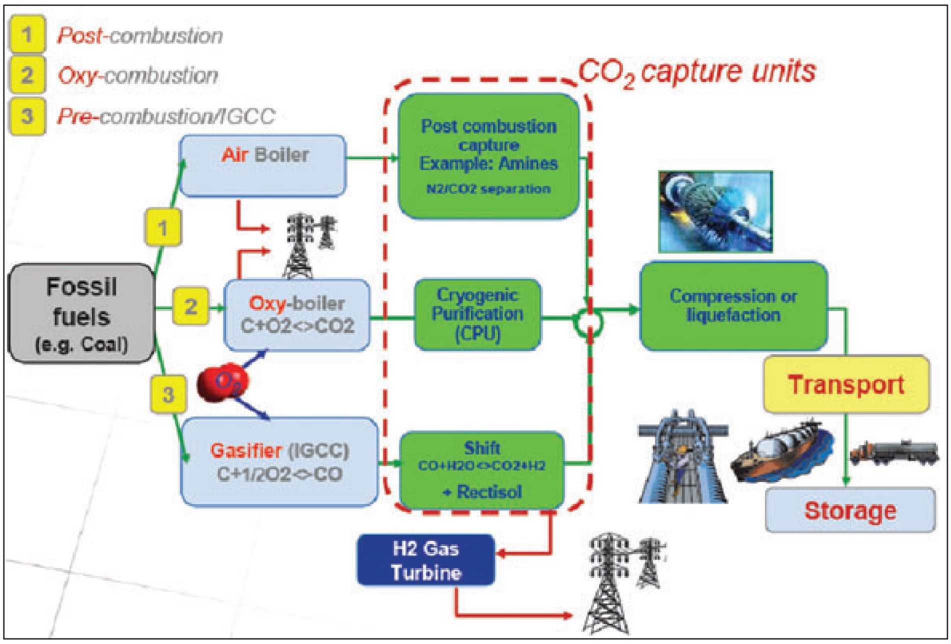


*Figure 1: Solutions for CO2 capture in coal power plants*

## How to produce oxygen onsite

A commercial-scale coal-fired oxy-combustion power plant requires thousands of tons of oxygen each day. Currently, cryogenic distillation is the only commercially viable technology that will produce such large quantities of O2. Other air separation technologies like pressure swing adsorption, vacuum swing adsorption, and polymeric membranes cannot economically produce such quantities.

Ceramic membranes (oxygen ion transport membranes) are not yet commercially available for large-scale oxygen production, therefore making it difficult to compare them to cryogenic distillation, both in terms of investment and performance.

Cryogenic ASU performances have improved tremendously over the last forty years. It is estimated that power consumption has been cut almost in half, while distillation column productivity (i.e., flow per square meter) has multiplied threefold. The technology should continue to advance over the next decade, specifically through targeted improvements in oxy-combustion and IGCC plants.

## Coal oxy-combustion special requirements

ASU oxy-coal combustion is chiefly characterized by three elements: size (typically over 8 000 metric tons per day for industrial-scale plants); low pressure (between 1.1 and 1.7 bar absolute); and potentially low oxygen purity. Low oxygen purity would mean a value in the range of 85-98% O2 content compared to the typical 99.5-99.8% O2 content of high-purity units. Using low-purity O2 enables significant ASU power consumption savings.

The cycles for the production of low-purity oxygen at 95% were developed in the early 1990s, primarily for two applications: gasification (including IGCC) and oxygen enrichment of blast furnace vent streams. These applications required the design of plants that demonstrated specific separation energy[1] around 200 kilowatt-hour per metric ton (kWh/t) of pure O2.

The cycles developed in the 1990s were not fully adapted for oxy-combustion. Instead, they were optimized to produce relatively high-pressure oxygen (5-80 bar absolute) and in some cases to perform co-production of nitrogen. In the past five years, however, programs have been launched to optimize ASUs for oxy-combustion by adapting the process cycle to the specific requirements of oxy-combustion (i.e., low oxygen pressure and no nitrogen requirement) rather than fully redesigning the ASU.

Additionally, this type of adaptation has incorporated technology improvements made in ASUs produced since the 1990s. Thus far, the energy requirement of the ASU has been improved from 200kWh/t to less than 160 kWh/t with heat integration, a process that consists of transferring heat from the ASU compressor(s) to the steam cycle.

*1 Separation energy is defined as the power required to produce 1 metric ton of pure oxygen contained in a gaseous oxygen stream for a given oxygen purity at an atmospheric pressure (101325 Pa) under ISO conditions of 15°C and 60% relative humidity. Compressor driver efficiency (for electrical, steam, or gas turbines), heat for regeneration of driers, and power consumption of the cooling system are not considered in this definition.*

Heat integration achieves reduction of two types of energy losses: those associated with compression and those associated with the heating of boiler feed water. This transfer of heat can be direct (feed water preheating) or indirect (oxygen preheating, coal drying, or the heating of any fluid in the oxy-combustion cycle).

Several studies have been performed on heat integration, and one conclusion has been that the benefits of the process are very dependent on the overall design of the plant: ambient conditions, efficiency of the steam cycle, cooling system (dry versus wet), coal type (water and sulfur content), etc. In some cases, a reduction of more than 10% in the ASU's power consumption can be achieved.

## The next steps for optimization

Other potential ASU optimizations have been identified and are currently under development to achieve separation energy around 140 kWh/t with heat integration by 2015. With trending cryogenic improvements, ASUs can be expected to reach 120 kWh/t with heat integration by 2020. This would mean a 40% reduction in power consumption from the state-of-the-art ASU of the past decade.

Figure 2 shows the magnitude of these improvements. This trend is expected to continue in the future, since the overall energy spent during separation is still significantly greater than the theoretically required separation energy (50 kWh/t).

When considering the oxy-fuel plant overall, it is possible today to design a plant with an Higher Heating Value (HHV) efficiency loss in the 5-7 percentage points range. By 2015, this range should reach 4-6 percentage points. By 2020, it could reach 3-5 percentage points.

These efficiency losses are based on the comparison with an air-fired case without heat recovery below acid dew point, achieving 40% HHV efficiency for today and 2015, and 45% HHV efficiency for 2020. The efficiency loss is given as a range to take into account parameters such as coal sulphur and moisture content, steam cycle efficiency…

These estimates are based on ASU energy-efficiency improvements as well as predicted improvements in the overall oxy-combustion cycle. This includes recycle location; implementation of technologies such as coal drying; improvement in the steam cycle (double reheating or 700°C steam by 2020); and improvements in flue gas compression and the purification unit.

## ASUs for IGCC

Given the gains already achieved in oxy-combustion, it is necessary to revisit the design of ASUs for IGCC developed in the 1990s. At that time, the main focus was on integration with gas turbines. Figure 3 shows the different options.

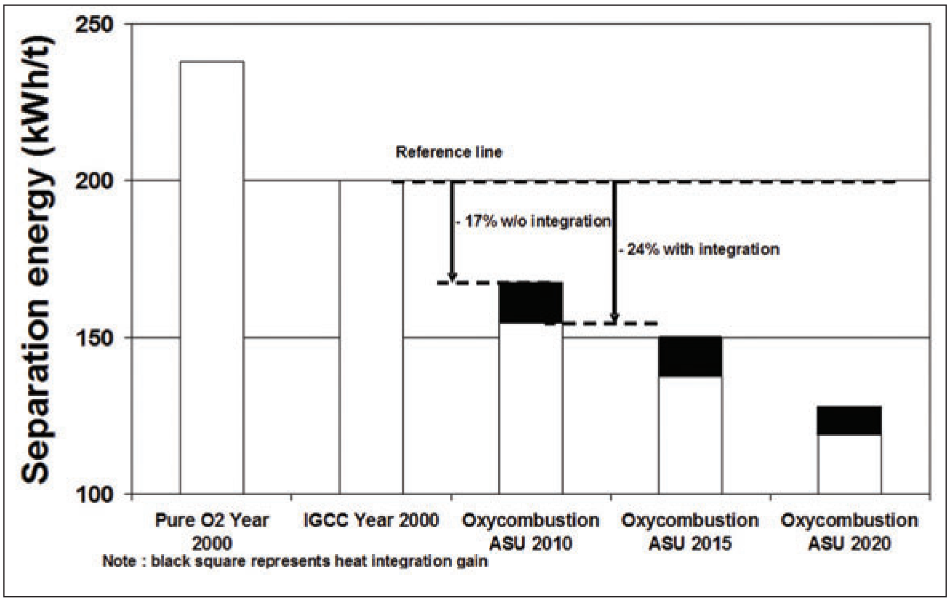


*Figure 2: Improvements in cryogenic ASU energy efficiency*

From the ASU design perspective, there are two solutions:

• Low-pressure cycle, when no nitrogen is injected into the gas turbine. In this case the ASU design is very similar to the ASU for oxy-combustion. Similar gain could be achieved in separation energy, where the energy for compression of oxygen from atmospheric pressure to gasifier pressure remains constant. This cycle will be used when no integration is considered.

• **High-pressure cycle**, when most of the nitrogen produced by the ASU is injected into the gas turbine. This cycle can be used when low or high partial integration or full integration is chosen. The advantage of this solution is a lower capital expenditure (CAPEX) and better separation energy, but it requires more additional compression energy to raise the pressure of the nitrogen. For an IGCC with CO2 capture, the high-pressure cycle may also be selected on the basis of the nitrogen requirements for diluting hydrogen before injection in the gas turbine.

Full integration is the lowest CAPEX option, as it does not require an independent air compressor to supply air to the ASU. However, it is not very convenient from an operational point of view. For this reason, partial integration is considered the best compromise from the point of view of CAPEX, efficiency and immediate operability. Low partial integration (with no air extraction from the gas turbine) would even be preferred to high partial integration for operability.

Given the improvements developed for oxy-combustion and the technological im-

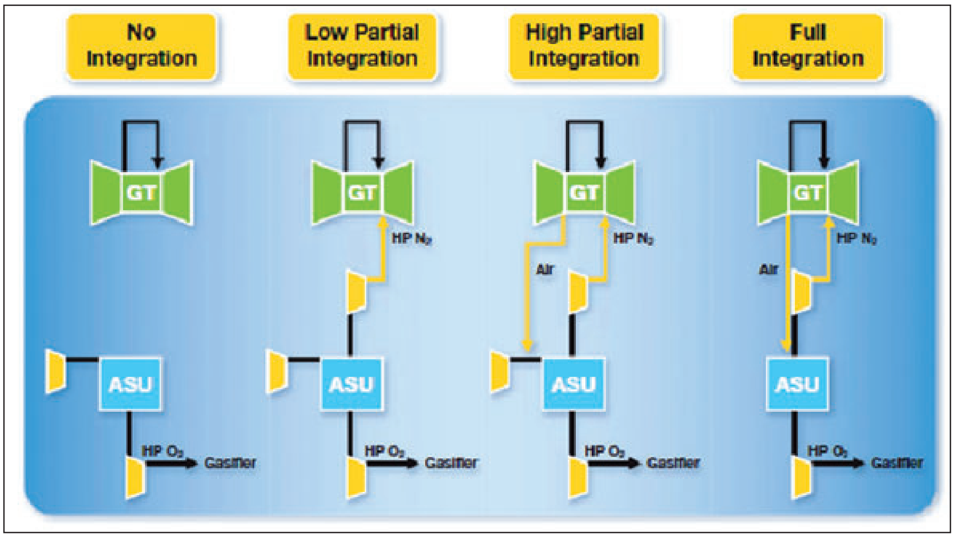


*Figure 3: ASU integration options with gas turbines*

provements of other ASUs built since the 1990s, significant gains can be achieved for ASUs for IGCC in the following areas.

- **Heat integration**: semi-adiabatic compression of air (even if independent of the gas turbine) can be used to heat nitrogen before injection into the gas turbine and oxygen before injection into the gasifier and/or boiler feed water during preheating. Heat integration would also considerably reduce the ASU's water-cooling requirements.
- **A new process cycle** including, in particular, replacement of oxygen compression by additional air compression and oxygen pumps: thanks to progress made in the manufacturing of brazed aluminum heat exchangers, it is now possible to design an ASU with full internal oxygen compression by pump, for pressures within a range of 40-100 bar absolute. In the 1990s, most of the ASUs for IGCC had only partial internal oxygen compression (from atmospheric pressure to intermediate pressure 5-15 bar range) followed by external compression. This new process cycle could significantly reduce the plant's CAPEX.
- **Reduction of the pressure drop** when injecting diluent nitrogen in the gas turbine: this represents a major loss of energy in the current design of IGCC plants. According to various studies, this loss can be equivalent to an increase of 40-80 kWh/t of $O_2$ produced. Reducing the pressure drop would require a redesign of the combustion chamber of the gas turbine.

Overall, the HHV efficiency of the IGCC could be increased by more than one percentage point through improvement in the ASU design and integration.

## Energy storage and flexibility

Energy storage is another area with potential for development. At one point in the process, oxygen is produced in a liquid form. This liquid oxygen can be easily stored using cryogenic ASU technology.

The idea is very simple. Liquid oxygen can be stored at off-peak hours (typically at night or when power from wind is available in great quantities) for later use during peak hours, potentially decreasing by 50% the ASU's power requirements. For an oxy-combustion plant, more than 5% additional power could be dispatched to the network at peak hours.

Energy storage can also be used to store power from renewables (wind or solar). In terms of flexibility, Air Liquide has demonstrated that at least 5% per minute capacity change can be achieved in ASUs for IGCC. In other words, the ASU can be ramped down from 100% to 50%, or up from 50% to 100%, in less than ten minutes.

## Conclusions

Air Liquide is committed to develop Air Separation Units in order to improve significantly the oxy-combustion and IGCC processes, making them attractive solutions for deriving electricity from coal while reducing $CO_2$ emissions.

By optimizing the overall coal oxy-combustion system, it is possible to identify several key advantages of the solution: minimal efficiency loss associated with $CO_2$ capture (3-5 percentage point penalty on HHV efficiency compared to no capture expected in 2020) together with near-zero emission, energy storage capability, quick load change and limited water requirements.

For the IGCC, even after the extensive efficiency improvements achieved in the 1990s, there is potential for further optimization that could increase HHV efficiency by more than one additional percentage point.

## More information

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# Clean Development Mechanism (CDM) as a real option for CCS - How do we get there?

Could much needed assistance for CCS could come in the form of the Clean Development Mechanism?

**By Steven M. Carpenter, VP, Advanced Resources International**

## Background

It is safe to say that Carbon Capture and Storage (or Sequestration) (CCS) is an essential part of the climate change portfolio. It is also safe to say that the vast majority of those in the CCS industry believe that use and acceptance of CCS has to be expanded. Enhanced Oil Recovery (EOR) is leading the way in the short term doing the early heavy lifting.

The early entry of CCS by EOR is limited however to the EOR producing regions of the US and Canada. EOR is also limited to funding or economics that make the use of CCS possible – better put - in the short term, CCS can't exist without EOR.

In order to expand the acceptance, and more importantly the deployment of CCS beyond EOR, pilot, and first of a kind installations – and more importantly to deploy CCS in developing economies – CCS needs some help. I just returned from the Tenth Annual Carbon Capture & Sequestration Conference in Pittsburgh, PA where we celebrated the conference's 10th anniversary.

The conference was aptly titled: Building on a Decade of Progress to Assure Commercial Deployment. Many in attendance suggest that CCS's much needed assistance may come in the form of CCS as part of a Clean Development Mechanism (CDM).

The UNFCCC Cancun meeting included discussion of inclusion of CCS as part of the CDM and it is likely that those same discussions will be carried over to the Durban, South Africa meeting as well. Most of the CCS roadmaps generated by the CCS NGO's all acknowledge the need to expand CCS.

If most agree that CCS is needed and CDM is a viable option to allow needed financing for developing countries to implement this "required GHG portfolio technology", why hasn't it occurred yet?

Stuart Dalton, Director of Generation for Electric Power Research Institute (EPRI) summed it up very eloquently in his plenary presentation at the CCS Conference. He suggested that one of the many causes for the delay in international movement of CCS is a result of very difficult and sometimes protracted international agreements.

In the present economic climate of government budget cuts, there are questions of funding and timing. He concluded his opening remarks with the following hierarchy, "Policy trumps funding and funding trumps technology".



## So how do we get there?

*"EOR will continue to lead the way as an early entrant into the CCS project world".- Steve Carpenter, Vice President for Advanced Resources International*

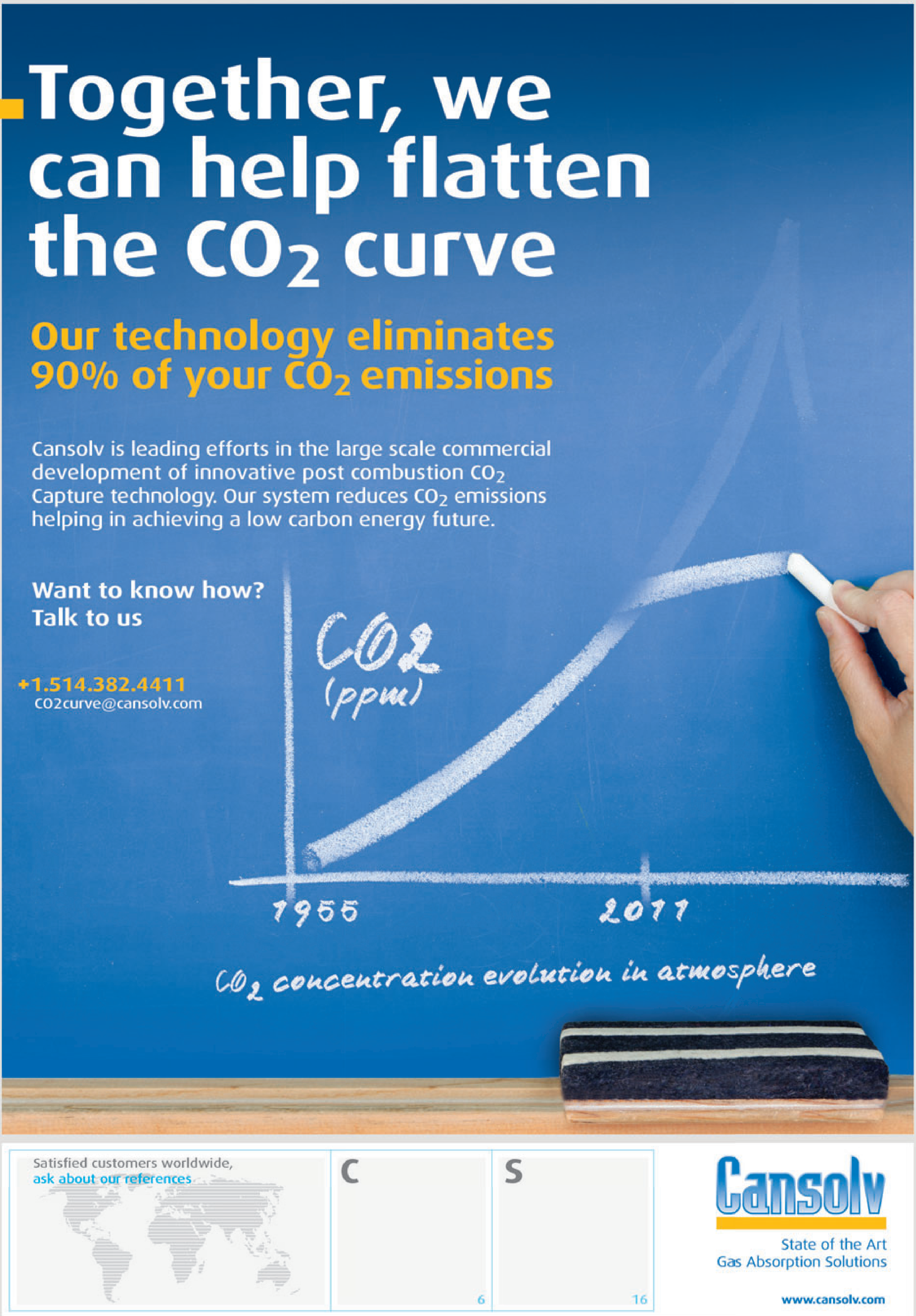
While Mr. Dalton's comments certainly were not meant to apply exclusively to CCS as CDM, it is clear that the issue of CCS as a CDM is not a technological one. It is partially a financial issue and partially a political issue. As such, CDM would address some issues of funding and access of funding to developing economies.

So again I ask myself, why hasn't this happened yet? A closer review of the body of evidence will reveal a host of issues – both nuanced and overt – that to date have kept CCS out of the CDM arena. One step in the right "policy" direct is an acceptable international standard for commercial geological storage of CO2.

In late November 2010, a group of two dozen experts from the US and Canada met for two days in Calgary, Alberta to begin "a first step" in the international standardization of geological storage of CO2. The plan is to produce the world's first formally recognized CCS standard for commercial deployment.

CSA Standards, a leading developer of standards, codes and personnel certification programs, and the International Performance Assessment Centre for Geologic Storage of Carbon Dioxide (IPAC-CO2) have partnered to develop a bi-national American-Canadian carbon capture and storage standard for the geologic storage of carbon dioxide.

IPAC-CO2 Research Inc., the International Performance Assessment Centre for Geologic Storage of Carbon Dioxide, is an environmental non-government organization committed to providing independent risk assessments to governments, industry and the public. IPAC-CO2 Research Inc. was estab-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lished in 2009 with $14 million in funding from the Government of Saskatchewan, Royal Dutch Shell and the Government of Canada. The secretariat or administrative offices are located at the University of Regina and IPAC-CO2 Research Inc. has established a global network of regional centers in eight countries on six continents.

CSA Standards is a leading standards-based solutions organization serving industry, government, consumers and other interested parties in North America and the global marketplace. Focusing on standards and codes development, application products, training, advisory and personnel certification services, the organization aims to enhance public safety, improve quality of life, preserve the environment and facilitate trade.

CSA Standards is a division of CSA Group, also consisting of CSA International, which provides testing and certification services for electrical, mechanical, plumbing, gas and a variety of other products; and OnSpeX, a provider of consumer product evaluation, inspection and advisory services for retailers and manufacturers.

CSA Standards and IPAC-CO2 assembled this group and have drawn from experts with full GSC project life cycle knowledge and experience and will represent a balance of stakeholder interests. These experts come from government, industry, consulting, NGO's, and academia. Their areas of expertise cover management, siting, engineering, risk, closure and operations and are member of the Technical Committee. They will lead working groups of matrix managed skill sets to create the standards and CSA Standards will manage the process and shall be responsible for maintaining the standard.

As a first step prior to the November kick-off meeting in Calgary, the committee members reviewed existing "seed documents" that consisted of existing industry guidelines, best practices, and related standards. The Committee, with process and editorial support from CSA Standards, will be completely responsible for the content of the final standard.

When complete, the bi-national American-Canada Consensus Standard will address the full geological carbon dioxide storage project life cycle including: site selection, operation, closure, and post-closure stewardship. The Standard will specify requirements for a commercial geological CCS project and will enable an organization/operator to:

- follow best management practices and present-state knowledge to effectively select, design, construct, and manage a CCS project
- establish protocols for the quantification of and reporting on geological carbon storage consistent with industry and international norms and regulations
- evaluate the adherence of a project to best management practices and present-state knowledge throughout the life cycle of a CCS project

The standards will provide guidance for site selection & development, operations, closure, and post-closure stewardship for CCS projects in geological formations that include enhanced oil recovery (EOR), gas or oil fields, saline formations, enhanced coal bed methane recovery (ECBM).

Additionally, the standard will provide technological and associated infrastructure solutions for geological assessment, well construction, operation and maintenance, and well abandonment. The management systems framework for CCS projects will address risk and quality management, public and worker health and safety, public consultation and comment, and environmental health and other impacts.

Finally the standard will deal with quantification and definition of methodology, validation and verification, permanence and leakage, and reporting.

Subject matter experts act as leads on six committees that are broken down into the major categories of:

- Management
- Site Selection Characterization
- Risk assessment
- Development and Operations
- Monitoring and Verification
- Closure

Each of the technical leads also serve as committee members on other committees to ensure a cross pollination of the required subject matter. Many hours meeting, calling and writing have occurred since the Calgary kick-off meeting. Many more are expected. The full committee plans to meet this June in Denver, Colorado to begin the next round of review and revision.

## Summary

EOR will continue to lead the way as an early entrant into the CCS project world. EOR provides an opportunity to address both climate and energy security. The role of government in the world-view of CCS is very important. Without the financial incentives provided by the governments around the globe, the rollout of numerous large-scale CCS projects is not likely.

It is expected that this standard is completed sometime in late 2011. It is intended that the new standard will be used as a basis for the promotion of international standards through the International Organization for Standardization (ISO). Is the development a bi-national American-Canadian carbon capture and storage standard for the geologic storage of carbon dioxide the answer? It is at least a good first step toward that end.

## References:

Carbon Dioxide Capture and Storage in the Clean Development Mechanism: Assessing market effects of inclusion, Technical Study Report Number: 2008/13, IEA GHG Programme, November 2008

CCS-CO2-EOR Whitepaper FINAL Advanced Resources International, Inc., April 2010

Making the case for CCS in the CDM - The developing world needs a support mechanism to also benefit from CCS's Climate Change mitigation potential. Why can this not be the CDM?, Henk Sa and Lodewijk Nell, EcoMetrix Africa, carbon Capture Journal, January 10, 2011

## About the author

Steve Carpenter is the newly appointed Vice President for Advanced Resources International, Inc. (ARI). Mr. Carpenter is an intenrationally recognized subject matter expert in the climate change, carbon sequestion and risk field. He is the technical committee chair of the Closure Working Group and a voting member of the CSA- IPAC-CO2 Research Standard for the Geologic Storage of Carbon Dioxide. Mr. Carpenter provides consultation to the Canadian Standards Association (CSA), International Standards Organziation (ISO), the Interstate Oil & Gas Compact Commission (IOGCC), the Energy Mineral Law Foundation (EMLF) and the US DOE.

ARI is a research and consulting firm providing services related to unconventional gas (coalbed methane - CBM, gas shales, tight sands), enhanced oil recovery (EOR), and carbon sequestration (CO2 sequestration). ARI's clientele includes major, independent and national oil and gas companies, coal producers and utilities, technology and service providers, legal and financial firms, research organizations, consortia and academia, policy groups, and governments.

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# CCS legal and policy – May / June 2011

In this column last July I made mention of an application to DECC that had been made by Endeavour International. The application was made under provisions of the Petroleum Act 1998 which allow a party seeking access to offshore oil and gas infrastructure to apply to the Secretary of State requesting that he review the applicant's negotiations with the infrastructure owner and, under powers granted in the Act, secure the access sought by the applicant and specify the terms upon which that access is to be granted.

Endeavour have recently announced that agreement has been reached with respect to the access it sought (which is to the Scott Platform) and I understand that, although a formal notice was not issued by DECC, and the details of the negotiations remain confidential, DECC did issue a 'minded to' letter to the parties involved, the content of which was evidently enough to bring the negotiations to an acceptable conclusion.

The relevance of all this to CCS is that DECC have chosen to use the third party access provisions in the Petroleum Act 1998, under which Endeavour made their application, as the basis of the 'Storage of Carbon Dioxide (Access to Infrastructure) Regulations' (the 'Regulations') which DECC has drafted to fulfil its obligation to transpose the third party access requirements of the EU Directive on the Geological Storage of Carbon Dioxide into UK national law.

The Regulations, and the way in which the Petroleum Act provisions from which they have been cloned have fared to date, are extremely important because the regulation of third party access to CO2 infrastructure is fundamental to the business cases of those currently considering investment in that infrastructure and will therefore affect enormously how it develops.

DECC published, and consulted upon, a draft of the Regulations last December and, following consideration of the views of what was a surprisingly small number of responders, issued the Government's response to the consultation last month. Apart from a couple of amendments which affect the amount of storage capacity that can be requested and amend the infrastructure owner's capacity reporting requirements the Regulations remain little changed from their original draft.

This being the case, it seems that the CCS infrastructure third party access regime will mirror that of the offshore petroleum industry in that it will allow those wishing to gain access to, or to make modifications to, existing or proposed infrastructure, but who have failed to reach acceptable terms with the infrastructure owner or developer, to apply to the relevant authority for a mandate that the access should be given, or modifications made, on specified terms. What these terms might be is worth considering.

Under the Regulations, in the event that an applicant seeking to have the design of proposed infrastructure modified is granted a notice to that effect, the notice must specify the sums to be paid for such modifications by the applicant to the infrastructure developer 'for the purpose of defraying so much of the costs of constructing the relevant infrastructure as is attributable to the variation'.

The construction of this term is extremely important and its natural meaning seems to be that the applicant will pay only the marginal cost of the modifications. I understand that this is DECC's interpretation of the term when considering it within the context of applications under the Petroleum Act. If the same construction is applied to the term in the Regulations then there is a possibility that investment in CCS infrastructure could be obtained at marginal cost.

The Regulations do not address what property ownership would accompany such investment; nevertheless, it would seem that such an opportunity may be one not to be missed for large emitters in the vicinity of infrastructure developments who foresee a need for CCS at some stage in the medium term.

Having the infrastructure built with the required capacity is only part of the picture however; the Regulations also provide for the relevant authority to set a sum payable by the applicant for the granting of a right to have CO2 conveyed through the infrastructure and to regulate the charges levied for conveyance services. It is currently unclear on what basis these sums would be assessed and this is likely to be an area of considerable interest for those considering the development of CCS infrastructure.

There is also a notable and intriguing subtle difference that has crept in as part of the transfer of the oil and gas regime to CCS. The Petroleum Act specifically prohibits the assignment of rights, obtained under its third party access provisions, to have fluids conveyed through oil and gas infrastructure. In contrast, the Regulations specifically state that the same rights with respect to CO2 infrastructure may be assigned. This is an important tweak as it may attract speculative investment into new CCS infrastructure by those who have no CO2 to dispose of but who think that capacity in CCS infrastructure may increase in value provided it can be sold to a market.

Calum Hughes, Yellow Wood Energy

On the whole, then, the Regulations are encouraging. Provided that DECC's demonstration programme can generate the necessary base projects the third party access regime could potentially facilitate the development of a CO2 transportation and storage network, on the back of those projects, which is 'right sized' via a mechanism of investment by a well informed market.

As alluded to above, there is little guidance from precedent applications under the Petroleum Act and a major uncertainty still remains regarding how the relevant authority will approach the assessment of the various sums and charges that will be payable by third party access applicants.

In their Consultation Response DECC have recognised this and have stated: 'we intend to produce guidance which sets out the approach the appropriate authority would take if asked to make a determination over access and the principles against which financial terms would be determined. Such guidance will also provide a benchmark against which those seeking to negotiate access can assess their positions.'.

Although there are a number of other twists in this particular tale, not least what the outcome of DECC's Call for Evidence regarding the long term development of CCS infrastructure might be, the drafting of the Regulations has greatly clarified the paths for development of CCS in the UK.

**Calum Hughes is Principal Consultant in CCS Projects, Regulation and Policy at energy consultancy Yellow Wood Energy.**

# Clean Energy Ministerial agrees steps to speed up CCS deployment

Energy Ministers from around the world have agreed to proposals to help speed up the global deployment of carbon capture and storage.

Ministers at the Clean Energy Ministerial in the United Arab Emirates endorsed recommendations from the Carbon Capture, Use and Storage (CCUS) Action Group chaired by Australia and the UK.

The endorsed CCUS Action Group recommendations call on Energy Ministers to:

- Advance policies that address the financial gap and risks associated with early-mover carbon capture and storage (CCS) projects;
- Identify and advance appropriate funding mechanisms to support the demonstration of large-scale CCS projects in developing economies;
- Advance the development of legal and regulatory frameworks for CCS;
- Promote the importance to global CCS deployment of ratifying key international marine treaty amendments;
- Support and encourage the development of best practice knowledge-sharing from early mover projects, in particular those with public funding;
- Review key gaps in storage data coverage and knowledge including capacity assessment; and
- Recognise the potential of CCS for industrial emission sources and review demonstration opportunities.

The following governments agreed to continue or initiate action in support of one or more of these recommendations by the next Clean Energy Ministerial: Australia, Canada, France, Germany, Japan, Mexico, Norway, Republic of Korea, South Africa, the United Arab Emirates, the United States and the United Kingdom.

A number of actions have already been initiated in support of the CCUS Action Group's recommendations. These include:

- The International Energy Agency (IEA), the Global CCS Institute (GCCSI) and the Carbon Sequestration Leadership Forum (CSLF) will develop a work plan to support the implementation of recommendations and establish a progress reporting schedule;
- The GCCSI agreed to coordinate work on identifying a funding mechanism to support CCS projects in developing countries and will work in partnership with the World Bank, Asian Development Bank, the CSLF and the World Resources Institute;
- The GCCSI released a report on how the uptake of CCS can be accelerated through the re-use of captured carbon dioxidefrom industrial sources, available at www.globalccsinstitute.com; and
- The World Resources Institute released a report titled CCS Demonstrations in Developing Countries: Priorities for a Financing Mechanism for Carbon Dioxide Capture and Storage. The report is available at www.wri.org.

Speaking at the meeting in Abu Dhabi, the UK's Energy and Climate Change Secretary Chris Huhne said:

"There can be no solution to climate change and energy security globally without carbon capture and storage. Deployment of the technology is tantalisingly close, but it won't happen at commercial scale without concerted efforts by governments around the world to address legal, financial and technical barriers.

"Our work with Australia to galvanise action and the commitments we've secured from key countries today are a step forward in this challenge. The UK will host the next Clean Energy Ministerial in London next spring and will be pressing hard for substantial progress by then."

Australia's Minister for Resources and Energy, Martin Ferguson AM MP said:

"Australia is leading the CCUS Action Group with the United Kingdom to bring expertise together from across the world and to help governments and industry work together to advance CCS.

"I would like to thank the United Arab Emirates for hosting a highly successful Clean Energy Ministerial meeting over the past two days and I look forward to the next significant opportunity for governments to work together to build momentum for deploying CCS during the Carbon Sequestration Leadership Forum meeting to be held in Beijing later this year."

# IEA Clean Energy Progress Report

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

Clean energy technologies are making clear progress globally, but fossil fuels continue to outpace them, finds the IEA's Clean Energy Progress Report. More aggressive clean energy policies are required, including the removal of fossil fuel subsidies and implementation of transparent, predictable and adaptive incentives for cleaner, more efficient energy options, it says.

The report was presented on 6 April in Abu Dhabi at the second Clean Energy Ministerial meeting. The report finds that while impressive progress has been made in developing clean energy technologies in recent years, the success stories are being overshadowed by surging demand for fossil fuels, which are outstripping deployment of clean energy technologies.

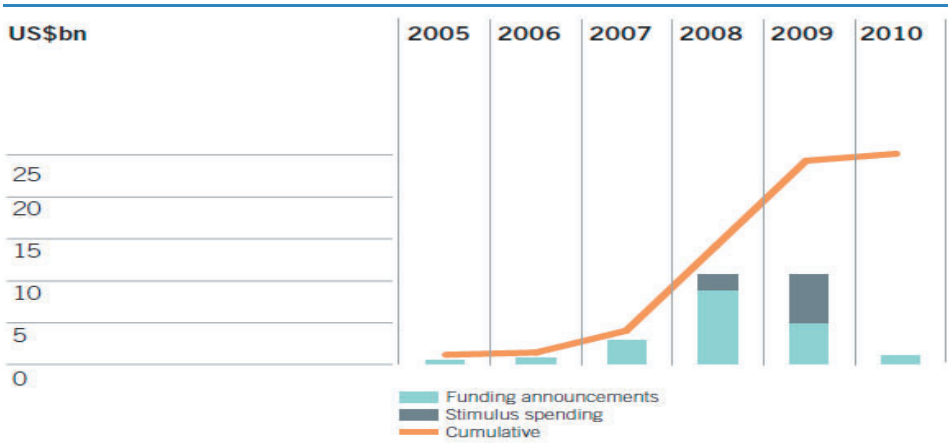
Coal has met 47% of the global new electricity demand over the past decade, eclipsing clean energy efforts made over the same period of time, which include improved implementation of energy efficiency measures and rapid growth in the use of renewable energy sources.

In order to change this status quo, the IEA argues that more aggressive clean energy policies are required, including the removal of fossil fuel subsidies and the implementation of transparent, predictable and adaptive incentives for cleaner energy options.

Ambassador Richard Jones, Deputy Executive Director of the International Energy Agency, presented the report to the ministers gathered in Abu Dhabi. Jones said the world's dependence on fossil fuels is posing short-term risks to political stability and economic activity and is threatening environmental sustainability.

"Despite countries' best efforts, the world is coming ever closer to missing targets that we believe are essential for meeting the goal agreed in Cancun to limit the growth in global average temperatures to less than 2 degrees Celsius," Jones said.

"A number of countries have shown that achieving rapid transition to cleaner technologies is possible, and can be done from the bottom up. We must see more ambitious, effective policies that respond to market signals while providing long-term, predictable support," Jones said.




*Status of public funding support to CCS (USD billion) (Source GCCSI 2011)*

## Success stories

The Clean Energy Progress Report provides an overview of key policy developments, public spending on research, development, demonstration and deployment of clean energy technologies – including renewable energy, energy efficiency, electric vehicles, nuclear power, biofuels and CCS – and their global deployment status.

Despite the persistent use of coal, the report notes that policy support over the last decade has led to a positive rise in renewable energy. The report cites solar and wind power as two areas where remarkable developments have been made.

"In the case of solar energy, at least ten countries now have sizeable domestic markets, up from just three in 2000," the authors observe. "Wind power also experienced dramatic growth over the last decade; global installed capacity at the end of 2010 was around 194 Gigawatts, more than ten times the 17 Gigawatts that was in place at the end of the year in 2000."

Despite this, and other progress with renewable sources of energy, the report states that worldwide renewable electricity generation since 1990 grew an average of 2.7% per year, which is less than the 3% growth seen for total electricity generation.

Consequently, "achieving the goal of halving global energy-related CO2 emissions by 2050 will require a doubling of all renewable generation use by 2020 from today's level."

## Tackling fossil fuels

In order to address the world's heavy reliance on fossil fuels, particularly coal, the report stresses the importance of raising the efficiency of existing and new coal-fired plants.

"Switching to less carbon-intensive fuels (e.g. from coal to natural gas) and improving the efficiency of coal plants will achieve significant reductions in CO2 and should be a top priority," the authors write.

However, for deep cuts in carbon emissions this is not enough, they emphasise, adding: "Extensive deployment of CCS is critical to achieve climate change goals."

In order to achieve a 50% reduction in energy-related CO2 emissions by 2050, IEA research shows that around 100 large-scale CCS projects will be needed by 2020, and over 3,000 by 2050. "This represents a significant scale-up from the five large-scale CCS projects that are in operation today."

While there are over 70 CCS projects currently planned, the report says it is uncertain how many will be realised because of recent delays in allocating public funding.

Download the report at:
www.iea.org/papers/2011/CEM_Progress_Report.pdf

# CCS Demonstration in Developing Countries

Without financial support from industrialized nations, the majority of developing countries are unlikely to take significant steps toward CCS development in the foreseeable future concludes a World Resources Institute working paper by Francisco Almendra, Logan West, Li Zheng, and Sarah Forbes.

In facing the challenge of mitigating global climate change, world leaders have acknowledged that no single solution exists, and therefore, a portfolio of carbon dioxide (CO2) reduction technologies and methods will be needed to successfully confront rising emissions, says the report. Due to their dependency on fossil fuels, the energy supply and industrial sectors are the greatest contributors to CO2 emissions, accounting for 25.9 percent and 19.4 percent of the total respectively.

In addition to efficiency improvements and enhancing clean energy use, one key option for limiting future CO2 emissions from fossil fuel energy use is carbon dioxide capture and storage (CCS). CCS is a suite of technologies integrated to capture and transport CO2 from major point sources to a storage site where the CO2 is injected down wells and then permanently trapped in porous geological formations deep below the surface. Candidates for CCS technology include fossil fuel power plants; steel, cement, and fertilizer factories; and other industrial facilities.

Despite often-aggressive programs to promote energy efficiency and deploy nuclear, renewable, and other low-carbon energy sources, many developing countries will still rely heavily on fossil fuel energy to power their development for decades to come.

There is therefore a need for developing countries to create strategies that address fossil fuel emissions in a way that minimizes the costs of doing so, and consequently minimizes impacts to their national development goals.

CCS is currently the only near-commercial technology proven to directly disassociate CO2 emissions from fossil fuel use at scale. Its deployment could potentially allow developing countries to gradually shift away from fossil fuels for energy and industrial needs with relatively little disruption to their long-term development strategies.

If deployed as an interim measure, it could allow time for other alternative low-carbon technologies to be developed and deployed, permitting fossil fuels to be gradually phased out. This strategy could assist developing countries to transition to a low-carbon economy in the next 15–50 years.

| Country | Activity Details |
|---|---|
| China | Strong domestic CCUS research carried out, EOR development, multiple CO2 capture pilots, industrial CCUS research and development, IGCC with plans for CCS, extensive bilateral cooperation with United States underway, regulatory framework under development |
| Brazil | Research center established, initial bilateral technical cooperation with United States underway, EOR development, CCS pilot at bioethanol plant under study |
| South Africa | CCS Centre established, national storage atlas and roadmap completed, regulatory research beginning |
| Indonesia | Proposed CCS project under Japan's offset program |
| India | Small-scale capture and utilization projects for fertilizer underway |

*Partial list of significant CCS activities in developing countries*

*Note: CCUS – carbon capture use and storage; EOR – enhanced oil recovery; IGCC – Integrated Gasification Combined Cycle*

While CCS is potentially attractive to some developing countries, there has been limited development of demonstration projects in Africa, Asia, or Latin America due mainly to their high cost in the absence of expected profits or significant carbon financing. The International Energy Agency (IEA) estimates the total cost for a new average-sized coal-fired power plant that captures up to 90 percent of its CO2 emissions to be US$1 billion over 10 years.

Existing financing for CCS is grossly insufficient to enable demonstration projects in developing countries. The few available funds are either spread over the full array of low-carbon technologies, or fall short of the magnitude or the mandate needed to propel commercial-scale CCS demonstrations forward.

Current carbon offset mechanisms are not sufficient to spur CCS deployment in developing countries in today's context either. Overall, existing CCS financing mechanisms help grow capacity, but their support is insufficient to leverage enough funding from capital markets to implement projects in a non-OECD context.

The IEA CCS Roadmap proposes 50 CCS projects in developing countries in the next 10 to 20 years. As well as reducing the developing world's greenhouse gas emissions, accelerating CCS demonstration efforts in non-OECD countries can likely also improve technologies, increase efficiency, reduce uncertainty and risk, and initiate learning-by-doing at a lower cost than would be possible in OECD countries.

The captured benefits from doing so will be more significant the sooner acceleration in CCS development in developing countries begins, the report concludes.

For more information and to download the report go to:
www.wri.org

# Bellona - a CCS roadmap for Poland

**Poland stands in a strong position and at a critical decision point regarding the future of its fossil-based energy supply. With the initiatives taken to promote two ambitious demonstration plants - at Belchatów and Kedzierzyn - and to conduct geological storage surveys in several regions of the country, a solid will has been demonstrated which could make Poland a regional leader on CCS technologies.**

Poland is rapidly approaching a decision point at which it will have to take action to secure its future energy supply, says a report from Bellona Environmental CCS Team (BEST).

Much of its power generation units will require replacement within one or two decades, and at that time critical choices will have to be made regarding the coun try s utilisation of coal and lignite resource, in the context of increasingly strict EU regulation of CO2 emissions. A similar situation faces the nation's heavy industrial sector, in which many factories are heavy emitters of CO2 that may be economically threatened by climate regulations.

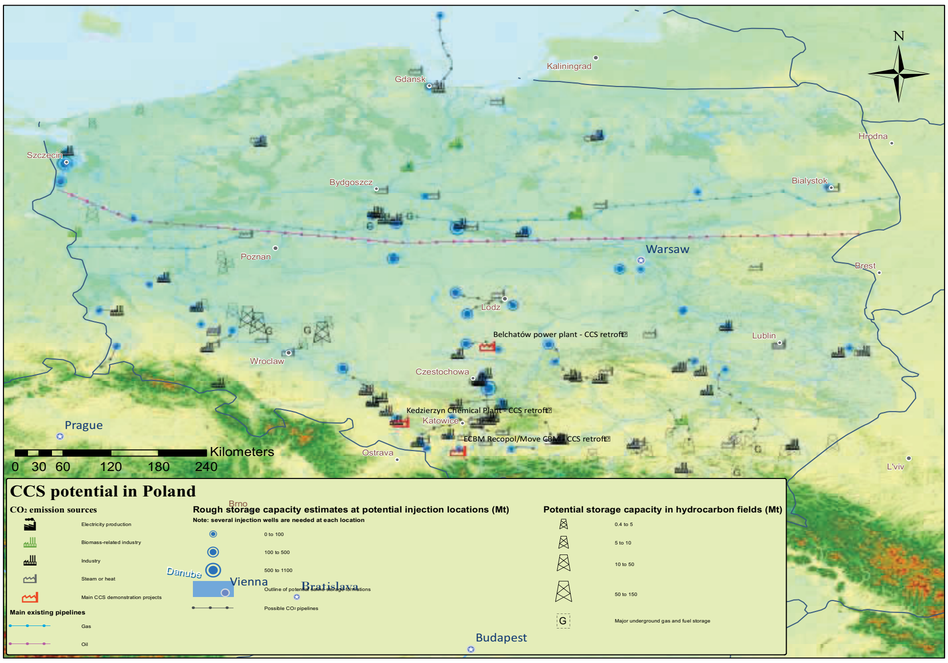
In the face of the need for drastic emission reductions, Renewable Energy Sources must eventually grow to provide an increasing share of energy, but it is probably unrealistic for Poland to break its dependence on fossil fuels before 2050. CO2 Capture and Storage (CCS) tech nologies offer a solution to this dilemma by potentially cutting emissions from coal- and natural gas-fired power plants by 90-95%.

Investing in this technology can serve as an insurance policy for Poland, putting the country in a position to freely choose between coal, lignite, gas, or renewables in its near and medium term energy mix. CCS also provides strong synergies with industry, where the same technology can be utilised to manage increasingly costly CO2 emissions.

Widespread CCS deployment in Poland is feasible, but immediate actions must to be taken to demonstrate the technology, characterise potential CO2 storage sites, and provide a stable regulatory framework. With the EU currently offering generous funding for CCS demon stration projects from the NER300, moving forward with proposed projects such as those at Belchatów and Kedzierzyn-Kozle is time critical.

The Roadmap examines the outcomes of widely deploying CCS under three different future energy mix trajectories. Specific figures are provided on costs, emis sions and benefits. Under all three trajectories – and across a wide range of possible EU climate & energy poli cies – it is clear that the activities to commercialize and deploy CCS in Poland must not be abandoned. They are the vital insurance required to ensure a secure economic future.

With its rich resources of coal and lignite, Poland is well positioned to preserve its energy independence for decades to come, until it can fully provide for itself using renewable energy. It can continue being self sufficient in energy while maintaining a competitive industry, both in the short and long term. The ever stricter EU regulations on greenhouse gas emissions will only pose a small threat to the economy, as long as the right actions continue to be taken.




*Possible future infrastructure for CO2 storage and transport in Poland*
*The suggested pipeline gates and storage locations are artificial and only included to illustrate one of several complete CCS value-chain solutions*

Such actions include continuing the initiatives already taken to develop and commercialise CCS technologies – which should be the main priority in the short term. In the longer term, the focus should be on actions to build the best possible future energy sector for the country, including both a widespread deployment of CCS, significant improvement of energy efficiency and a ramp up of renewable energy generation.

## Conclusions

The roadmap presents an analysis of the current situation and outlines possible paths to take, but it does not aspire to make absolute recommendations regarding the choices that Poland needs to make to secure its future. It is, however, clear that there is one insurance policy in which Poland needs to invest in order to maintain its strong position and freedom of choice regarding its future energy supply.

It must go forward with its CCS demonstration plants, and the other activities required to allow commercialisation of CCS – such as continued and extended geological storage surveys, implementation of necessary policies and legal framework, public information campaigns, etc.

The roadmap examines the outcomes of applying CCS to three different energy mix trajectories reflecting possible development in Poland's energy mix and demand for electricity. This was done in order to put specific figures on the costs, emissions, and benefits of the different choices at hand.

Under all three trajectories – and across a wide range of possible EU climate & energy policies – it is clear that the activities to commercialize and deploy CCS in Poland must not be abandoned as they are indeed required to ensure a secure economic future.

The report can be downloaded at: www.globalccsinstitute.com
See also "How to efficiently implement CCS in Poland" - demosEUROPA
www.demoseuropa.eu

# Policy, company and regulation news

## Seven UK CCS applications submitted for EU NER300 funding

ec.europa.eu/clima/funding/ner300

**Of the 12 applications submitted to the EIB ahead of the 9 May deadline, seven are for CCS projects and five for renewable energy projects. Two CCS applications were withdrawn voluntarily by the Project Sponsors.**

The European Investment Bank (EIB) will now spend nine months performing 'due diligence' on the applications submitted to it, checking their financial and technical deliverability. After this the European Commission will verify the eligibility criteria assessment and re-confirm with Member States the public funding contribution for Recommended Projects, before making its Award Decisions.

The seven CCS applications are:

- Alstom Limited Consortium: oxyfuel new supercritical coal-fired power station on Drax site in North Yorkshire;
- C.GEN: new integrated gasification combined cycle (IGCC) power station (pre-combustion with CCS on the coal-feed) in Killingholme, Yorkshire;
- Peel Energy CCS Ltd: post-combustion amine capture on new supercritical coal-fired power station in Ayrshire, Scotland;
- Don Valley Power Project (formerly known as the Hatfield Project): new IGCC power station in Stainforth, Yorkshire;
- A consortium led by Progressive Energy Ltd; pre-combustion coal gasification project in Teesside, North East England;
- Scottish Power Generation Limited: post-combustion amine capture retrofitted to an existing subcritical coal-fired power station at Longannet, Scotland; and
- SSE Generation Limited: post-combustion capture retrofitted to an existing CCGT power station at Peterhead, Scotland.

The Government is committed to continuing public sector investment in four CCS projects and aims to launch a selection process to identify projects for UK funding later this year.

*Peel Energy CCS Ltd's proposed supercritical coal-fired power station in Ayrshire, Scotland would use post-combustion amine capture*

## IHS report says coal CCS still costly

www.ihs.com

Melissa.manning@ihs.com

**A side-by-side comparison of the most promising technologies for advanced carbon capture of coal-fired emissions reveals that the processes are still costly, despite improvements, according to a new report from information and analysis provider IHS.**

The IHS report examined the technology and economics of 10 processes for the post-combustion capture of carbon emissions from electric power generation using pulverized coal.

"The scrubbing technologies currently moving through demonstration are very expensive and it's hard to see how to significantly bring down their cost," said Michael Arné, senior analyst at IHS and author of the report. "There are some promising new approaches on the drawing board, but they are at least 10 years away."

Robert LaCount, senior director, climate change and clean energy at IHS CERA, agrees that the processes are costly, particularly in the demonstration stages, but cites a recent IHS CERA report, entitled Carbon Capture and Storage: At a Critical Juncture, which says that, in addition to cost, there are more factors that put carbon capture and storage technologies at a disadvantage today.

"Carbon capture and sequestration (CCS) is a crucial technology for meeting aggressive, long-term climate policy objectives," LaCount said. "However, through a coalescence of factors, CCS is at a disadvantage today — lower natural gas prices, technical and regulatory questions for CO2 storage, and an uncertain climate-change policy environment, are at the core of CCS's challenges."

"With that being said," LaCount added, "coal is currently the most significant fuel source for power generation." According to IHS, coal-fired generation accounted for 40 percent of the 20,000 terawatt-hours (TWh) of electricity generated worldwide but accounted for three-quarters of all the CO2 emitted by the global power sector.

"It is clear that coal is currently a crucial fuel source, and at the same time, it bears a huge responsibility for GHG emissions. If the often mentioned 80 percent GHG reduction target is to be met by mid-century, CO2 from coal-fired generation will have to be captured and stored, and the technologies addressed in the Advanced Carbon Capture report will help industry better evaluate which technical options are most promising in order to meet emission targets."

"The prospect for reduction of CO2 cost using scrubbing processes is limited due to the significant power requirements and high capital costs for the separation and compression units," added Arné.

Advanced oxy-combustion has the potential for the lowest costs of any of the technologies examined, the study noted. The use of corrosion-resistant boiler tubes to eliminate the need for desulfurization in the flue-gas recycle loop has the potential to cut CO2 costs significantly. This approach has the added appeal of mitigating sulfur emissions in a "two for the price of one" remediation scheme.

"Advanced oxy-combustion, if used in conjunction with an ion-transport membrane instead of cryogenic air separation, could drive down costs even further, but such technology is still years away," said Arné. "The solution to making carbon capture economi-

cally viable is a technological challenge, which is something that the engineering community can solve — that's the good news. Technical improvements will be made to drive costs down, but to get to that point we'll need to see significant investments in ongoing research over time."

## Air Products' CO2 capture technology goes online at Schwarze Pumpe

www.airproducts.com
www.vattenfall.com

**Air Products' proprietary carbon dioxide capture, purification and compression system at Vattenfall AB's research and development facility in Schwarze Pumpe, Germany is onstream.**

Vattenfall held an inauguration ceremony at the facility, which is hosting a CO2 oxyfuel demonstration project. Air Products' technology is focusing specifically on the purification and compression of oxyfuel combustion flue gas during the scheduled three year demonstration project.

Hubertus Altmann, head of the Power Plant Unit of Vattenfall in Germany is pleased with the transatlantic collaboration on this project. "Increasing efficiency is one of the crucial tasks when developing CCS (carbon capture and storage). In a few years, the technology will be competitive in the market and in order to reach that goal there remains a lot of R&D to be done. It's important for international companies such as Air Products and Vattenfall to join forces and cooperate on projects like the one we are celebrating today," said Altmann.

At the Schwarze Pumpe facility, Air Products will take flue gas directly off Vattenfall's 30 megawatt (MW) wall-fired boiler at the oxyfuel pilot plant. It will purify and compress the carbon dioxide to a purity acceptable for storage or enhanced oil recovery. Air Products' proprietary sour compression technology uses a staged compression process to optimize pressure, hold-up, and residence time to allow removal of impurities during the compression process. This allows cost savings in the oxyfuel combustion process and minimizes the concentration of acidic components, important in preventing corrosion during the CO2 storage process.

This pilot will demonstrate the efficient purification of CO2, and removal of atmospheric gases, in particular oxygen. In addition, it will incorporate novel membrane technology, targeting carbon capture rates as high as 98 percent. More information on Air Products' CO2 purification technologies can be found at www.airproducts.com/CO2_capture.

Vattenfall inaugurated the 30 MW pilot plant for carbon dioxide capture at its lignite coal-fired power plant at Schwarze Pumpe in September 2008. Based on the conclusions from this pilot plant, the next step will be to build larger demonstration power plants, for which feasibility studies have already been initiated and target onstream status for 2015.

Air Products is currently working on several CCS projects around the world for the power market. These projects include:

- Air Products will design, construct and operate a system to capture CO2 from its two steam methane reformers (SMR) located at a refinery in Port Arthur, Texas, United States. The CO2 removal technology will be retrofitted to the SMRs, which produce hydrogen to assist in the making of cleaner burning transportation fuels by refinery customers on Air Products' Gulf Coast hydrogen pipeline network. Approximately one million tons of CO2 annually will be recovered, purified by Air Products, and delivered by Air Products via a pipeline for injection into enhanced oil recovery projects in Texas.

- Working with Shanxi International Energy Group Co., Ltd (SIEG) to perform a feasibility study and reference plant design on its proprietary oxyfuel carbon dioxide (CO2) purification technology for potential installation at SIEG's 350 MW Oxyfuel Electrical Generation Demonstration Project.

- In collaboration with the Alberta Energy Research Institute in Canada, a study focusing on advanced CO2 capture technology for use with gasification.

- In cooperation with DOE, Air Products designed and constructed a CO2 purification system in support of an oxyfuel technology development project at a boiler simulation facility in Windsor, Connecticut, United States.

*Air Products' David Taylor (left) Vice President - Energy Businesses and Vattenfall's Hubertus Altmann, head of the Power Plant Unit of Vattenfall in Germany, officially activate Air Products' carbon capture and purification facility at Vattenfall in Germany. "Image courtesy of Air Products and Chemicals, Inc."*

## 2Co Energy acquires Powerfuel and Hatfield Project

www.2coenergy.com

**UK based 2Co Energy has acquired Powerfuel Power Ltd and its Carbon Capture and Storage Hatfield project.**

2Co Energy was selected as the preferred bidder for Powerfuel Power Ltd in March this year after its parent company, Powerfuel plc, went into administration in December 2010.

The company says it is also putting in place a financial guarantee that will enable a

€180 million grant from the European Commission to be drawn down.

Based in South Yorkshire, the project, which will now be renamed the Don Valley Power Project, is set to generate 900MW of low-carbon power from 2015-2016 and to capture and store up to 5 million tonnes per annum of CO2 under the North Sea.

The project, in partnership with National Grid, was awarded a €180 million grant in December 2009 as part of the EU's European Energy Programme for Recovery which is aimed at accelerating the development of CCS technology. This has already enabled National Grid to begin work on transportation and storage options capable of serving the project as well as the wider needs of a future cluster of Yorkshire carbon capture projects.

2CoEnergy is today providing the financial guarantee the European Commission requires for a €45 million pre-financing payment to be made, enabling the grant money to be used to further progress the project.

2Co Energy believes it now provides both the technical and financial robustness the project needs to be successful in its application for further funding under the EU's New Entrant Reserve (NER) 300 scheme.

Selection of the best CO2 storage site is vital for any proposed CCS project so 2Co Energy and National Grid will pursue two options over the next year or so. 2Co Energy will take forward the technical and economic evaluation of potential CO2 storage and EOR projects in the Central North Sea. National Grid will focus on saline formations in the Southern North Sea that could be made available for 2Co Energy's project or others in a future Yorkshire cluster of projects.

## DOE initiative aims to speed up technology to market

fossil.energy.gov

**The Office of Fossil Energy's National Energy Technology Laboratory (NETL) has begun research under the Carbon Capture Simulation Initiative (CCSI), partnering with other national laboratories, universities, and industry to develop computational modelling and simulation tools to accelerate commercialization of CCS technologies.**

CCSI aims to use a software infrastructure to accelerate the development and deployment cycle for bringing new, cost-effective CCS technologies to market:

* Promising concepts will be more quickly identified through rapid computational screening of devices and processes.

* The time and expense to design and troubleshoot new devices and processes will be reduced through science-based optimal designs.

* The technical risk in taking technology from laboratory-scale to commercial-scale will be more accurately quantified.

* Deployment costs will be quantified more quickly by replacing some of the physical operational tests with virtual power plant simulations.

While the ultimate goal of the CCSI is to deliver a set of tools that can simulate scale-up of a broad suite of new carbon capture technologies, from laboratory to commercial scale, the first 5 years of the project will focus on developing capabilities applicable to oxy-combustion and post-combustion capture by solid sorbents and advanced solvents. Among possible carbon capture technologies, these are expected to have the most immediate impact on U.S. pulverized coal power plants, which currently generate nearly half of the nation's electricity and are expected to emit 95 percent of the United State's coal-based CO2 emissions between 2010 and 2030.

The CCSI is led by NETL and leverages the core strengths of DOE's national laboratories in modeling and simulation. The project brings together the best capabilities at NETL, Los Alamos National Laboratory, Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory, and Pacific Northwest National Laboratory.

The CCSI's industrial partners represent the power generation industry and power equipment manufacturers. The initial industrial partners are ADA Environmental Solutions, Alstom Power, Ameren, Babcock Power, Babcock & Wilcox, Chevron, EPRI, Eastman, Fluor, General Electric, Ramgen Power Systems, and Southern Company.

## UK ETI seeks CCS for gas solutions

www.energytechnologies.co.uk

**The UK Energy Technologies Institute (ETI) has started the search for organisations to take part in a multi million pound project to develop and demonstrate cheaper carbon capture technologies specifically for gas fired power stations.**

The ETI's strategic modelling has highlighted CCS as a crucial part of the UK's energy mix alongside nuclear power, offshore wind, bio energy and marine energy if legally binding cuts in greenhouse gases of 80% by 2050 are to be met and security of supplies maintained.

The ETI expects to invest in the initial development of two promising 'next generation' technologies before selecting the best one for large scale testing at a Combined Cycle Gas Turbine (CCGT) plant.

A Request for Proposals giving full details of the project and what the ETI expects from potential bidders chas been released.

The deadline for the notification of intention to submit a proposal is 27 May and all proposals must be received by 27 June.

Bidders will need to demonstrate and justify how their approach would enable their technology to reach a state of development that would allow future investors to start engineering the design of a power station using this next generation technology in 2015, with operation commencing in 2020.

As retrofitting of existing power stations is desirable the RfP will target post-combustion technologies with low capital costs.

ETI Chief Executive Dr David Clarke said: "Gas remains the UK's primary energy source and our estimates suggest we will have around 30GW of CCGT capacity by 2030. Even though gas is much cleaner than coal, achieving the UK's CO2 reduction targets in the longer term will still require CCS to be fitted to all fossil-fuelled power stations by the 2030s.

"The contribution of gas fired stations to the energy mix in the UK has grown and appears set to continue to grow rapidly over the next decade. Although work is now being done on CCS technology demonstrations the UK effort has been largely focussed on coal so far.

"Through CCS technology, fossil fuels can be economically used in an environmentally acceptable way to provide significant quantities of competitively priced energy on demand and so will be an important contribution to the energy mix in the future."

The costs of CCS are heavily influenced by costs of carbon capture and the roll out of CCS in the 2020s and 2030s will require new capture systems which significantly cut the capital and operating cost penalties associated with current technologies.

The ETI has completed an extensive analysis of likely future UK requirements for CCS new build and retrofit power generation and has examined the economic potential of the most promising 'next generation' technologies.

The overall aim of the project is to develop a technology with the potential to make a substantial reduction in capital and operating costs in the capture plant, which will be ready to catch the wave of CCS implementation in CCGTs expected to occur in the 2020s and early 2030s.

From its review of the technology landscape, the ETI believes that potential technologies will require an intermediate scale of development before being ready for full scale implementation.

# GCCSI report finds a role for Industrial Reuse of CO2

**Advancing the work of the Clean Energy Ministerial (CEM) Technology Action Plan, the Global CCS Institute and Parsons Brinckerhoff have released a report investigating the industrial use of captured CO2 to accelerate the uptake of CCS.**

"The findings indicate that CO2 reuse has the potential to provide a moderate revenue stream for near-term CCS project development in favourable locations where reuse applications and markets are close to the emission source," said Peter Grubnic, Acting General Manager-Projects, Global CCS Institute.

"CO2 reuse may provide a particular benefit in developing nations, where there is high demand for energy and construction materials," he said.

The report was commissioned through the governments of Australia and the United Kingdom under the auspices of the Carbon Capture Use and Storage (CCUS) stream of the CEM, formerly known as the Major Economies Forum.

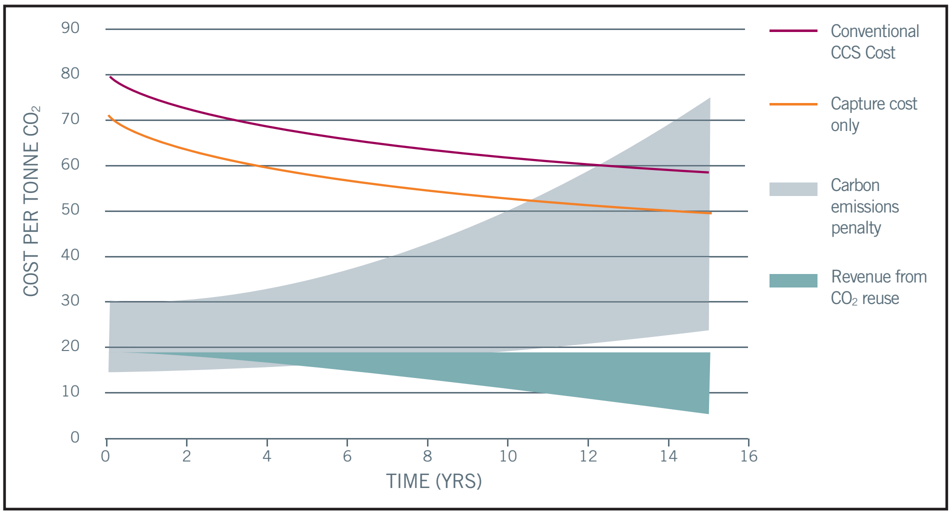
It forms part of the CEM's Technology Action Plan to encourage the use of captured CO2 to generate revenue that can partially offset the cost of CO2 capture, as a transitional measure to assist the accelerated uptake of CCS.

Client Relationship Executive in Parsons Brinckerhoff's Energy, Mining and Industry Group, Craig Chambers, said the findings of the report encourage industry to consider all available technologies that may help advance CCS and effectively tackle climate change.

"The report focuses on existing and emerging reuse technologies which have CO2 utilisation potential commensurate with the scale of emissions from industrial processes such as power generation, steel and cement making," Chambers said.

"Some of the beneficial uses of CO2 examined in the report may help form part of an overall carbon mitigation strategy," he added. "CCS remains a very real solution to the significant reduction of CO2 emissions and it is encouraging to see Australia taking a lead in support of the industry's development."

Among the existing and emerging technologies reviewed in the report are the use of CO2 as a feedstock in urea yield boosting; mineralisation (including carbonate mineralisation, concrete curing and bauxite processing); liquid fuels (including renewable methanol); and CO2 enhanced coal bed methane recovery, among others.




*A graphical representation of the key costs and revenues associated with CCS and CO2 reuse (Source: ACCELERATING THE UPTAKE OF CCS: INDUSTRIAL USE OF CAPTURED CARBON DIOXIDE MARCH 2011)*

Findings indicate that while reuse does not have material global CO2 abatement potential, it can help to support near-term CCS project development in some locations and applications.

## Key Findings

1. The current and potential future demand for CO2 reuse is only a few per cent of anthropogenic CO2 emissions, and while reuse does not have material global CO2 abatement potential it has the potential to provide a moderate revenue stream for near-term CCS project development in favourable locations where reuse applications and markets are close to the emission source.

2. EOR will remain the dominant form of CO2 reuse in the short to medium term due to its maturity and large-scale utilisation of CO2. As a result it has a role to play in supporting the near-term development of large-scale CCS demonstration projects in regions of EOR potential and in the absence of strong carbon pricing. This initial phase of large-scale CCS demonstration is an essential pre-requisite to commercial deployment, and is critical to the establishment of practical legal and regulatory regimes, to community acceptance and to CCS project optimisation and cost reduction.

3. Most of the emerging reuse technologies still have years of development ahead before they reach the technical maturity required for deployment at commercial scale. Mineralisation technologies may ultimately provide a complementary form of CCS to geological storage, and can facilitate abatement of a small proportion of anthropogenic CO2 emissions. Technologies that reuse CO2 in fuel production may also provide indirect mitigation through replacement of fossil fuels. While these are useful attributes, in the near-term they cannot provide a driver to accelerate the commercial deployment of CCS due to their lengthy development timeframes.

4. CO2 reuse has the potential to be a key component of large-scale CCS demonstration projects in emerging and developing economies, where there is strong demand for energy and construction materials and less likelihood of the early adoption of carbon pricing. The main focus will be on EOR due to its maturity, and potential CO2 utilisation capacity. Carbonate mineralisation, CO2 concrete curing, bauxite residue carbonation, enhanced coal bed methane (ECBM), urea yield boosting and renewable methanol may also be of interest in emerging economies such as China and India. However, as noted

in point 3 above, some of these technologies are still in the early stages of development and may not be at the required maturity for deployment at commercial scale to coincide with CCS development timeframes.

5. The current market price (US$15–19/tonne) for bulk CO2 is indicative of the upper limit of prices that can be expected in the future. There is little prospect of a general long-term strengthening of the current bulk CO2 market price for reuse, and there is every prospect of downward pressure on market prices as and when restrictions on CO2 emissions are introduced. The revenue generated from reuse will be inadequate to drive the development of CCS for power, steel and cement plants, all of which will require a strong carbon price and/or project-specific funding. CO2 supply from low-cost sources, such as natural gas processing and fertiliser production, is likely to dominate any reuse supply growth in the medium term.

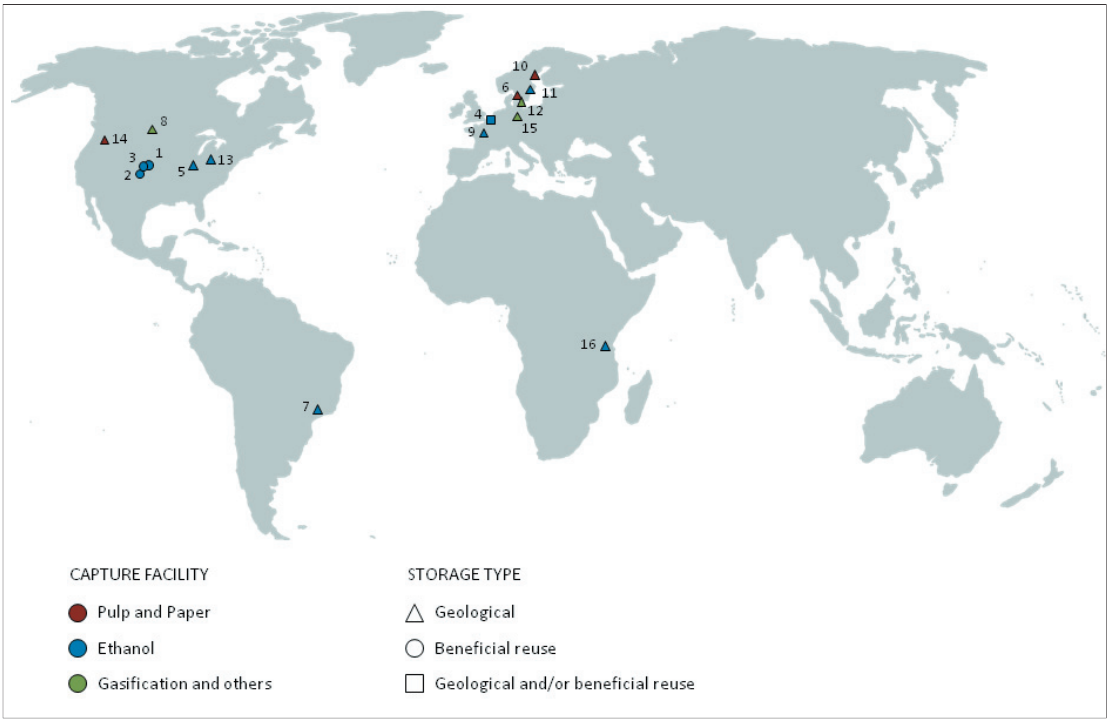
6. CO2 reuse has an initial role to play in supporting the demonstration phase of CCS development in the absence of strong carbon prices and in emerging economies. However that initial role, centred on EOR (due to its maturity), becomes less important as and when the cost of emitting carbon rises, which must ultimately happen to facilitate the widespread-commercial deployment of CCS. Furthermore, as noted in point five above, the likelihood is that the market price for bulk CO2 will fall as carbon prices rise with tightening restrictions on emissions.

# GCCSI report- CCS with bio-energy

**The use of bio-energy with carbon capture and storage creates the possibility of decreasing the level of carbon dioxide in the atmosphere, according to a newly released Global CCS Institute report.**

"Bio-energy with CCS (BECCS) is a very useful tool for the future as it is the only technology by which we can actually reduce the level of CO2 in our atmosphere, rather than stabilise it," said Bob Pegler, Institute General Manager - Europe. "The application of BECCS would make it possible to reach agreed climate targets at lower costs, and involves opportunities to raise the ambitions for the level of emission reductions."

BECCS works because trees and crops, when they grow, remove CO2 from the atmosphere. Using this biomass to produce energy or feed industrial processes, then capturing and permanently storing underground the CO2 released during conversion, leads to a "carbon negative" technology.




*Global BECCS project map*

"BECCS combines the natural CO2 capture process in trees and plants, with the benefits of geological carbon storage", said Pegler. "What sets BECCS apart as a climate mitigation measure is that it may result in permanent net negative carbon emissions."

According to the Global Status of BECCS Projects 2010, commissioned by the Global CCS Institute and carried out by Biorecro AB, a Swedish energy consultancy, the process could be applied to a range of biomass related technologies, such as power stations, combined heat and power plants, a range of flue gas streams from the pulp industry such as from recovery boilers and lime kilns, fermentation in ethanol production and biogas refining processes.

The potential climate impact of combining biomass with CCS in BECCS systems is large, with negative emissions in the order of billions of tonnes. BECCS could also be a cost-effective technology for meeting ambitious climate targets.

However, BECCS is still a new technology and the biomass it consumes must be produced in a sustainable way, without negative impacts on food production.

The report describes the 16 first projects worldwide aiming to install a BECCS process. Most of these are in Europe and North America.

"There is an urgent need to expand the number of BECCS projects in all phases," Pegler said. "It is often overlooked, but the current insufficient efforts in research and deployment are detrimental for climate mitigation policies in general."

The reports can be downloaded at: www.globalccsinstitute.com

## Capture news

### CIUDEN lights first fire in the CO2 Capture Centre

www.ciuden.es

**CIUDEN has completed a milestone at its CO2 Capture Centre near León, Spain.**

"Saturday 16 April, at 7:30 pm, a stable and simultaneous ignition of the four burners on the pulverised coal (PC) boiler was carried out, thus reaching this important milestone in the commissioning of the Technology Development Centre for CO2 Capture, performed by the Fundación Ciudad de la Energía", confirmed José Ángel Azuara, CIUDEN Managing Director.

"This first lighting was achieved using natural gas which is a prior step to ignition using pulverised coal", Pedro Otero said, Technical Director of the Project. "To get to this point, a series of requirements needed to be met, such as having available systems for fire prevention, power supply, boiler feedwater, cooling and compressed air, as well as the corresponding distributed control system and the circuit of gas. Moreover, all the necessary operating permits were required. After a week of tests and verification of all the gas burner safety devices, the milestone could be finally reached" Otero added.

CIUDEN is the Spanish Government's principal instrument for developing CO2 capture, transport and storage (CCS) technologies, through the construction and operation of the Technology Development Centre for CO2 Capture located in Cubillos del Sil, (León, NW Spain), with an investment of €128.4 million.

The installation is one of the largest in the world for the R&D of CO2 capture technology using oxycombustion. The facility is unique because it allows research with all types of coals and incorporates two distinct oxycombustion technologies, Pulverised Coal (PC) and Circulating Fluidized Bed (CFB), the latter being first of its class in the world. The technical characteristics of the plant provide great operational flexibility and versatility, and make it point of reference worldwide for the development and validation of these technologies.

The Spanish Climate Change and Sustainable Development strategies show CCS to be one of the technological options for contributing to the stabilisation of greenhouse gas concentration in the atmosphere.

The Fundación Ciudad de la Energía was created in 2006 as a Spanish Government initiative by carrying out projects and activities related to energy and the environment.

*The first fire at CIUDEN's CO2 Capture Centre near León, Spain*

### Alcoa launches carbon capture and reuse pilot

www.alcoa.com

**Alcoa has announced a new pilot program, in collaboration with CO2 Solution and Codexis focused on carbon capture technology designed to create a commercially viable product.**

The project will be funded by aluminium producer Alcoa along with approximately $13.5 million in funding from the U.S. Department of Energy (DOE) received from an award with the National Energy Technology Laboratory (NETL). This funding was made available by the American Recovery and Reinvestment Act (ARRA).

The pilot program will use a proprietary induct scrubber technology to capture emissions. The collaboration is intended to devise solutions that treat and use a primary byproduct of the aluminum manufacturing process known as alkaline clay, or bauxite residue, as well as other alkaline industrial residuals.

The pilot project will test a scrubbing process that combines treated flue gas, enzymes and alkaline clay to create a mineral-rich neutralized product that could be used for environmental reclamation projects.

Scientists and engineers from Alcoa Technical Center in Pittsburgh will lead the three-year project, which has an investigation phase that runs through December. The DOE grant was received as part of an initiative to find ways of converting captured carbon dioxide emissions from industrial sources into useful products such as fuels, plastics, cement and fertilizers.

CO2 Solution and Codexis have been collaborating since late 2009 on the development of custom carbonic anhydrase (CA) enzymes and processes that could significantly decrease the cost of carbon dioxide capture from industrial sources. CA is an enzyme which catalyzes the transfer of carbon dioxide in nature, and program results to date show that the technology can be used to create and deploy CA biocatalysts with substantially improved stability and performance under harsh industrial conditions.

### Vattenfall opens a new carbon dioxide capture plant

www.vattenfall.com

**The CO2 capture pilot power plant Willem-Alexander in Buggenum, the Netherlands, has been officially opened.**

Vattenfall is using coal and biomass gasification technology for the two-year trial, as the first company in the energy sector.

At a gala ceremony on 15 April Arnoud Kamerbeek, Vattenfall, officially opened the CO2 capture pilot in the Willem-Alexander power plant in Buggenum.

Arnoud Kamerbeek is proud that Vattenfall is the first energy company in northern Europe to set up a pilot plant for CO2 capture in combination with coal and biomass gasification: "This plant is exceptionally important for Vattenfall. We believe in

a cleaner and more flexible production portfolio. Through this trial we will build up valuable knowledge about CO2 capture, fitting in with our strategy of reducing our CO2 emissions."

The project team has worked hard in recent years to prepare this pilot. A substantial research programme is linked to the project. Organisations involved are ECN, Delft University of Technology and KEMA. Nuon has received a subsidy of EUR 10 million for this by the Ministry of Economic Affairs, Agriculture and Innovation.

Vattenfall is using coal gasification technology for the trial at the Willem-Alexander power plant. The CO2 will be captured and examined and then transported back to the power plant. The trial will last two years.

Although the technique of CO2 capture has been used for the last 50 years in the petrochemical industry, CO2 capture in combination with gasification of coal and biomass has never before been applied in the energy sector. Through the trial Vattenfall aims to acquire knowledge and gain more experience of innovative solutions for reducing CO2 emissions. By devoting itself to CO2 capture and storage Vattenfall is making a step forward in the transition to a more sustainable energy supply.

## Oil refinery CO2 capture pilot in Brazil

www.co2captureproject.com

**The CO2 Capture Project (CCP) has started an oxy-combustion capture trial on a pilot-scale Fluid Catalytic Cracking (FCC) unit.**

The test is expected to bring closer a more cost-effective technology capable of capturing up to 95% of FCC CO2 emissions, potentially equating to some 20-30% of emissions from a typical refinery.

The demonstration is taking place at a full burn FCC unit at a Petrobras research complex in Parana state, Brazil, with testing scheduled for completion at the end of May 2011. It is expected to confirm the technical and economic viability of retrofitting an FCC unit to enable CO2 capture through oxy-combustion. The project will test start-up and shut-down procedures and different operational conditions and process configurations – allowing the CCP partners to gain reliable data for scale-up.

The refinery is a challenging environment for capturing CO2, with many different operations producing emissions. In a refinery, the FCC unit converts heavy, lower-value hydrocarbon feedstock into lighter, more valuable products. This unit is often the largest single source of CO2 emissions in a refinery.

Traditionally, air is used to regenerate the catalyst, by burning the coke deposited on the surface. In the oxy-combustion mode, air is replaced by pure oxygen, which is diluted with recycled CO2 to maintain thermal balance and catalyst fluidization.

Established in 2000, the CCP aims to advance the technologies that will underpin the deployment of industrial-scale CCS in the oil and gas industry. The CCP identified oxy-combustion as one of the most promising capture technologies to take forward for demonstration, from over 200 options evaluated.

It initially conducted an economic assessment of oxyfiring and post-combustion amine absorption for CO2 capture from the FCC regenerator. Both processes were able to achieve the required specifications and recovery level. Although the post-combustion option had a lower capital cost, the lower operational costs for oxyfiring delivered a lower overall capture cost.

## IEA paper on CO2 capture performance

www.iea.org/papers/2011/costperf_ccs_powergen.pdf

**The IEA has released a working paper on "Cost and Performance of Carbon Dioxide Capture from Power Generation".**

The working paper evaluates cost and performance trends related to carbon dioxide (CO2) capture from power generation, based on extensive analysis of data from major engineering studies published between 2006 and 2010.

Since individual studies use different methodologies and boundary conditions, study estimates for over 50 CO2 capture installations are re-evaluated on a consistent basis and updated to current cost levels.

The paper discusses the need for further standardisation of evaluation methodologies and additional data for specific CO2 capture routes. Further analysis for non-OECD countries is considered crucial for global energy scenario models, says the IEA, and for improving the skills and knowledge developing countries need to evaluate the role of CCS in their national energy contexts.

## FuelCell Energy to evaluate carbon capture

www.fuelcellenergy.com

**FuelCell Energy has received a contract to evaluate the effectiveness of Direct FuelCells to separate carbon dioxide from the emissions of industrial operations such as refineries, cement kilns and pulp and paper mills.**

Direct FuelCells (DFC) can use renewable biogas as a fuel to generate electricity. They combine fuel with oxygen from the ambient air to produce electricity and heat using an electrochemical process, without combustion.

An award from the US Environmental Protection Agency will fund initial testing of the ability for Direct FuelCells to consume flue gas instead of ambient air for the power generation process and their capability to cost effectively separate the CO2 within the flue gas.

The research under this initial $0.1 million phase I award is expected to take up to six months. Successful results may lead to a demonstration project at an industrial site using a DFC power plant to provide clean electricity and usable heat to the industrial operation while separating CO2 from the flue gas for sequestration.

## ICO2N report on cost analyses of CO2 capture technologies

www.ico2n.com/wp-content/uploads/2010/07/ICO2N-Review-Conducting-CO2-Capture-Analyses.pdf

**ICO2N has released a report titled "Perspectives on Conducting Cost Analyses of CO2 Capture Technologies".**

The report addresses the challenges arising when conducting a cost analysis of CO2 capture, and offers recommendations on how to ensure cost analyses of capture technologies are as robust as possible, and are truly comparable and contrastable to other cost analyses.

According to ICO2N, a number of capture cost analysis considerations were identified:

* The overall basis for capture costs: defining what is to be included in capture cost analyses

* Financial considerations: ensuring comparisons can be made with other capture work

* The need for an accurate cost reference point: undertaking comparative analyses to ensure capture cost estimating is as robust as possible

* CO2 volume calculations: reporting CO2 capture costs a captured (physical volumes) basis or an abated (net physical volumes after accounting for all on-site and off-site effects of capturing CO2)

* Cost portrayal: presenting capture costs in the form of "cost per unit of commodity produced" (e.g. cost per MWh production) as well as in "cost per tonne of CO2".

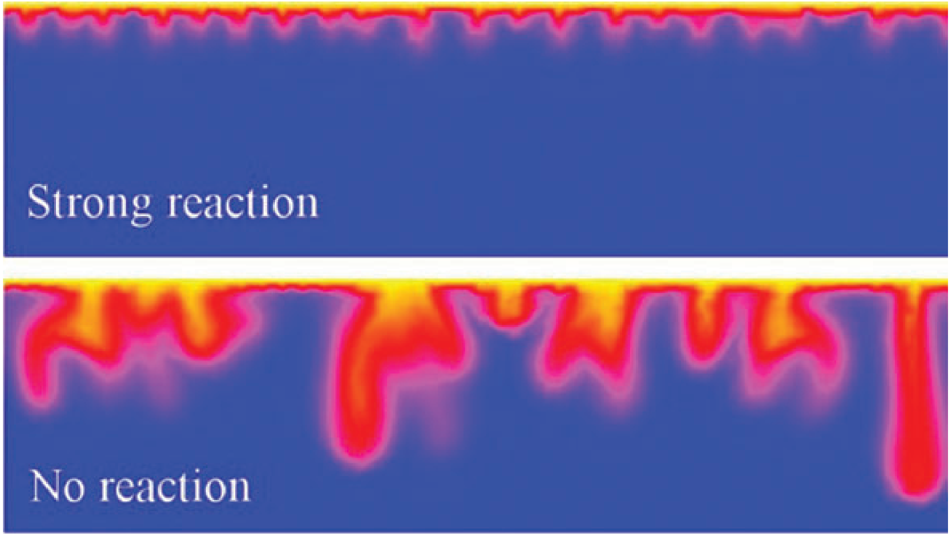
# Chemistry curbs spreading of carbon dioxide

## The presence of even a simple chemical reaction can delay or prevent the spreading of stored carbon dioxide in underground aquifers, new research from the University of Cambridge has revealed.

The findings may have implications for carbon sequestration in saline aquifers – one of the many methods being explored to mitigate rising CO2 levels in the atmosphere.

Depending on the strength of the reaction between dissolved CO2 and porous rock, the new research shows that distinct scenarios of CO2 transport may occur in deep saline rock formations.

Jeanne Andres, a Schlumberger Foundation PhD researcher at the Department of Chemical Engineering and Biotechnology at the University of Cambridge, said: "If one knows the physical properties of the aquifer, one can now calculate the movement of CO2 across it, and when it will begin to mix with the brine. In theory, one can manipulate the strength of reactions, thereby engineering the movement of CO2 – keeping it in one area or moving it to another within the aquifer – to enhance its storage underground."




*CO2 fingers - Strong chemical reactions between dissolved carbon dioxide and porous rock (top) may stop CO2 fingers from spreading from the top throughout an aquifer's depth, in contrast to systems with no reaction (bottom).*
*Jeanne Therese H. Andres*

With weak reactions, the CO2 will spread from the top throughout the depth of the aquifer, but with stronger reactions, the CO2 remains near the top of the reservoir, leaving the deeper part inactive.

The strength of these reactions can vary significantly among deep saline reservoirs - rock formations possess a wide range of chemical reaction rates depending on the mineralogy (e.g. calcite, dolomite, etc) as well as other factors such as temperature and pressure,. With the new insight this research provides, it would now be feasible to consider creating and injecting compounds which could alter the strength of reactions in the aquifer.

To arrive at their conclusions, the researchers established that the basic interaction between fluid flow and the rate of chemical reactions (chemical kinetics) in a deep porous medium is governed by a single dimensionless number, which measures the rate of diffusion and reaction compared to that of the natural mixing of fluids (convection).

As applied to the storage of CO2 underground, the scientists demonstrate how this new parameter controls CO2 flow and mixing in briny porous rock. Through numerical simulations, the researchers found that above this parameter's critical value, reaction stabilizes the CO2 system and convection no longer occurs. Below the parameter's critical value, stronger reactions result in longer delays in the onset of convective mixing throughout the reservoir.

For systems with similar convective mixing strengths, stronger reactions, indicated by rising values of the new parameter, can increase the minimum rate at which pure, lighter CO2 dissolves into the brine, enhancing storage and reducing the risk of leakage.

Dr Silvana Cardoso, Reader in the Department and project leader, said: "This research shows how rigorous mathematical analysis coupled with strong physical understanding can help us grasp the complex interactions of flow and reaction in a carbon reservoir. Such knowledge will be valuable in guiding future approaches to carbon storage."

The paper 'Onset of convection in a porous medium in the presence of chemical reaction' was published in the journal Physical Review E.

# Transport and storage news

## Drilling to begin at Wyoming storage project

www.uwyo.edu

**The first phase of the Wyoming Carbon Underground Storage Project (WY-CUSP) will begin with the start of drilling on the Rock Springs Uplift in Sweetwater County.**

The $16.9 million WY-CUSP Phase I project, managed by the Carbon Management Institute (CMI) at the University of Wyoming and co-sponsored by the U.S. Department of Energy's Office of Fossil Energy, could lay the groundwork for Wyoming's first successful carbon capture and storage project.

Drilling the 2,000-foot top hole, the first stage of a 14,000-foot stratigraphic test well, will be conducted by Baker Hughes, an industry partner on the project. It will take between 30 and 60 hours to complete. The remainder of drilling will begin once a large rig is on-site and take about 100 days.

"The start of drilling at the WY-CUSP site represents the first concrete step toward actual demonstration and commercialization of CO2 sequestration in Wyoming and the Rocky Mountain region. For the first time, we'll have the data necessary to substantially reduce uncertainty surrounding CO2 storage on the Rock Springs Uplift," says CMI Director Ron Surdam. "Results from drilling will help us address a wide variety of issues related to geologic CO2 storage -- both for specific reservoir targets in Wyoming and for similar potential storage reservoirs across the U.S. and around the world."

The project's initial phase began in December 2009 and is scheduled for completion in December 2012. It will produce a detailed characterization of two deep saline aquifers in the Rock Springs Uplift for potential pilot- and commercial-scale CO2 sequestration.

Preliminary data from prior research indicates that the Rock Springs Uplift could store 26 billion tons of CO2 over 50 years. It has been targeted for carbon storage due to the geological setting and its proximity to some the state's largest sources of anthropogenic CO2.

## CIUDEN launches PISCO2 pilot project for CO2 biomonitoring tools

www.ciuden.es

**The Fundación Ciudad de la Energía (CIUDEN), a Spanish state foundation created in 2006 for Research and Development in CCS, has launched a new Project to develop biomonitoring strategies of potential CO2 leakages through testing biogeochemical effects of CO2 injection in soils.**

The test site for CO2 injection in soils (known as PISCO2, by its Spanish acronym) consists of 18 cells of concrete excavated in the ground; each of them, with an area of 16 square meters and a depth of 2.5 meters.

These cells will be filled with soils from different areas of Spain with potential capability for CO2 storage including Hontomín (Burgos), where CIUDEN's CO2 Storage Technological Development Plant is under development.

Micro-perforated tubes buried at 1 and 2 meters under the surface, will allow the injection of small quantities of diffuse CO2 at different given flow rates. The facility will serve to test how small CO2 diffuse leakages can influence the vegetation, microorganisms, lichens and soils and aims to find useful, cheap and ecological bio-indicators of any CO2 concentration variation in wide areas.

It will also serve as a laboratory for agricultural tests of the beneficial effects of low CO2 emissions. In addition, the installation will be a tool to test and calibrate measurement instruments such as accumulation chambers, sensors, etc.

Construction started in April 2011 and it is planned to be fully operational in October 2011. Its configuration makes it unique and CIUDEN is open for cooperative research projects with institutions all over the World.

# Status of CCS project database

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

For the full list, with the latest data as it becomes available, please see the pdf version online at www.carboncapturejournal.com

| Project Name | Description | Asset Lifecycle Stage | Country | State / District |
|---|---|---|---|---|
| AEP Mountaineer 235-MWe CO2 Capture and Storage Project | AEP's Mountaineer coal-fired power station was retrofitted with Alstom's patented chilled ammonia carbon capture technology. This project has been operational at pilot scale since September 2009 and full-scale operation is expected by 2015. | Define | UNITED STATES | West Virginia |
| Air Liquide | Air Liquide is building a new hydrogen plant in Rotterdam. The installation of a cryogenic purification unit (CPU) at the plant, capturing up to 550,000 tonnes per annum of carbon dioxide, is under evaluation. | Define | NETHERLANDS | Rotterdam |
| Air Products Steam Methane Reformer EOR Project | This project proposes to capture more than 1 million tonnes per year of carbon dioxide from two steam methane reformers. The CO2 will be transported via Denbury's Midwest pipeline to the Hastings and Oyster Bayou oil fields for enhanced oil recovery. | Define | UNITED STATES | Texas |
| Alcan Lynemouth Power Station | Progressive Energy is proposing to install a gasification unit with pre-combustion carbon dioxide capture technology, capturing approximately 2.2 million tonnes per annum of carbon dioxide. This project is part of the North East CCS Cluster. | Define | UNITED KINGDOM | Northumberland, England |
| Archer Daniels Midland Company Ethanol Plant Industrial CCS | The project will capture around 1 million tonnes per annum of carbon dioxide from ethanol production. The carbon dioxide will be stored approximately 2.1 km underground in the Mount Simon Sandstone, a deep saline formation. | Define | UNITED STATES | Illinois |
| Battelle, Boise White Paper Mill | The Battelle Memorial Institute is partnering with Boise White Paper and Fluor Corp to demonstrate carbon capture from the combustion of black liquor at a paper mill. Around 700,000 tonnes per annum of CO2 will be stored in deep flood basalt formations. | Evaluate | UNITED STATES | Washington |
| Belchatow CCS | Alstom and PGE EBSA are partnering to build an 858 MW lignite-fired power plant with CCS. Around 1.8 million tonnes per annum of carbon dioxide will be captured and stored in deep saline formations. | Define | POLAND | Lodz Voivodeship |
| Bow City Power Plant CO2 Capture | The Bow City Power Project is a proposed super critical 1,000 MW coal-fired power plant incorporating post combustion carbon capture and storage. Around 1 million tonnes per annum of carbon dioxide will be captured at the plant. | Evaluate | CANADA | Alberta |
| Browse LNG Development | Up to 3 million tonnes per annum of carbon dioxide will be captured at this proposed liquid natural gas development located in the government precinct near James Price Point on the Dampier peninsula. | Evaluate | AUSTRALIA | Western Australia |
| CEMEX CO2 Capture Plant | CEMEX proposes to demonstrate a dry sorbent carbon capture and compression technology at one of its cement plants in the United States, capturing around 1 million tonnes per annum of carbon dioxide. | Evaluate | UNITED STATES | TBD |
| Chemical Plant, Yulin | This project developed by Dow Chemical proposes to build a coal to liquids plant. Various storage options are under evaluation. | Identify | CHINA | Shanxi Province |
| CO2 Global - Project Viking | This project proposes to convert refinery pitch to MSAR® synthetic fuel oil, which will in turn be used to produce power, steam and carbon dioxide through an oxycombustion process. The carbon dioxide will be used for enhanced oil recovery. | Identify | UNITED STATES | New Mexico |
| Coffeyville Resources Nitrogen Fertilizer Plant | Coffeyville Resources is proposing to build a carbon capture unit at an existing gasification plant in Kansas. The project would capture up to 850,000 tonnes per annum of carbon dioxide for urea production and enhanced oil recovery. | Define | UNITED STATES | Kansas |
| Coolimba Power Project | Aviva Corporation Ltd proposes the construction of a "CCS-ready", coal-fired base-load power station using circulating fluidized bed (CFB) technology. Suitable storage sites are being sought. | Identify | AUSTRALIA | Western Australia |
| Dongguan Taiyangzhou IGCC with CCS Project | Dongguan Taiyangzhou Power Corporation intends to construct an 800 MW IGCC plant capturing up to 1 million tonnes per annum of carbon dioxide, which would be stored in depleted oil and gas reservoirs. | Define | CHINA | Guangdong |
| Drax CCS Project | Alstom UK Ltd, Drax Power Limited and National Grid plc are jointly developing a new 426 MW oxy-fired plant in North Yorkshire which would capture around 2 million tonnes per annum of carbon dioxide. The project is part of the Humber CCS Cluster. | Evaluate | UNITED KINGDOM | North Yorkshire |
| Emirates Steel Industries (ESI) | This project proposes to capture around 800,000 tonnes per annum of carbon dioxide from a steel plant in the Industrial City of Abu Dhabi (ICAD) by 2014. The project is being developed as part of the Abu Dhabi CCS Network (Masdar). | Evaluate | UNITED ARAB EMIRATES | Mussafah (Abu Dhabi) |
| Enhance Energy EOR Project | Enhance Energy and Fairborne Energy Trust are jointly developing an enhanced oil recovery project at their Clive D2A and D3A fields, using carbon dioxide captured from a refinery and a fertiliser plant, and transported via the Alberta Carbon Trunk Line. | Execute | CANADA | Alberta |
| Enid Fertilizer Plant | The Enid Fertilizer plant sends around 680,000 tonnes per annum of carbon dioxide to be used for enhanced oil recovery. The pipeline and wells are operated separately by Anadarko Petroleum. This project has been in operation since 2003. | Operate | UNITED STATES | Oklahoma |
| Entergy Nelson 6 CCS Project | This project developed by Tenaska and Entergy will capture up to 4 million tonnes per annum of carbon dioxide from an existing coal-fired power station when operating at full scale. The carbon dioxide will be used for enhanced oil recovery. | Define | UNITED STATES | Louisiana |

| Volume $CO_2$ | Operation Date | Facility Details | Capture Type | Transport Type | Transport Length | Storage Type | Project URL |
|---|---|---|---|---|---|---|---|
| 1.5 Mtpa | 2015 | 235 MWe slipstream from 1300 MW net coal-fired power plant | Post-Combustion | Pipeline | 30 km | Deep Saline Formations | http://www.aep.com/environmental/climatechange/carboncapture/ |
| 0.55 Mtpa | 2012 | Hydrogen production | Pre-Combustion | Ship | Not specified | Enhanced Oil Recovery | http://www.airliquide.com/ |
| 1 Mtpa | 2015 | Hydrogen production at oil refinery | Pre-Combustion | Pipeline | Not specified | Enhanced Oil Recovery | http://www.airproducts.com/index.asp |
| 2.2 Mtpa | 2015 | 420 MW coal / biomass fired power plant | Pre-Combustion | Pipeline | 250 km | Deep Saline Formations | http://www.progressive-energy.com/ |
| 1 Mtpa | 2012 | Ethanol plant | Industrial Separation | Pipeline | 1.6 km | Deep Saline Formations | http://www.adm.com/ |
| 0.72 Mtpa | 2014 | Pulp and paper mill | Post-Combustion | Not Specified | Not specified | Deep Basalt Formations | http://www.battelle.org/ |
| 1.8 Mtpa | 2015 | 260 MW equivalent on 858 MW lignite-fired power plant | Post-Combustion | Pipeline | 60-140 km | Deep Saline Formations | http://www.bot.pl/ |
| 1 Mtpa | 2016 | 1000 MW coal-fired power plant | Post-Combustion | Pipeline | 6-30 km | Enhanced Oil Recovery | www.bowcitypower.ca |
| 3 Mtpa | 2017 | Liquefied natural gas (LNG) plant | Gas Processing | Pipeline | Not specified | Not Specified | http://www.woodside.com.au/ |
| 1 Mtpa | 2015 | Cement plant | Post-Combustion | Pipeline | Not specified | Not Specified | http://www.cemex.com/SustainableDevelopment/CarbonCapture.aspx |
| 5 Mtpa | 2019 | Coal to liquids plant | Pre-Combustion | Pipeline | Not specified | Various Storage Options Being | http://www.dow.com/ |
| 1.2 Mtpa | 2014 | 150 MWe oxyfuel combustion using synthetic fuel oil | Oxyfuel Combustion | Pipeline | 48 km | Enhanced Oil Recovery | http://www.co2.no/ |
| 0.585 Mtpa | 2013 | Fertiliser plant | Pre-Combustion | Pipeline | 112 km | Enhanced Oil Recovery | http://www.cvrenergy.com/NitrogenFertilizerOperations/index.html |
| 2 Mtpa | 2015 | 2x200 MW or 3x150 MW coal-fired CFB power plant | Post-Combustion | Pipeline | 20-80km | Depleted Oil and Gas Reservoirs | www.coolimbapower.com.au |
| 1 Mtpa | 2015 | 800 MW net coal-fired IGCC power plant | Pre-Combustion | Pipeline | 100 km | Depleted Oil and Gas Reservoirs | http://www.dgpowerfuel.com/english/profile.asp |
| 2 Mtpa | 2015 | 426 MW gross coal-fired power plant | Oxyfuel Combustion | Pipeline | Not specified | Depleted Oil and Gas Reservoirs | http://www.draxpower.com/ |
| 0.8 Mtpa | 2014 | Steel plant | Other | Pipeline | 50 km | Enhanced Oil Recovery | http://www.esi-steel.com/ |
| 1.8 Mtpa | 2012 | Fertiliser production and hydrogen production at the oil refinery | Pre-Combustion | Pipeline | 240 km | Enhanced Oil Recovery | http://www.enhanceenergy.com/projects/clive.html |
| 0.68 Mtpa | 2003 | Fertiliser plant | Pre-Combustion | Pipeline | 192 km | Enhanced Oil Recovery | http://www.kochfertilizer.com/ |
| 4 Mtpa | 2015 | 585 MW coal-fired power plant | Post-Combustion | Pipeline | < 160 km | Enhanced Oil Recovery | http://www.entergy.com/ |

# Status of CCS project database

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|---|---|---|---|---|
| **Eston Grange CCS Plant** | Progressive Energy proposes to develop an 850MW IGCC coal-fired power plant with pre-combustion CO2 capture on a brownfield site in Teesside. This project is part of the North East CCS Cluster initiative. | Define | UNITED KINGDOM | Teesside, England |
| **Faustina Hydrogen** | ion facility in Louisiana which will use petcoke to produce various industrial chemicals. The carbon dioxide captured at this plant will be used for enhanced oil recovery. | Evaluate | UNITED STATES | Louisiana |
| **Freeport Gasification Plant** | Hunton Energy proposes to build a gasification plant that will convert syngas to substitute natural gas (SNG) and generate 400 MW of additional electricity. The carbon dioxide captured at the plant will be used for enhanced oil recovery. | Evaluate | UNITED STATES | Texas |
| **FutureGen 2.0** | FutureGen 2.0 is an initiative to demonstrate state-of-the-art CCT by repowering an existing 200 MW unit at Amerden's coal fired power plant in Meredosia, Illinois, with advanced oxy-combustion technology. | Identify | UNITED STATES | Illinois |
| **Good Spring IGCC** | EmberClear Corporation, in partnership with China's Thermal Power Research Institute, plans to build a 270 MW IGCC plant in Pennsylvania. Around 1 million tonnes per annum of carbon dioxide will be captured at the plant. | Identify | UNITED STATES | Pennsylva-nia |
| **Gorgon Carbon Dioxide Injection Project** | This component of a larger gas production and LNG processing project will inject 3.4 to 4 million tonnes per annum of carbon dioxide into a saline formation. Construction is under way after a final investment decision was made in September 2009. | Execute | AUSTRALIA | Western Australia |
| **Great Northern/Allied Syngas IGCC South Heart** | Great Northern Power Development and Allied Syngas are planning a 175MW IGCC plant capturing about 90 per cent of its carbon emissions. The plant will produce 2.1 million tonnes per annum of carbon dioxide for enhanced oil recovery. | Evaluate | UNITED STATES | North Dakota |
| **GreenGen IGCC Project** | GreenGen Co. proposes to build a coal-based energy system that includes hydrogen production, electricity generation and carbon capture. The carbon dioxide captured at the site will be used for enhanced oil recovery. | Evaluate | CHINA | Tianjin |
| **Hatfield Endex CCGT Project** | This 450 MW combined cycle gas turbine power plant is being jointly developed by Powerfuel Power Limited and Calix Limited. The project will share the carbon dioxide transport and storage infrastructure used by the Hatfield IGCC plant. | Identify | UNITED KINGDOM | South Yorkshire (England) |
| **Hatfield IGCC/CCS Project** | Powerfuel Power Ltd is developing this project to capture nearly 5 million tonnes per annum of carbon dioxide from a 900 MW coal-fired power station. The project is part of the Yorkshire Forward initiative. | Evaluate | UNITED KINGDOM | South Yorkshire (England) |
| **Hunterston Power Station** | Ayrshire Power is developing a new multi-fuel power station fitted with CCS infrastructure at Hunterston, Scotland. The project intends to capture around 2 million tonnes per annum of carbon dioxide when operating at full scale. | Evaluate | UNITED KINGDOM | North Ayrshire (Scotland) |
| **Hydrogen Energy California Project (HECA)** | This project will use IGCC technology at a petcoke plant to produce hydrogen and carbon dioxide. The hydrogen will then be used to fuel a power station. The carbon dioxide will be transported by pipeline to nearby oil fields for enhanced oil recovery. | Define | UNITED STATES | California |
| **Immingham Carbon Capture and Storage Project** | This project proposes to use IGCC and pre-combustion carbon capture technology at an oil refinery. The carbon dioxide captured at the plant will we transported offshore to the Southern North Sea for geological sequestration. | Identify | UNITED KINGDOM | Lincolnshir e (England) |
| **In Salah CO2 Injection** | In Salah is a fully operational onshore gas field in Algeria. Since 2004, 1 million tonnes per annum of carbon dioxide are separated from produced gas and reinjected into the producing hydrocarbon reservoir zones for storage in a deeper saline formation. | Operate | ALGERIA | Ouargla Wilaya |
| **Indiana Gasification** | This coal-gasification plant project will include a methanation process to produce pipeline quality substitute natural gas (SNG). The carbon dioxide captured at the plant will be used for enhanced oil recovery. | Evaluate | UNITED STATES | Indiana |
| **Korea-CCS1** | This project proposes to capture up to 1.5 million tonnes per annum of carbon dioxide from an integrated Circulating Fluidized Bed Combustion (CFBC) power plant. The carbon dioxide captured at the plant would be stored in deep saline formations. | Evaluate | REPUBLIC OF KOREA | Not Specified |
| **Wandoan Power IGCC CCS Project** | This project based on General Electric's IGCC and capture technologies will capture up to 2.5 million tonnes per annum of carbon dioxide from a 400 MW power plant. The carbon transport and storage components are pursued in alliance with Xstrata Coal. | Evaluate | AUSTRALIA | Queenslan d |
| **Weyburn-Midale Storage Project** | This project captures about 3 million tonnes per annum of carbon dioxide from a synfuels plant. The carbon dioxide is transported by pipeline across the Canadian border for enhanced oil recovery. The project has been in operation since 2000. | Operate | CANADA | Saskatche wan |
| | | | | |
| **Victorian CarbonNet Project** | The Victorian Government is developing this carbon transport and storage hub project in the state of Victoria. The project aims to collect between 3 and 5 million tonnes per annum of carbon dioxide from various capture facilities. | Evaluate | AUSTRALIA | Victoria |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 5 Mtpa | 2015 | 850 MW IGCC power plant | Pre-Combustion | Pipeline | 225 km | Deep Saline Formations | http://www.estongrange.co.uk/test/index.htm |
| 1.5 Mtpa | 2019 | Coal to liquids plant | Pre-Combustion | Pipeline | Not specified | Enhanced Oil Recovery | http://www.eastman.com/ |
| 2 Mtpa | 2013 | Petcoke to SNG plant (plus 400 MW electricity from excess steam) | Pre-Combustion | Pipeline | Not specified | Enhanced Oil Recovery | http://www.huntonenergy.com/ |
| 1 Mtpa | 2020 | 200 MW coal-fired oxyfuel combustion plant | Oxyfuel Combustion | Pipeline | 51 km | Not Specified | http://www.futuregenalliance.org/ |
| 1 Mtpa | 2015 | 270 MW coal-fired IGCC power plant | Pre-Combustion | Pipeline | Not specified | Deep Saline Formations | http://www.emberclear.com/ |
| 3.4 Mtpa | 2014 | Liquefied natural gas (LNG) processing plant | Gas Processing | Pipeline | 10 km | Deep Saline Formations | http://www.chevronaustralia.com/ourbusinesses/gorgon.aspx |
| 2.1 Mtpa | 2017 | 175 MW net lignite-fired IGCC plant | Pre-Combustion | Pipeline | Not specified | Enhanced Oil Recovery | http://www.greatnorthernpower.com/ |
| 2 Mtpa | 2016 | 1x400 MW (phase III) coal-fired IGCC power plant | Pre-Combustion | Pipeline | Not specified | Enhanced Oil Recovery | http://www.greengen.com.cn/en/index.asp |
| 1 Mtpa | 2015 | 450 MW combined cycle gas turbine power plant | Pre-Combustion | Pipeline | 175 km | Depleted Oil and Gas | http://www.powerfuel.plc.uk/ |
| 4.75 Mtpa | 2015 | 2x450 MW gross coal-fired IGCC power plant | Pre-Combustion | Pipeline | 175 km | Depleted Oil and Gas | http://powerassetmodelling.co.uk/html/hatfield_igcc_.html |
| 2 Mtpa | 2017 | 2x926 MW multi-fuel (coal/biomass)-fired power plant | Post-Combustion | Pipeline | Not specified | Depleted Oil and Gas | www.ayrshirepower.co.uk |
| 2 Mtpa | 2016 | 250 MW net multi-fuel-fired IGCC power plant | Pre-Combustion | Pipeline | 6.4 km | Enhanced Oil Recovery | http://www.hydrogenenergycalifornia.com/ |
| 4 Mtpa | 2020 | 800-1200 MW multi-fuel IGCC power plant at oil refinery | Pre-Combustion | Pipeline | 300 km | Not Specified | http://www.conocophillips.com/EN/susdev/environment/climatechange/carboncapture/Pages/index.aspx |
| 1 Mtpa | 2004 | Natural gas processing plant | Gas Processing | Pipeline | 14 km | Deep Saline Formations | http://www.insalahco2.com/ |
| 1 Mtpa | 2020 | Coal to SNG plant | Pre-Combustion | Pipeline | 7.2 km | Enhanced Oil Recovery | http://www.leucadia.com/ |
| 1.5 Mtpa | 2017 | 300 MW coal-fired power plant | Post-Combustion | TBD | 250 km | Deep Saline Formations | http://www.kepco.co.kr/eng/ |
| 2.5 Mtpa | 2015 | 400 MW net coal-fired IGCC power plant | Pre-Combustion | Pipeline | 200 km | To Be Determined | http://www.wandoanpower.com.au |
| 3 Mtpa | 2000 | Synfuels plant including SNG | Pre-Combustion | Pipeline | 330 km | Enhanced Oil Recovery | http://www.cenovus.com/operations/oil/weyburn.html |
| | | | | | | | |
| 3.3 Mtpa | 2018 | Various CO2 capture facilities | Pre-Combustion and Post-Combustion | Pipeline | 150 km | Deep Saline Formations | http://www.invest.vic.gov.au/ |

# Status of CCS project database

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|---|---|---|---|---|
| **Korea-CCS2** | This project proposes to capture 1.5 to 2.5 million tonnes per annum of carbon dioxide from an oxyfuel or IGCC power plant. The carbon dioxide captured at the plant would be shipped for injection into a deep saline formation. | Identify | REPUBLIC OF KOREA | TBD |
| **Lake Charles Gasification Plant** | Leucadia and Lake Charles Cogeneration plan to build a gasification plant to produce substitute natural gas from petcoke. Around 4 million tonnes per annum of carbon dioxide will be captured at the plant and used for enhanced oil recovery. | Define | UNITED STATES | Louisiana |
| **Leucadia Energy Capture Project - Mississippi** | Leucadia Energy LLC and Mississippi Gasification LLC propose to capture around 4 million tonnes per annum of carbon dioxide from a petcoke gasification plant in Moss Point, Mississippi. The carbon dioxide will be used for enhanced oil recovery. | Evaluate | UNITED STATES | Mississippi |
| **Lianyungang IGCC with CCS Project** | This project will construct a 1200 MW IGCC capturing up to 1 million tonnes per annum of carbon dioxide. Substitute natural gas (SNG) and chemicals will be co-produced at this plant. | Define | CHINA | Jiangsu |
| **Longannet Clean Coal Power Station** | This project led by Scottish Power will retrofit two 600 MW turbines with amine-based carbon capture units. Up to 2 million tonnes per annum of carbon dioxide will be transported by pipeline to depleted gas fields in the Central North Sea for storage. | Define | UNITED KINGDOM | Fife (Scotland) |
| **Lost Cabin Gas Plant Capture Project** | This project will retrofit the Lost Cabin natural gas processing plant in Wyoming with CCS facilities, capturing around 1 million tonnes per annum of carbon dioxide to be used for enhanced oil recovery. | Define | UNITED STATES | Wyoming |
| **Mongstad Full-Scale CCS** | StatoilHydro and the Norwegian government entered into an implementation agreement to develop carbon capture solutions at the Mongstad natural gas energy plant, with a view to capture and store up to 1 million tonnes per annum of carbon dioxide. | Evaluate | NORWAY | Hordaland |
| **Occidental Gas Processing Plant** | p to 9 million tonnes per annum of carbon dioxide for use in enhanced oil recovery. | Execute | UNITED STATES | Texas |
| **Plant Ratcliffe (Southern Company IGCC)** | Mississippi Power (Southern Company) plans to build an air-blown 582 MW IGCC plant using a coal-based transport gasifier. Up to 2.5 million tonnes per annum of carbon dioxide will be captured at the plant and used for enhanced oil recovery. | Execute | UNITED STATES | Mississippi |
| **Porto Tolle** | This project will capture around 1 million tonnes per annum of carbon dioxide from 660 MW coal power station units using post-combustion capture technology. The carbon dioxide will be injected into a deep saline aquifer in the northern Adriatic Sea. | Define | ITALY | Rovigo |
| **Quest CO2 Capture and Storage Project** | The Quest Project proposes to capture more than 1.2 million tonnes per annum of carbon dioxide from an oil sands upgrader. The carbon dioxide will be transported in a 80 kilometre pipeline to a deep saline formation, with possible sales to third parties. | Define | CANADA | Alberta |
| **Rangely Weber Sand Unit CO2 Injection Project** | ChevronTexaco, the current owner and operator of the Rangely Weber Sand Unit, sources around 1 million tonnes per annum of carbon dioxide from a gas processing plant that is used for enhanced oil recovery. This project has been in operation since 1986. | Operate | UNITED STATES | Colorado |
| **Romanian CCS Demo Project (Getica)** | This project will capture around 1.5 million tonnes per annum of carbon dioxide from a lignite-fired power plant. The carbon dioxide captured at the plant will be stored in offshore deep saline formations. | Evaluate | ROMANIA | Gorj County |
| **Rotterdam Afvang en Opslag Demo (ROAD)** | Electrabel and E.ON are developing this project in partnership with the Rotterdam Climate Initiative (RCI). A 250 MW capture plant is being built at E.ON's Maasvlakte power plant and operation is expected to start in 2015. | Define | NETHERLANDS | Zuid-Holland |
| **Rotterdam CCS Network Project** | This project aims to develop a business case for a large-scale carbon transport hub based in Rotterdam. Nine capture facilities have been validated, as well as the transport infrastructure. The independent storage assessment is under way. | Evaluate | NETHERLANDS | Rotterdam |
| **RWE Eemshaven** | RWE and Gasunie aim to capture and store around 1.2 million tonnes per annum of carbon dioxide in this project, which is scheduled to become operational in 2015. | Define | NETHERLANDS | Groningen |
| **Salt Creek Enhanced Oil Recovery** | Carbon dioxide recovered from the Shute Creek gas processing plant in southwest Wyoming is transported by pipeline to Anadarko's enhanced oil recovery project at the Salt Creek field. This project has been operational since 2004. | Operate | UNITED STATES | Wyoming |
| **SaskPower Boundary Dam 3 CCS Project** | SaskPower proposes to rebuild a coal-fired power generator with carbon capture technology near Estevan, in the Saskatchewan province. When fully operational in 2015, this project will capture around 1 million tonnes per annum of carbon dioxide. | Execute | CANADA | Saskatchewan |
| **Scottish and Southern CCS Project (Peterhead)** | Around 1 million tonnes per annum of carbon dioxide will be captured at GCTT Peterhead, the largest power station in Scotland. The carbon dioxide captured at the plant will be used for enhanced oil recovery at the Miller Field in the North Sea. | Evaluate | UNITED KINGDOM | Aberdeenshire (Scotland) |
| **SCS Energy PurGen One** | SCS Energy LLC is proposing to build a 500 MW IGCC power plant with CCS in New Jersey. Around 2.6 million tonnes per annum of carbon dioxide would be transported by pipeline to deep saline formations about 110 km offshore. | Evaluate | UNITED STATES | New Jersey |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1.5 Mtpa | 2019 | 300 MW coal-fired oxyfuel or IGCC power plant | TBD | Ship | 800 km | Deep Saline Formations | http://www.kepco.co.kr/eng/ |
| 4 Mtpa | 2014 | Petcoke to SNG plant | Pre-Combustion | Pipeline | 19 km | Enhanced Oil Recovery | http://www.leucadia.com/ |
| 4 Mtpa | 2014 | Petcoke to SNG plant | Pre-Combustion | Pipeline | 176 km | Enhanced Oil Recovery | http://www.denbury.com/ |
| 1 Mtpa | 2015 | 1200 MW IGCC and 2x1300 MW ultra supercritical PC | Pre-Combustion and Post-Combustion | Pipeline | 100 km | Deep Saline Formations | http://english.cas.cn/ |
| 2 Mtpa | 2014 | 2x600 MW units at a 2400 MW coal-fired power plant with co- | Post-Combustion | Pipeline | Not specified | Depleted Oil and Gas | http://www.scottishpower.com/carbon_capture_storage/ |
| 1 Mtpa | 2014 | Natural gas processing plant | Gas Processing | Pipeline | 370 km | Enhanced Oil Recovery | http://www.conocophillips.com/EN/tech/Pages/carbon-article.aspx |
| 1 Mtpa | 2020 | Natural gas-fired power plant (280 MW electric, 350 MW | Post-Combustion | Pipeline | Not specified | Deep Saline Formations | http://www.statoil.com/en/OurOperations/TerminalsRefining/ProdFacilitiesMongstad/Pages/EnergiverkMongstad.aspx |
| 9 Mtpa | 2011 | Natural gas processing plant | Gas Processing | Pipeline | 256 km | Enhanced Oil Recovery | http://www.oxy.com/ |
| 2.5 Mtpa | 2014 | 582 MW net coal-fired IGCC power plant | Pre-Combustion | Pipeline | 98 km | Enhanced Oil Recovery | http://www.mississippipower.com/kemper/ |
| 1 Mtpa | 2015 | 3x660 MW ultra supercritical PC power unit | Post-Combustion | Pipeline | 100 km | Deep Saline Formations | http://www.zeportotolle.com/ |
| 1.2 Mtpa | 2015 | Hydrogen production at oil sands upgrader | Pre-Combustion | Pipeline | 80 km | Deep Saline Formations | http://www.shell.ca/ |
| 1 Mtpa | 1986 | Natural gas processing plant | Gas Processing | Pipeline | 285 km | Enhanced Oil Recovery | http://www.chevron.com/ |
| 1.5 Mtpa | 2015 | 330 MW lignite-fired power plant | Post-Combustion | Pipeline | 20-50 km | Deep Saline Formations | http://www.ispe.ro/en/ |
| 1.1 Mtpa | 2015 | 250 MW on 1070 MW coal and biomass-fired power plant | Post-Combustion | Pipeline | 25 km | Depleted Oil and Gas | http://www.eon-benelux.com/ |
| 3.35 Mtpa | 2015 | Various capture facilities | Various | Combination | 25 km | Depleted Oil and Gas | http://www.rotterdamclimateinitiative.nl/en/ |
| 1.2 Mtpa | 2015 | 780 MW net coal-fired power plant (biomass in future) | Post-Combustion | Pipeline | 80 km | Depleted Oil and Gas | http://www.rwe.com/ |
| 2.4 Mtpa | 2004 | Natural gas processing plant | Gas Processing | Pipeline | 201 km | Enhanced Oil Recovery | http://www.anadarko.com/Operations/Pages/EnhancedOilRecovery.aspx |
| 1 Mtpa | 2013 | 115 MWe coal-fired power plant | Post-Combustion | Pipeline | 100 km | Enhanced Oil Recovery | http://www.saskpower.com/sustainable_growth/projects/carbon_capture_storage.shtml?linkid=home_right2_carbon_capture_and_storage_demo |
| 1 Mtpa | By 2020 | 400MW gas-fired power plant | Post-Combustion | Pipeline | 320 km | Not Specified | http://www.sse.com/ |
| 2.6 Mtpa | 2016 | 500 MW coal-fired IGCC power plant | Pre-Combustion | Pipeline | 160 km | Deep Saline Formations | http://www.purgenone.com/ |

# Status of CCS project database

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| **Sharon Ridge EOR** | This enhanced oil recovery project uses carbon dioxide sourced from the Mitchell, Gray Ranch, Puckett and Turrell gas processing plants and transported via the Val Verde and CRC pipelines. This project has been in operation since 1999. | Operate | UNITED STATES | Texas |
| **Shenhua CTL Phase 2 (1 Mtpa)** | This project intends to capture around 1 million tonnes per annum of carbon dioxide from a coal- to-liquids facility by 2020. It is the second phase of the pilot-scale Ordos Shenhua DCL plant CCS Project. | Identify | CHINA | Inner Mongolia |
| **Sleipner CO2 injection** | Sleipner is a fully operational offshore gas field with carbon dioxide injection. The carbon dioxide is separated from produced gas and reinjected into a saline aquifer above the hydrocarbon reservoir zones. This project has been in operation since 1996. | Operate | NORWAY | North Sea |
| **Snøhvit CO2 injection** | The Snøhvit offshore gas field and related CCS activities have been in operation since 2007. Carbon dioxide separated from the gas produced at an onshore liquid natural gas plant is reinjected into an offshore saline aquifer below the reservoir zones. | Operate | NORWAY | Barents Sea |
| **Southland Coal to Fertiliser Project** | Solid Energy and Ravensdown have partnered to investigate a coal to fertiliser plant (1.2 million tonnes per annum of fertiliser) with carbon capture and sequestration in a deep saline formation. The plant is projected to begin operations in 2016. | Evaluate | NEW ZEALAND | Southland |
| **Spectra - Demonstration Phase - Fort Nelson CCS Project** | Carbon dioxide sourced at the Fort Nelson natural gas-processing plant will be injected into a nearby saline formation at a depth of approximately 2200 metres. Injection rates will ramp up to 1.2 to 2 million tonnes per annum of CO2. | Evaluate | CANADA | British Columbia |
| **Swan Hills Synfuels In-Situ Coal Gasification (ISGC) / Sagitawah Power Generation** | This project intends to build a 300 MW combined cycle power plant, using syngas produced at an adjacent coal gasification unit. Around 1.4 million tonnes per annum of carbon dioxide will be captured and sold to local enhanced oil recovery operators. | Evaluate | CANADA | Alberta |
| **Sweeny Gasification** | This project proposes to build an IGCC plant in Southeast Texas using petroleum coke and ConocoPhillips's proprietary E-Gas gasification technology. The plant with capture around 3 million tonnes per annum of carbon dioxide for enhanced oil recovery. | Evaluate | UNITED STATES | Texas |
| **Taweelah Asia Power Company / Emirates Aluminium CCS Project** | This project proposes to capture up to 4.2 million tonnes per annum of carbon dioxide from an amine-based natural gas fired power plant by 2017. The project is being developed as part of the Abu Dhabi CCS Network (Masdar). | Identify | UNITED ARAB EMIRATES | Taweelah (Abu Dhabi) |
| **Taylorville Energy Center (IGCC)** | (gross) IGCC power plant located in Illinois. Around 1.9 million tonnes per annum of carbon dioxide will be captured at the plant and used for enhanced oil recovery. | Evaluate | UNITED STATES | Illinois |
| **Tenaska Trailblazer Energy Center** | Tenaska, Inc. is developing a site near Sweetwater, Texas, upon which to construct a supercritical pulverized coal-fueled electric generating plant designed to capture up to 85-90 per cent of the carbon dioxide that would otherwise enter the atmosphere. | Define | UNITED STATES | Texas |
| **Texas Clean Energy CCS Project (NowGen)** | Summit Power Group, Inc. is developing a 400 MW IGCC power plant capturing 2.7 million of tonnes per annum of carbon dioxide to be used for enhanced oil recovery in the Permian Basin in West Texas. | Define | UNITED STATES | Texas |
| **The Cash Creek Project** | The ERORA Group proposes to build a Hybrid IGCC project in Henderson County, Kentucky. It will produce about 565 MW as well as substitute natural gas. The plant will capture about 2.5 million tonnes per annum of carbon dioxide for enhanced oil recovery. | Evaluate | UNITED STATES | Kentucky |
| **The Collie South West Geosequestration Hub Project** | This project proposes to develop a transport and storage hub collecting carbon dioxide captured from various facilities in Western Australia. The project aims to store between 2.5 and 7.5 million tonnes per annum of carbon dioxide in saline formations. | Evaluate | AUSTRALIA | Western Australia |
| **The Compostilla Project** | This project uses oxyfuel and fluidised bed technology on a 30 MW pilot plant which will scale up to 300 MW. It has received funding from the European Energy Programme for Recovery (EEPR). | Define | SPAIN | Leon |
| **The Medicine Bow Project** | Medicine Bow Fuel and Power LLC proposes to build a green-field, coal-to-transport fuels plant that will produce up to 21,000 barrels of gasoline per day, and capture up to 3.6 million tonnes of carbon dioxide per annum for enhanced oil recovery. | Define | UNITED STATES | Wyoming |
| **TransAlta Project Pioneer** | This project will capture 1 million tonnes per annum of carbon dioxide from one of TransAlta's three local coal-fired power plants, using Alstom's chilled-ammonia process. The carbon dioxide will be used for enhanced oil recovery or sequestered locally. | Define | CANADA | Alberta |
| **ULCOS Florange** | The Ultra-Low-CO2-Steel (ULCOS) consortium proposes to build a prototype blast furnace that will be able to efficiently capture around 500,000 tonnes per annum of carbon dioxide from a steel plant. The CO2 will be stored in a deep saline formation. | Define | FRANCE | Moselle (Lorraine) |
| **Vattenfall Jänschwalde** | Vattenfall's Jänschwalde project will capture 1.7 million tonnes per annum of carbon dioxide using oxyfuel and post-combustion capture at a 3000 MW lignite-fired power plant. Storage options in the area are under investigation. | Define | GERMANY | Brandenbu rg |

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| 1.3 Mtpa | 1999 | Natural gas processing plants | Gas Processing | Pipeline | Not specified | Enhanced Oil Recovery | http://www.exxonmobil.com/ |
| 1 Mtpa | By 2020 | Coal to liquids plant | Pre-Combustion | Not Specified | 30-100 km | Deep Saline Formations | http://www.shenhuagroup.com.cn/english/ |
| 1 Mtpa | 1996 | Natural gas processing platform | Gas Processing | On Site | Minimal (capture same as | Deep Saline Formations | http://www.statoil.com/en/TechnologyInnovation/ProtectingTheEnvironment/CarboncaptureAndStorage/Pages/CarbonDioxideInjectionSleipnerVest.aspx |
| 0.7 Mtpa | 2007 | Natural gas processing platform | Gas Processing | Pipeline | 160 km | Deep Saline Formations | http://www.statoil.com/en/technologyinnovation/newenergy/co2management/pages/snohvit.aspx |
| 1.2 Mtpa | 2016 | Coal to fertiliser plant | Pre-Combustion | Pipeline | 100 km | Deep Saline Formations | http://www.coalnz.com/ |
| 1.2 Mtpa | 2014 | Natural gas processing plant | Gas Processing | Pipeline | 15 km | Deep Saline Formations | http://www.spectraenergy.com/our_responsibility/climate/carbon_capture/ |
| 1.4 Mtpa | 2015 | In-situ coal gasification (syngas) with 300 MW net combined cycle | Pre-Combustion | Pipeline | Not specified | Enhanced Oil Recovery | http://www.swanhills-synfuels.com/ |
| 3 Mtpa | 2015 | 680 MW petcoke IGCC power plant | Pre-Combustion | Pipeline | Not specified | Enhanced Oil Recovery | www.sweenygasification.com |
| 4.2 Mtpa | 2017 | Amine-based natural gas-fired power plant | Post-Combustion | Pipeline | 450 km | Enhanced Oil Recovery | http://www.tapco.ae/ |
| 1.9 Mtpa | 2015 | 716 MW gross hybrid IGCC coal power plant | Pre-Combustion | Pipeline | Not specified | Enhanced Oil Recovery | http://www.cleancoalillinois.com/tec.html |
| 5.75 Mtpa | 2016 | 600 MW net supercritical PC power plant | Post-Combustion | Pipeline | Not specified | Enhanced Oil Recovery | http://www.tenaskatrailblazer.com/ |
| 2.7 Mtpa | 2014 | 400 MW coal-fired IGCC power/ poly-generation plant | Pre-Combustion | Pipeline | 132 km | Enhanced Oil Recovery | http://texascleanenergyproject.com/ |
| 2.5 Mtpa | 2015 | 565 MW IGCC and 130 MSCF/day SNG gasifier | Pre-Combustion | Pipeline | Not specified | Enhanced Oil Recovery | http://www.erora.com/ |
| 2.5 Mtpa | 2015 | Various CO2 capture facilities | Pre-Combustion and Post-Combustion | Pipeline | 80 km | Deep Saline Formations | http://www.dmp.wa.gov.au/9525.aspx |
| 1.1 Mtpa | 2015 | 300 Mwe (Phase 2) coal-fired oxyfuel combustion power | Oxyfuel Combustion | Pipeline | 120 km | Deep Saline Formations | http://www.compostillaproject.es/ |
| 3.6 Mtpa | 2014 to 2015 | Coal-to-transport fuels (coal-to-liquids) plant | Pre-Combustion | Pipeline | Not specified | Enhanced Oil Recovery | http://www.dkrwadvancedfuels.com/ |
| 1 Mtpa | 2015 | 450 MW gross coal-fired power plant | Post-Combustion | Pipeline | 50 km | EOR or Geological | http://www.projectpioneer.ca/ |
| 0.5 Mtpa | 2015 | Steel plant | Post-Combustion | Pipeline | 100 km | Deep Saline Formations | http://www.ulcos.org/en/ |
| 1.7 Mtpa | 2015 | 300 MW equivalent (250 MW oxyfuel and 50 MW PCC) on a 3000 MW lignite-fired power plant | Oxyfuel combustion and Post-Combustion | Pipeline | 150 km | Deep Saline Formations | http://www.vattenfall.com/www/co2_en/co2_en/879177tbd/879231demon/879320demon/index.jsp |


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