carbon capture journal

July / August 2011 Issue 22

CIUDEN Spain's city of energy

IEA report on legal and regulatory progress

CO_2 capture from air

CO_2 pipeline structural safety

Alstom Power study concludes CCS is cost effective

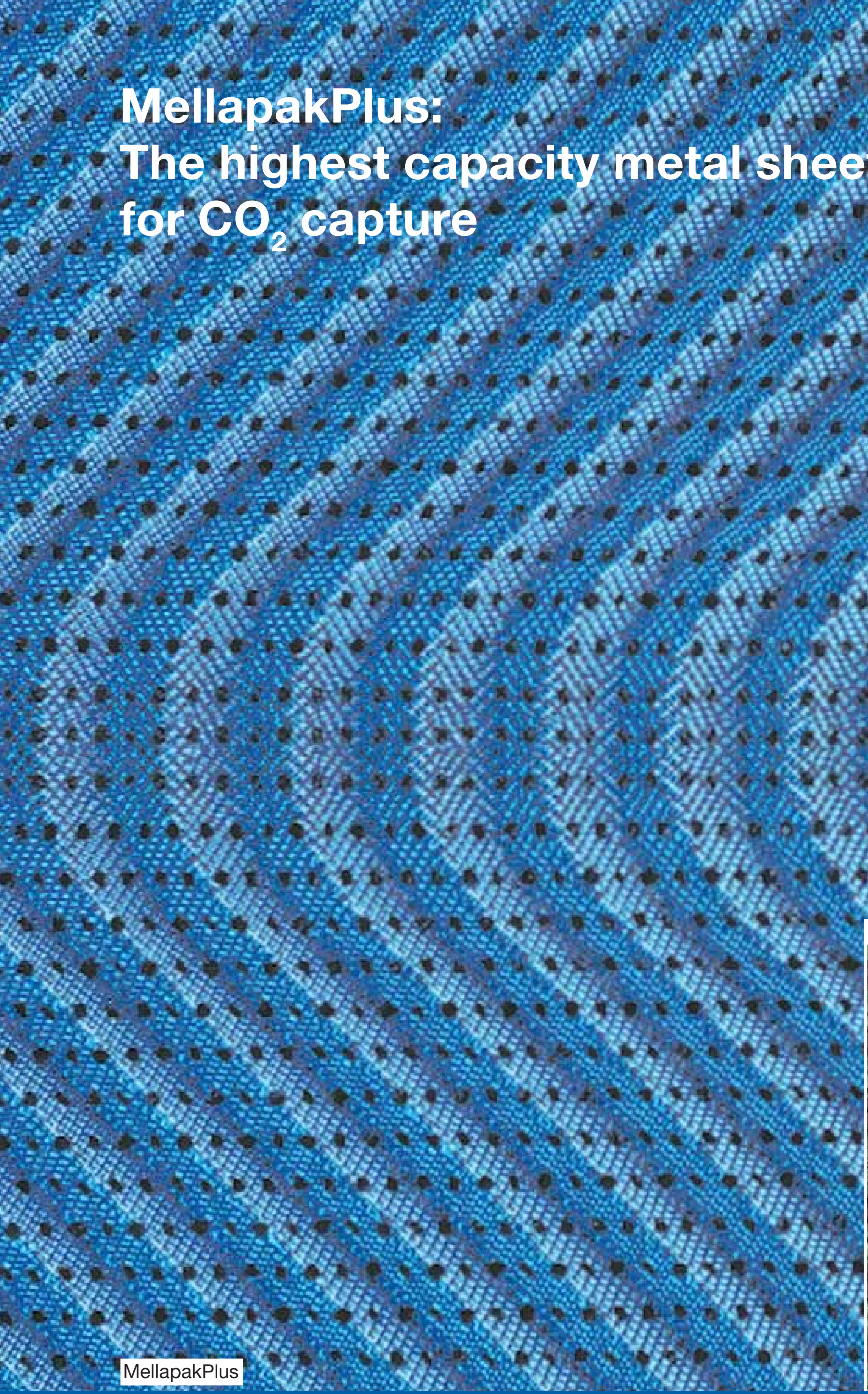
Report - six in ten Europeans want CCS in new coal power plants

UK Government electricity market reform

Carbon Management Canada funds 18 projects

New trials at Australian Otway project

MellapakPlus: The highest capacity metal sheet packing for CO_2 capture



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Front cover: CIUDEN's Technology Development Centre for CO2 Capture in Cubillos de Sil, Leon, Spain. The centre will be open for use by any company or institution wishing to conduct oxyfuel CO2 capture research there.

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CIUDEN - city of energy in Spain

CIUDEN is leading Spain's carbon capture and storage research efforts, with programmes covering the whole CCS chain, as well as founding a National Museum of Energy and collaborating with universities on post-graduate training.

CIUDEN, standing for city of energy, ciudad de la energia in Spanish, was founded five years ago to promote economic development through activities related to energy and the environment in the relatively poor region of El Beirzo in North West Spain. It is leading Spain's carbon capture and storage research efforts, with programmes covering the whole CCS chain, as well as founding a National Museum of Energy and collaborating with universities on post-graduate training.

The Technology Development Centre for CO2 Capture in Cubillos de Sil, Leon. The centre will be open for use by any company or institution wishing to conduct oxyfuel CO2 capture research

The El Bierzo region has long been associated with industries including coal mining and power production. The site of the CO2 capture technology development plant (TDP) in Cubillos del Sil is next to the oldest operating power station in Spain, Endesa's Compostilla II plant.

The TDP will be available for any institution to use. “Companies can come here and do their own R&D work,” explained Pedro Otero, CO2 Capture Programme Technical Director. “We are non-profit and we are not charging for the investment costs of the facility. Companies just pay for the running costs, the coal and other expenses. We will be very happy to host any company here, from Australia or wherever not just from within the EU.”

As a public institution, it also benefits from a closer relationship to the general population, and its efforts at public outreach seem to have met with far greater success than in some other countries, where large multinationals have received a relatively hostile reception.

Fernando Torrecilla, CIUDEN's Director of International Communication, boasts that the research facility, located only a few kilometres from the city of Ponferrada, is widely supported because of their outreach programmes. Only a few weeks before, they invited anyone from the area to come and take a look, and over one thousand people came and walked around the site.

The CO2 Capture Technology Development Plant

CIUDEN's installation is unique in that it is designed to be extremely flexible in the range of experiments that can be conducted. It is an oxyfuel combustion test bed, but it incorporates two separate boilers, one pulverized coal (PC) and the other circulating fluidized bed (CFB). It is also designed to use a range of different coals, with two hoppers that can take different types and be mixed to produce more variety. There is also a 3MW biomass gasifier.The aim is to test the flexibility of the boilers for oxy-combustion and CO2 capture with a range of different fuel types.

The PC boiler will operate up to 20MW while the CFB boiler will be up to 30MW in oxy-combustion mode.

The Technology Development Plant will allow research, development and innovation activities to be carried out in a number of relevant fields, namely:

1. Testing of the individual stages and the complete technological chain.

2. Evaluation and optimization of the design and operation of boilers.

3. Validation of tools for boiler design, dynamic simulation and performance prediction.

The experimental setup includes a 3MW biomass gasifier


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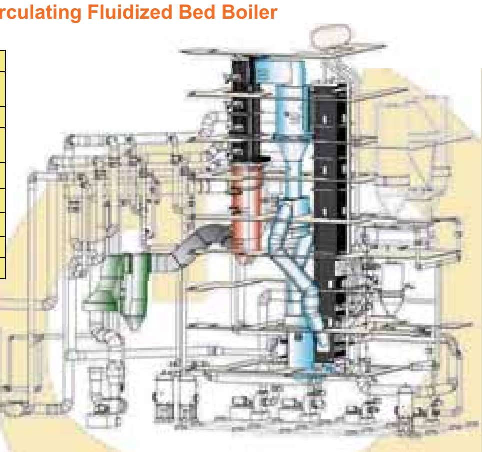
CIUDEN's
Pulverized Coal Boiler

Size (m)	24 x 7,6 x 4,5
Burners	4 horizontal burners 2 vertical burners
MWth PCS max oxycombustion mode	20
O_2 (kg/h)	6600
Recirculation gas flow (kg/h)	17900
Flue gas flow (kg/h)	26400
Coal flow rate (kg/h)	3350
Steam (t/h)	25
P(bar) / T (°C)	30 / 420

CIUDEN's
Circulating Fluidized Bed Boiler

Dimensions (m)	21x2,7x2,4
MWth SCP max oxy-combustion	30
O_2 (kg/h)	8775
Flue gas recycle (kg/h)	25532
Flue gas (kg/h)	28800
Coal feed (kg/h)	5469
Limestone feed (kg/h)	720
Steam (t/h)	44,6
P(bar) / T (°C)	30 / 250



4. Identification of the best combination of technologies for CO2 flow depuration for transport and storage.

5. Testing of start-up, shut-down and load follow-up routines, with special attention to the oxygen-related safety issues.

The aim is to first validate the full chain of processes from fuel preparation to CO2 purification, producing an stream ready for transport and storage, then produce data for scaling-up the PC, CFB, FGD (flue gas desulphurization) and CPU (compression and purification unit) technologies.

When I visited, Mr Otero and the rest of the staff had only just moved into the new purpose built centre, comprising control room, labs and offices, where engineers and technicians can all work together on the experimental programme.

Mr Otero is excited about the potential of the plant to conduct a broad range of experiments in a relatively short space of time.

"We have designed this plant for more than 20 years' life and we expect to be conducting many tests during the whole of this time," he said. "In the power plant next door we did experiments in an industrial installation with all the difficulties that entails. I worked there for over 30 years and in that time we conducted just a few experiments."

As a publicly funded project, the pilot had to go through a difficult procurement process for the different elements of the plant. Coordinating the over 30 suppliers has been one of the major challenges until now. Although the principal providers are large multi-nationals, many were small Spanish companies that were not always used to working with others on a large project.

Also the large technology providers were not always so keen to make time for what they saw as a small-scale project.

"This is a big project for experimentation but for a technology provider it is really a small project. Take for example the FGD unit. For this project it has a budget of say €4 million. For a full size power station such as Compostilla the cost would be €120 or €150 million. The engineering work to be done is the same for the small as the big one."

"We have been fortunate that our boiler technology provider Foster Wheeler is very committed to this project. They come here very often and we are developing a very good relationship with the Finnish people who are developing the basic and conceptual engineering and who will be in charge of the experimental programme for the CFB boiler."

"We are also developing a good relationship with Air Liquide, the CPU has been awarded by Esolux, a Spanish company, with Air Liquide as the technology provider."

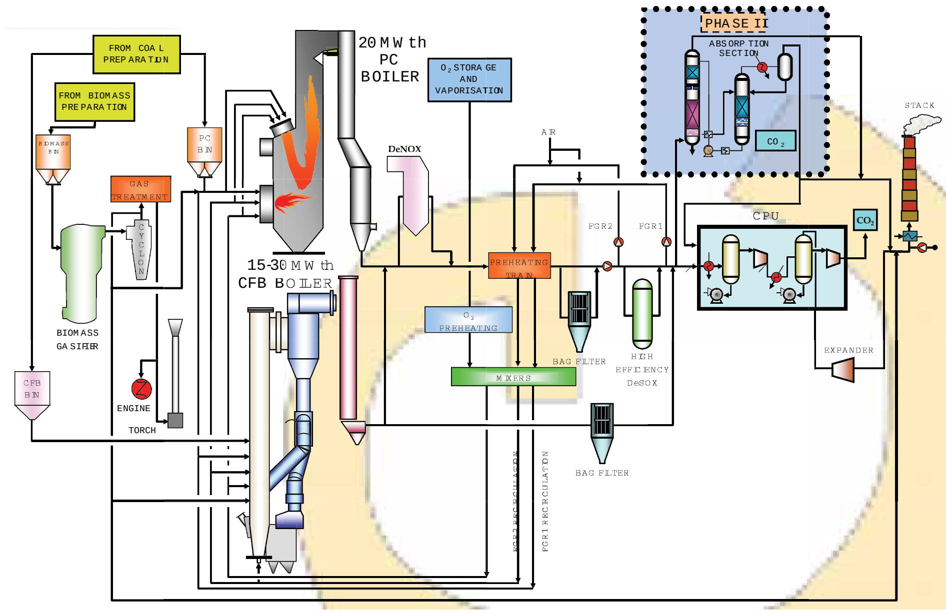
"I hope that both companies will be here for many days and many years, because our interests are the same, they also have to do some technology development and find new ways of purifying CO2 and we are here for that."

The plant will also be available to any company wishing to use it, not just those who have supplied the technology. "We expect to be the host of many companies willing to do R&D work here with our help."

Bringing together many people from different backgrounds and with different levels of experience makes the centre an ideal place for knowledge transfer.

"We have prepared the site with lost of infrastructure ready to be used, and we are assembling a very skilled team of operators. We have designed the training of those people in a very sensible way, mixing young people with more senior people, so we will be able to transfer knowledge to the younger people in a very short space of time."

"It is one of the aims of CIUDEN that the centre here will act as a training academy to prepare the next generation of engi-



Simplified process diagram of the technology development plant

neers in Spain with specific knowledge in the CCS field. We are working on a collaboration agreement with Leon University not just in CO_2 capture but over the whole CCS field."

"We intend to use this centre as a training centre for people coming from Spanish universities, from overseas universities and for professional development for working engineers and technicians so they can gain specific skills related with CCS and electrical generation in general."

"We will have some equipment here which will not yet be in operating power stations, such as the CO_2 capture and compression unit and it is only in places such as this that it will be possible to gain experience with operating it."

Knowledge gained from the pilot experiments will be shared with the CCS community, although CIUDEN has some specific agreements with technology providers that some developments will remain proprietary.

"We should be able to manage the two scenarios, knowledge-sharing as a requirement of the EU funding, and that some part of the developments made here will be the property of the technology providers. But at the end, all that knowledge goes to the market, and will be shared with the world."

"We will try to manage an equilibrium between programmes which are funded by CIUDEN with different research institutions and projects which are shared with different parties for which CIUDEN receives funding."

The site of the National Museum of Energy in the Compostilla I power station next to CIUDEN's office can be seen at the bottom of the picture, with the city of Ponferrada in the background

The Compostilla demonstration project

The current pilot installation will conduct Phase I experiments as part of the Compostilla OXYCFB300 project, which is one of the seven demonstrations funded through the EU Energy Programme for Recovery. As well as the capture TDP, transport and storage pilots are under way to test the full chain before progressing to a full scale demonstration in Phase II.

Phase 2 of the project is to build a full scale 300MW CFB demonstration plant on the same site. The final investment decision for the project will be made mid 2012, based on the knowledge and results obtained in the Phase 1 technology demonstrations.

National Museum of Energy

CIUDEN also manages a public education project which will become a National Museum of Energy (NME). It will be housed in three buildings including the former Compostilla I and MSP power stations. The Compostilla building will house the main visitor's area focused on universal energy concepts. The MSP complex will explain the extraction and use of coal for power generation. The Foundation has an ambitious goal of attracting 250,000 visitors to the site each year.

The first site, Ene.térmica, opened in July 2011 and will offer over 350 hours of activities free over the summer including guided tours, visits and workshops for children explaining the role of coal in energy-generation and energy in everyday life.

The NME is part of CIUDEN's public outreach agenda to educate and inform and thereby gain more support for its activities.

PISCO2 storage demonstration

Located near Burgos in the centre of Northern Spain, PISCO2 is a project to develop biomonitoring strategies of potential CO_2 leakages through testing biogeochemical effects of CO_2 injection in soils.

The test site for CO_2 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 CO_2 storage including Hontomín (Burgos), where CIUDEN's CO_2 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 CO_2 at different given flow rates. The facility will serve to test how small CO_2 diffuse leakages can influence the vegetation, microorganisms, lichens and soils and aims to find useful, cheap and ecological bio-indicators of any CO_2 concentration variation in wide areas.

It will also serve as a laboratory for agricultural tests of the beneficial effects of low CO_2 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.

The research team is comprised of a multidisciplinary group of researchers such as biologists, chemists, geologists and several collaborators. The work at the plant will consist of periodical sampling, continuous monitoring and modeling of CO_2 transport across various interfaces.

The EU has funded this project, of which costs of construction and first research phase are estimated at 1M€.

The results obtained will be applied to CIUDEN's CO_2 Storage site in Hontomín, Burgos (Spain) which is planned to be completely operational in early 2013.

More information

www.ciuden.es

IEA reports progress on CCS regulation

There has been visible progress in setting legal and regulatory frameworks for CCS according to a new report from the International Energy Agency.

By Justine Garrett and Sean McCoy, IEA Secretariat

The International Energy Agency (IEA) released the second edition of the IEA Carbon Capture and Storage Legal and Regulatory Review on 27 May 2011.

Produced bi-annually, the review provides an up-to-date snapshot of global CCS regulatory developments by gathering contributions by national and regional governments, as well as leading organisations engaged in CCS regulatory activities. The second edition of the review reflects ongoing progress at national and regional levels towards comprehensive CCS legal and regulatory frameworks.

Particular progress has been made in Europe, given the 25 June 2011 deadline for transposition of the EU CCS Directive.[1] Spain, France and the United Kingdom are among 11 of 27 EU member states to have formally communicated transposition measures to the Commission by this deadline. Work is ongoing in Germany, Poland, the Czech Republic, Ireland and Greece, amongst other countries. The European Commission has a number of enforcement powers that may be relevant where member states fail to communicate transposition measures in time.

In addition to these national transposition developments, the European Commission released four guidance documents on 31 March 2011, after an extended period of consultation. The documents, which are intended to assist national transposition measures, deal with risk management across the CCS chain, site characterisation, composition of the CO2 stream, monitoring and corrective measures, transfer of liability, financial security and financial contributions from operators.

The provisions on financial security and contributions have generated particular interest from industry and other CCS stakeholders. The Commission will also be verifying conformity of national measures with the directive as transposition measures are officially communicated to the European Commission.

Across the Atlantic, progress is also being made towards comprehensive legal and regulatory frameworks for CCS. In the United States, the Environmental Protection Agency (EPA) has finalised two federal rules related to geological storage, under the Safe Drinking Water Act[2] and the Clean Air Act.[3] Developments also continue at a state level: approximately a dozen states already have elements of frameworks in place to address geological storage.

In Canada, the provinces are leading the way, with Alberta being the first Canadian jurisdiction to finalise its regulatory framework. The province is embarking on a comprehensive review process to ensure that its regulations are fit for purpose as CCS demonstration efforts ramp up in the jurisdiction.

The Australian federal government has built on its significant work to date. In June, the government finalised secondary legislation to support dedicated legislation for offshore geological CO2 storage that it enacted in 2008. In addition, legislation is in place to regulate onshore geological storage in three Australian states, with developments in a further state progressing well.

Beyond the regions that have been at the forefront of CCS regulatory developments for some time, many other countries are implementing or considering CCS regulation, including Malaysia, South Africa, Vietnam, Mexico and Indonesia. Preparatory steps are being undertaken in these jurisdictions to set the stage for framework development over the coming years.

In addition to providing an update on national-level progress, the second edition of the CCS review addresses long-term liability for stored CO2, one of the key challenges facing countries in developing regulatory approaches to CCS, as its theme.

It also looks at: developments made by the international CCS community in advancing CCS deployment through amendments to international marine treaties and in the context of the UNFCCC framework, and the process behind developing CCS regulatory frameworks.

Long-term liability for stored CO2

Long-term liability for stored CO2 is one of the most challenging and complex aspects of regulating CO2 storage activities. In a CCS context, liability tends to be used as a generic term to refer to three specific responsibilities: general or civil law liabilities for damage to the environment, human health or third party property; responsibility for undertaking and bearing the cost of any corrective or remediation measures associated with a storage site; and responsibility for leakage of CO2 to the atmosphere, where CCS operations are undertaken as part of a CO2 emissions reduction scheme.

Discussion of long-term liability has generally focused on whether liabilities associated with a storage site should be transferred to government or retained by operators indefinitely. The second edition of the CCS review shows a trend towards transferring liability, with Australia, the European Union and some Australian, Canadian and US states and provinces taking this approach.

However, there is no clear consensus on whether liability should be transferred: some CCS regulation is silent on certain elements of long-term liability, which may mean that the operator or related entities are liable for a storage site and the injected CO2 in perpetuity.

Generally, where provision is made for transfer of liability from the operator three requirements are imposed before liability is transferred: evidence that there is no significant risk of stored CO2 leaking to the atmosphere or impacting other subsurface resources (e.g. groundwater or oil and gas resources); a minimum time period having elapsed from cessation of injection; and a financial contribution to fund long-term stewardship of the site, reducing the financial exposure of the entity designated to take on long-term liability.

The CCS review shows that there are marked differences between jurisdictions, however, on how these requirements are interpreted in legislation and the processes by which an operator can demonstrate that they have been met. The extent of the liability transfer and its timing also differs, with some jurisdictions transferring responsibility for certain types of liability, such as corrective or remediation measures, before liabilities arising under civil law, for example.

Some jurisdictions have also discussed

1 Directive 2009/31/EC of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide.

2 42 U.S.C. §300f et seq. (1974). Federal Requirements under the Underground Injection Control (UIC) Program for Carbon Dioxide (CO2) Geologic Sequestration Wells, Final Rule, 75 Fed. Reg. 77230 (Dec. 10, 2010).

3 Environmental Protection Agency, Mandatory Reporting of Greenhouse Gases: Injection and Geologic Sequestration of Carbon Dioxide, Final Rule, 75 Fed. Reg. 75060 (Dec. 1, 2010).

a transfer of responsibility for certain liabilities only up to a specified threshold. In practice, there is much to consider beyond the preliminary question of whether liability should be transferred. The second edition of the CCS review expands upon these issues with country-specific examples.

Talking process: how do you develop a CCS regulatory framework?

The contributions to the second edition of the CCS review not only demonstrate the significant progress that is being made towards developing national CCS legal and regulatory frameworks worldwide: they also provide interesting insights into the process involved in getting appropriate regulation in place. Jurisdictions implement CCS regulation in the context of different legal and regulatory environments and traditions, as well as existing resource extraction or environmental impact frameworks.

This means that it is difficult to come up with universal rules on how best to develop enabling frameworks for CCS. The second edition demonstrates, however, that there are common elements in the way jurisdictions are approaching the task. These trends may guide and inform national or regional governments that are setting out to develop regulation.

Steps in the regulatory development progress addressed in the second edition include: whether comprehensive CCS regulatory framework development should precede, run parallel with or come after pilot and demonstration projects; establishing interagency working groups to progress CCS framework development; undertaking "gap and barrier" analyses to determine how existing frameworks compare with the aims of future CCS regulation; and ensuring regulation is fit for purpose.

Developments on the international CCS scene: London, OSPAR and Cancun

The second edition also reports on a number of CCS developments in the context of international marine laws and climate change negotiations since the launch of CCS review.

The London Protocol was amended in 2009 to allow for cross-border transportation of CO2 for the purposes of storage. The amendment requires ratification by two-thirds of the contracting parties – effectively, 27 of the 40 countries that have ratified the London Protocol to date – to enter into force.

To date, only Norway has ratified the amendment to Article 6 and only one contribution to second edition of the CCS review – from the Netherlands – refers to plans to ratify the Article 6 amendment. Of the 40 contracting parties, only about 16 are currently pursuing CCS development and active in international CCS forums such as the Carbon Sequestration Leadership Forum, IEA Greenhouse Gas R&D Programme, Global CCS Institute and IEA.

Even within those contracting parties that are actively looking at CCS and engaged in international CCS dialogue, not all are interested in offshore CO2 storage or transboundary movement of CO2 for offshore storage, making ratification of the Article 6 amendment a low priority. Thus, achieving a further 25 of ratifications will be a significant challenge and is likely to require a concerted, international effort.

While the 2009 amendment is not in force, contracting parties will be constrained in their ability to co-operate on offshore storage. The second edition reports that further work is needed to understand the emissions profile and potential interest in CCS of the contracting parties to the London Protocol; likely applicability of transboundary CO2 transport for the purposes of offshore storage to each contracting party, either as an importer or exporter of CO2 emissions, and individual CCS projects globally; and potential impact on global CCS deployment if offshore storage continues to be restricted by Article 6.

In terms of the OSPAR Convention, Annexes II and III were amended in 2007 to enable CO2 injection into the sub-seabed under the Convention. The amendments must be ratified by at least seven parties before they will enter into force. Six have now ratified the amendments: Norway, the United Kingdom, the European Union, Germany, Luxemburg and Spain.

The meeting of OSPAR contracting parties in June 2011 will consider an update from those parties yet to ratify. The majority of these countries are well advanced with their ratification processes, including the Netherlands, which has introduced legislation for ratification of the OSPAR amendments into the senate, and it is therefore likely that the 2007 amendments will enter into force this year.

At the "COP 16" climate change negotiations in Cancun, Mexico, in November and December 2010, it was determined that CCS should be included as an eligible clean development mechanism (CDM) project activity, subject to specified issues being addressed and resolved in a satisfactory manner.

This is the most significant progress towards an international incentive mechanism for supporting CCS operations in developing countries over the past five years. The Cancun decision requests the Subsidiary Body for Scientific and Technological Advice (SBSTA) to elaborate modalities and procedures for the inclusion of CCS as a project activity under the CDM, with a view to recommending a decision at "COP 17" in Durban, South Africa, in November and December 2011.

The modalities and procedures are to address specified technical issues, including site selection criteria, monitoring, project boundaries, transboundary projects, accounting for project emissions, liability and risk and safety assessments. A dedicated work programme has been developed for 2011 to facilitate this process and although significant progress has been made, a substantial amount of work remains before CCS projects can realise funding through the CDM.

More information

The IEA Carbon Capture and Storage Legal and Regulatory Review is available on the IEA website at:
www.iea.org/ccs/legal/review.asp

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CCS legal and policy – July / August 2011

Calum Hughes, principal consultant in CCS regulation and policy at Yellow Wood Energy, discusses how CO_2 EOR projects fit with current UK and EU regulatory frameworks and whether they might benefit from state funding. Calumhughes@yellowwoodenergy.com

Until recently the matter of whether the economics of enhanced oil recovery (EOR) in the North Sea was sufficiently robust to provide a bankable revenue stream that could reliably be included in the business case of a CCS project seemed a largely academic, if much debated, one as EOR was not a feature of any of the CCS projects slated for the UK. Recent developments have, however, altered this situation and the question of how EOR projects might fit within CCS policy and regulatory frameworks, as well as how they might benefit from state funding, have become extremely relevant for the developers of both EOR and non-EOR CCS projects.

Whilst the Energy Act 2008 was wending its way through the legislative process there was much concern and, I believe, behind the scenes lobbying, on the issue of whether the prohibition on the storage of CO_2 beneath UK waters included in the Act, and the concomitant requirement that a storage site must be licensed, should apply where the storage was 'ancillary to the getting of petroleum' (i.e. should apply to EOR). A procrastinatory compromise was achieved via the inclusion of a carve-out provision in the Act to the effect that CO_2 injection for EOR shall only be considered as storage, for the purposes of the Act, in the circumstances as may be specified by Order of the Secretary of State.

Such Orders will presumably be used to address EOR projects on a case by case basis and it is uncertain what criteria will be applied in ascertaining which EOR projects will, and which will not, require a CO_2 storage licence and therefore which will be required to comply with the extensive monitoring, verification, post-closure and financial security conditions of such a licence. This places EOR CCS projects in a peculiar position and the current state, and application, of legislation raises some interesting issues.

Interaction with the CCS Directive

The CCS Directive is clear that Member States are obliged to ensure that no CO_2 storage site within their territory is operated without a storage permit and, under the UK's recent licensing regulations, a storage permit for a storage site in UK waters is obtained via a storage licence. It would therefore appear that the operation of an EOR site would breach the provisions of the CCS Directive if, and only if, the holder of a petroleum production licence who is injecting CO_2 for the purposes of EOR is doing so also with the intention of 'storing' the CO_2 and does not have a permit to do so. Adopting the purposive approach typically applied in EU law, this interpretation would appear to agree with the aims of the Directive as evidenced in the preamble, which states "where [EOR] is combined with geological storage of CO_2, the provisions of this Directive … should apply".

It would seem an obvious presumption, therefore, that in cases where an EOR project was also a CO_2 storage project (for the purposes of the CCS Directive), the Secretary of State would issue an Order providing that the activities at the site included storage (for the purposes of the Energy Act 2008), thereby requiring that site to be the subject of a storage licence. This is however only a presumption as there is no explicit requirement in the Act for the Secretary of State to behave in this way.

Furthermore, there is a question as to the definition of 'storage' for the purposes of the Directive? The Directive states that it establishes a legal framework for the environmentally safe geological storage of CO_2 and that the purpose of such storage is the "permanent containment of CO_2" but, the Directive includes no explicit definition of 'storage' or, for that matter 'permanent'.

ETS Exemption

It may be argued that the obvious pragmatic solution to the difficulty of ascertaining when an EOR project should be considered to be storing CO_2 might be to let the injection site operator elect whether the relevant site is a storage site or not and apply for the necessary licences accordingly. The making of this decision would be commercially driven as it would affect the EOR project's revenue streams.

A fundamental part of the value of CCS projects to CO_2 emitters is the saving realised by storing CO_2 and thereby avoiding the requirement to purchase and surrender allowances (EUAs) under the EU Emissions Trading Scheme (ETS). If an EOR project developer wishes to offer the emitter from whom it takes CO_2 the benefit of not having to surrender EUAs then it can acquire a CO_2 storage permit and accept the associated costs and obligations. Alternatively, the EOR developer can avoid the costs and obligations if it chooses not to offer the emitter the EUA savings.


Calum Hughes, Yellow Wood Energy

There are a number of counter-points to the case for letting developers decide how their project should be categorised but even putting these aside the above argument only holds if it is certain that emitters sending their CO_2 to a non-permitted EOR site would still be obliged to surrender EUAs for that CO_2. The ETS Directive was amended in 2009 to make it explicit that where CO_2 is stored in a storage site permitted in accordance with the CCS Directive then the liability to surrender EUAs, with respect to that CO_2, would not accrue.

There are however no explicit provisions clarifying the position with respect to EOR/CCS projects using non-permitted injection sites. It is clear that in the latter case an emitter would not benefit from the explicit exemption provisions but it is less clear whether that emitter could tenably claim that as the CO_2 it had sent for EOR injection had not, in fact, been 'released into the atmosphere', as is required under the ETS Directive for the liability to surrender EUAs to accrue, that it had no such liability.

So, the purposive intent of EU law with regard to permitted EOR sites is reasonably clear but in the case of non-permitted sites the situation is more vague.

Requirement for a Crown Lease?

Property rights respecting the sea bed and subsoil beneath waters extending beyond a States' territorial boundaries are secured under international maritime law. In the UK, those rights have been claimed for the Crown by Act of Parliament. The rights with respect to the getting of hydrocarbons are licensable by the Secretary of State and, whilst those appertaining to the storage of gases are also licensable by the Secretary of State, the 'land' itself is placed within the auspices of The Crown Estate. The

point of interest this raises is, if the activity in question is both the getting of hydrocarbon and the storage of gases, what property rights are required to inject CO2 beneath the sea-bed and store it there indefinitely and who may grant them.

Many precedents exist with respect to the re-injection of natural gas into hydrocarbon reservoirs for the purpose of maximising extraction of reserves and, I understand, a number of existing petroleum production licences authorise the injection of CO2 for this purpose. Nevertheless the question remains as to whether the storage of CO2 in the sub-soil below UK waters under a petroleum production licence is permissible without a lease granted by The Crown Estate and if so, under what powers is the right to store granted and who has ownership of, and liability for, the injected CO2 going forward?

There are several other interesting legal issues surrounding EOR CCS projects which there is not space to consider here, not least if such projects will benefit from the various state financial support schemes available to CCS projects if a CO2 storage licence and Crown Lease is not obtained; most of these issues, including the three discussed above, hinge partly or entirely upon what 'storage' means within the context of EOR under EU and UK law. Pinning down the definition of the term within this context would be a challenging task but the lack of such a definition introduces further regulatory uncertainty into an industry which already has more than its fair share.

6 in 10 Europeans wants CCS for new coal

The European Commission has published a special Eurobarometer report about public awareness of CCS in 12 EU member states. Public knowledge is still generally low, but a higher proportion thought that CCS is effective to combat climate change, than those who did not. Also, 60 % said that CCS should be compulsory in new coal power plant. By Niklas Kalvø Tessem, Bellona

The International Energy Agency estimates that the cost of achieving desired climate change stabilisation by 2050 will be at least 70 % higher if CCS is not available and widely deployed after 2020. Still, public knowledge of CCS is limited.

The fact that CCS is a complicated issue makes it less known than energy efficiency and renewable energy measures. 13,091 respondents in twelve EU member states were interviewed between February 9th and March 5th 2011 about their awareness and acceptance of CCS.

Here are some of the most interesting findings:

Awareness of CCS technology

Whilst over a quarter of respondents indicated that they had heard of CCS, only one in ten (10%) said they also knew what it was. One in five (18%) indicated that they had heard of it but did not really know what it was. The majority, over two thirds (67%), had not heard of CCS.

Awareness of the specific CCS projects

Within individual countries there were some small variances to the overall figures, the exception being in the Netherlands, where more than a third (35%) had heard of the EU co-financed CCS project in Rotterdam. in comparison, fewer than one in ten had heard about a specific CCS project in Germany (9%), Italy (9%), Poland (8%) and the UK (5%). Only 2% of Spanish people had heard of such a project.

Opinions about the CCS technology

A high proportion of people 'do not know' whether CCS technology is effective in the fight against climate change, but a higher proportion thought that it is effective (39%) than those who did not (25%).

Nearly four in ten people felt that CCS could be effective in the fight against climate change. A third (33%) felt CCS technology could be 'fairly effective', while a further one out of every sixteen (6%) believed it could be 'very effective'.

A quarter of respondents thought that it would not be effective in fighting climate change, around one in fourteen (7%) thought that CCS was 'not at all effective' in fighting climate change, while just under a fifth (18%) thought it was 'not very effective'. However, well over a third (36%) said that they 'did not know' whether CCS technology could be effective or not to fight climate change.

Benefits from CCS technology

People were unclear about the benefits of CCS technology. Overall a higher proportion thought that they would not benefit from CCS technology (38%) than thought they would benefit from it (23%).

The main reason why people thought they would benefit from CCS technology was 'an improvement of air quality'. The main reason people thought they would not benefit was that it would 'not have a positive effect on the environment'

Opinions about the safety of CO2 storage

Respondents in each country were asked how concerned they would be if a deep underground storage site for CO2 were to be located within 5km of their home. Overall around six in ten people (61%) expressed some concern about the safety of CO2 storage. Just under a quarter were 'very concerned' about it. The two main concerns people had about CO2 storage were 'effects on the environment and health' and the 'risk of leaks while the site was in operation'

Best options for storing CO2

Public opinion was almost evenly divided about the best ways to store captured CO2 emissions: under the seabed, in areas of low population density and near the facility that produced the emissions.

Sources of information about CCS

Overall, universities and research institutions emerged as the organisations that the highest proportion of respondents trusted in terms of providing them with information about CCS (45%). Just under a third (31%) indicated that they trusted NGOs whilst just under a quarter trusted journalists (24%) and a similar proportion (23%) trusted regional and local authorities. One in five (20%) indicated that they trusted their national government. Just over one in eight trusted The European Union (14%), energy companies (13%) or friends and family (13%).

Future developments in the energy sector and the role of CCS

Six in ten people (60%) agreed that CCS should be compulsory for the building of new coal-fired power plants. Over half (55%) agreed that CO2 represents a safety risk for the future.

Download the report at:
ec.europa.eu/energy/coal/sustainable_coal/ccs_eurobarometer_en.htm

UK Government electricity market reform

The UK Secretary of State for Energy and Climate Change Chris Huhne has outlined plans for reform of the UK electricity market, including feed-in tariffs and an emissions performance standard.

Building on the Carbon Price Floor announced in the Budget, he talked about a number of steps aimed at supporting low carbon electricity generation.

Key elements of the reform package include:

- a Carbon Price Floor (announced in Budget 2011) aimed at reducing investor uncertainty, putting a fair price on carbon and providing a stronger incentive to invest in low-carbon generation now;

- the introduction of new long-term contracts (Feed-in Tariff with Contracts for Difference) to provide stable financial incentives to invest in all forms of low-carbon electricity generation. A contract for difference approach has been chosen over a less cost-effective premium feed-in tariff;

- an Emissions Performance Standard (EPS) set at 450g CO2/kWh to reinforce the requirement that no new coal-fired power stations are built without CCS, but also to ensure necessary short-term investment in gas can take place; and

- a Capacity Mechanism, including demand response as well as generation, which is needed to ensure future security of electricity supply. The government is seeking further views on the type of mechanism required and will report on this around the turn of the year.

"We will send a clearer message that low-carbon electricity is a key part of our future energy mix," said Mr Huhne.

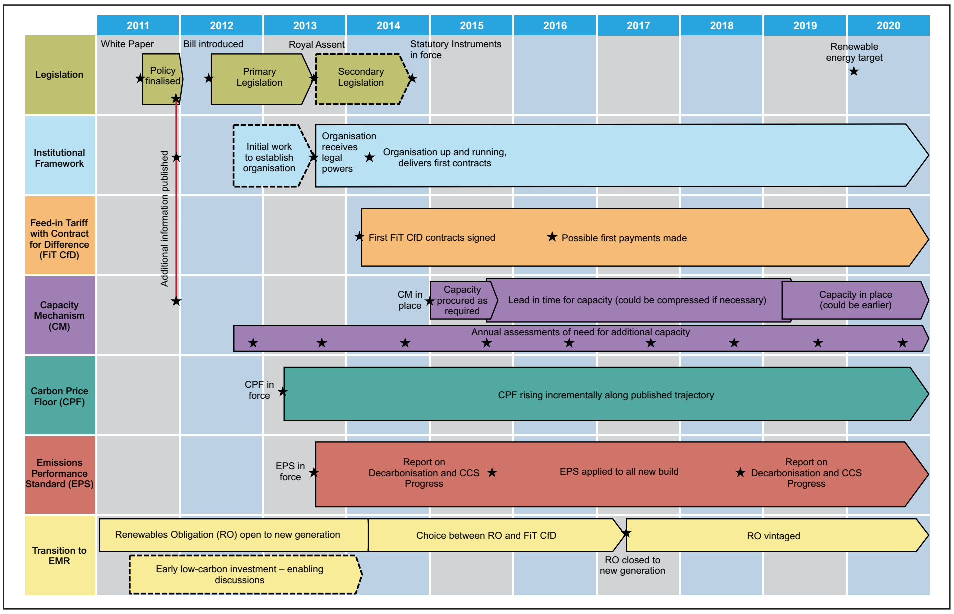
"We will introduce a new system of long-term contracts, to remove uncertainty for both investors and consumers, and make low-carbon energy more attractive."

"Contracts for Difference will be introduced for all forms of low-carbon generation. Lowering the cost of capital, and allowing clean technologies with high-up front and low long-run costs to compete fairly against traditional unabated fossil fuels."

"This will build on the Carbon Price Floor, providing the additional clarity and certainty that investors need."

"We will introduce an Emissions Performance Standard, to send a clear regulatory signal on the amount of carbon new fossil-fuel power stations can emit."

"This will reinforce the requirement that no new coal-fired power stations are built without carbon capture and storage, while ensuring that vital investment in gas can take place."



An indicative timetable for implementation and transition

"CCS is a key part of our plan to decarbonise electricity generation. It is the only technology that can potentially reduce emissions from fossil fuel-fired power stations by as much as 90%."

The Carbon Capture and Storage Association (CCSA) has welcomed the publication of the Electricity Market Reform (EMR) White Paper.

Jeff Chapman, Chief Executive of the CCSA commented:

“A Contract for Difference Feed in Tariff, index-linked to fuel price, is the right mechanism to support CCS now and into the future, and we would welcome this mechanism as part of the EMR package.

“The CCSA estimates that at least 20-30GW of fossil-fuel power generation capacity fitted with CO2 capture and storage will need to be installed to meet the UK’s aim of largely decarbonising its power sector by 2030.

“Delivering that amount of CCS capacity by 2030 is challenging but achievable and industry will rely on this mechanism to deliver a bankable incentive. The White Paper establishes the world’s first support mechanism for all low carbon technologies that enables CCS to be deployed on a par with other options.

“This represents a tremendous step forward, sends the right signal to industry that this Government is serious about CCS and could give the UK a technological leadership in what will be a massive future global CCS market.

”We recognise that the Government’s objective to achieve a decarbonised power sector by 2030 will put additional cost on hard pressed consumers but including CCS in the EMR will be the most cost-effective way to address climate change and so will effectively save on electricity bills.

“We need to get UK CCS projects under way as quickly as possible and so we are pleased to see that the arrangements detailed in the White Paper may be applied to the coming four CCS Demonstration Projects, to ensure a smooth transition into deployment of CCS under the EMR.

“The CCSA also believes that the White Paper provides the framework necessary for the implementation of CCS beyond the four Demonstration Projects which will be required if we are to meet UK and international targets on climate change.

“We welcome the statement in the White Paper that Government will support cost-effective and flexible low carbon power generation, including CCS - recognising the need for the introduction of a market based capacity payment.”

Download the white paper at:
www.decc.gov.uk

Carbon Management Canada funds projects

Carbon Management Canada (CMC-NCE) is funding 18 new projects for a total of $10 million.

CMC-NCE is a Canadian Network of Centres of Excellence that supports game-changing research to eliminate carbon emissions from the upstream fossil energy industry. The network comprises over 140 researchers across 25 universities and colleges in Canada.

Projects funded in Round 2 range from work toward developing what could become the world's first zero-emission solid oxide fuel cell, to research seeking a way to convert CO2 into water and methanol (see below), to an investigation into public attitudes toward greenhouse gas mitigation strategies.

The largest award, $1.92 million, was given to a project to coax communities of microorganisms to convert coal into natural gas, or methane, while still in the ground. The methane produced from bioconversion would then be collected for use as a clean-burning fuel.

This project, led by Dr. Sushanta Mitra at the University of Alberta, exemplifies CMC-NCE's emphasis on funding interdisciplinary, multi-institution projects. The 15 principal investigators on the project are from four universities, plus government and industry. Researchers represent disciplines ranging from biology to hydrology to geosciences, and both mechanical and chemical engineering.

Dr. Steve Larter, CMC-NCE scientific director and a researcher on the project, notes the interdisciplinary approach is critical to the project's success.

"The problems can't be solved by a really good geochemist, or just a really good microbiologist, or just a very good engineer. We're trying to build an orchestra."

This round of funding increases the number of CMC-NCE supported research projects from 18 to 36. Last year, $8.7 million was awarded to 17 projects.

Viola Birss, Canada Research Chair in Electrochemistry of Materials at the University of Calgary, is part of a team working to develop what could become the world's first zero-emissions solid oxide fuel cell. The research project is funded by Carbon Management Canada
Photo: Riley Brandt, University of Calgary

Turning CO2 into liquid fuel

U of T chemists Douglas Stephan and Eugenia Kumacheva are laying the foundation for an efficient and cost-effective method to transform CO2 and hydrogen into water and methanol, a liquid fuel. The ultimate goal is an energy-generation system that would be carbon neutral, with every CO2 molecule released from fuel consumption being converted back into methanol.

The research project is fueled by a $268 thousand grant from Carbon Management Canada through its Round 2 funding.

"The CMC funding is giving us an opportunity to explore chemistry that relates to one of the biggest problems facing humankind," said Stephan.

Methanol, or methyl hydrate, is the same clean-burning fuel that's used to heat a fondue pot. A liquid, methanol is relatively easy to store and transport, even with existing delivery systems—gas station pumps, for example.

"The big problem with new possible fuels is the infrastructure for transportation," commented Stephan.

The unprecedented approach to CO2 capture and reuse builds on his group's breakthrough discovery of a new way to capture and use CO2, research that has been supported in part by NSERC and the green chemistry commercialization body, GreenCentre Canada.

"It's really incredibly simple chemistry that we've discovered," said Stephan. "We generate this new reactivity that we've been able to observe with CO2 and a variety of other small molecules."

To carry out the process, chemical reagents dubbed "frustrated Lewis pairs" are used to effect these new chemical reactions. Extremely effective and versatile, the frustrated Lewis pairs are also nontoxic—unlike conventional catalysts employed to convert CO2 to methanol.

"Now the question is," said Stephan, "can we tweak the system? Optimize the system?"

"If we could do this catalytically," he explained, "…so that you could use a very small amount of our catalyst…to grab CO2, transform it to methanol, release it, and then go back and do it again…you really bring down the cost of the process."

Another challenge is that the reactions happen so quickly, it is difficult to study them. However, a new technique developed in the Kumacheva lab is making it easier to obtain the needed data.

Along with a clean source of hydrogen—a technology that Stephan noted is imminent—the team hopes that the CO2 to methanol system will one day revolutionize the fuel sector.

"New chemistry is going to be part of the solution to environmental issues," said Stephan, adding "it's not widely recognized just how much chemistry goes into just about every solution to any problem."

For more information and a full list of the projects go to:
www.cmc-nce.ca

Policy, company and regulation news

Alstom Power study "CCS is cost effective"

www.alstom.com/power

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

The cost of electricity generated in a coal-burning power plant with CCS equipment, which will be available at a commercial scale in 2015 and will allow to capture 90% of the emitted CO2, will be between 6.5 and 8.5 eurocents/kWh depending on the fuel and location, says an Alstom study.

This cost is already competitive against power coming from renewable energy sources, while it will improve over the years as the CCS technology matures. The same conclusion applies for a gas-burning power plant using CCS.

After 10 years of development, CCS technology is on the point of large-scale deployment, Mr joubert said. A new global market is opening up, from which Europe is well positioned to benefit given its technological lead, the steps taken to put in place a regulatory framework and the decisions made to incentivize CCS deployment through the financing of large demonstration plants.

Philippe Joubert added, "This is a decisive moment for players in the European energy field, in industry or in policy-making, if they want to actively position themselves as leaders on the world stage for this field of decarbonised fossil fuels, where there is considerable potential."

Alstom has long maintained that all solutions to reduce emissions, while generating the power needed for economic development and social welfare, will be necessary to tackle climate change: increasing the use of all renewable forms of energy, improving the efficiency of fossil power generation on both new and existing plants, and developing carbon capture and storage (CCS).

Over half of the world's electricity will still be produced from fossil fuels in 2035, and CCS is currently the only valid solution for drastically reducing emissions from fossil fuel generation. The application of CCS to both coal-fired and gas-fired power stations and to industry is essential, as this technology could account for up to 20 percent of the required emissions reduction by the year 2050, according to the International Energy Agency (IEA), said Mr Joubert.

SaskPower's Boundary Dam power plant (Image: Wtshymanski at en.wikipedia)

Cansolv Boundary Dam project begins construction

www.cansolv.com

Cansolv Technologies Inc., a subsidiary of Shell, has received approval for construction of its integrated carbon and sulphur capture system at Boundary Dam power station in Saskatchewan, Canada.

The approval for construction was granted by the Saskatchewan provincial government. Saskatchewan Power Corporation (SaskPower) is leading the development of the Boundary Dam Integrated Carbon Capture and Storage Demonstration Project in Estevan, Saskatchewan.

The project will fully integrate and rebuild an aging lignite coal-fired unit to reach a capacity of 150 megawatts (MW), with the captured CO2 being used for enhanced oil recovery (EOR) to increase production in nearby fields and the SO2 being used as a key feedstock for the local fertilizer industry.

"As the first commercial scale project to get this type of investment, this is a highly significant vote of confidence by the Saskatchewan government and SaskPower that our technology offering is solid and competitive," said Steve Bryce, President of Cansolv. "This Cansolv first is expected to capture about one million tonnes of CO2 annually, and we are delighted to be part of Saskatchewan's journey to a lower CO2 energy system. We look forward to participating in more programmes of this type around the world."

"We're pleased to be working with private sector partners like Cansolv on an innovative project that will lead to a more secure energy future and a cleaner environment," added Robert Watson, SaskPower President and Chief Executive Officer. "This project will help determine whether we can continue to operate our three coal-fired power stations in a cost effective and environmentally sustainable manner."

The Cansolv-patented technology is a flexible system that uses regenerable amines to capture CO2 and SO2. It is applicable to a broad range of industrial applications in addition to power plant flue gases. SNC-Lavalin Inc. will be in charge of the construction of the system at Boundary Dam.

Construction was started immediately following government approvals, and operations are planned to commence in 2014.

Funding agreed for Shell Quest Project

www.shell.ca

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

The Quest Project will capture and permanently store underground more than one million tonnes of CO2 per year from Shell's Scotford Upgrader near Edmonton, Alberta, which processes heavy oil from the Athabas-

ca oil sands.

"Quest would be the first application of CCS technology for an oil sands upgrading operation," said John Abbott, Shell's Executive Vice President of Heavy Oil. "Not only would it allow us to significantly reduce the carbon footprint of our oil sands operation here in Alberta, but it will contribute to the global knowledge that will help to get other CCS projects up and running more quickly."

Shell says it aims to be a leader in continuously improving its oil sands environmental performance, through CO2 reduction, improved water management and minimizing the impacts of tailings ponds.

A number of innovative technological solutions, including CCS, will be required to achieve that goal.

"By continuing to move CCS technology forward, Alberta is demonstrating its ongoing leadership in realizing the commercial-scale deployment of this technology and greening our energy production," said Alberta Premier Ed Stelmach.

The signing of the funding agreement was announced today as part of an event marking the earlier start-up of Shell's 100,000-barrel-per-day expansion of its Athabasca Oil Sands Project (AOSP), bringing total capacity to 255,000 barrels per day. The AOSP includes the Muskeg River Mine, Jackpine Mine and Scotford Upgrader.

Regulatory applications for the Quest Project were submitted in November 2010. The signing of the funding agreements represents another important milestone prior to Shell taking a financial investment decision in 2012, subject to the outcome of the regulatory process and economic feasibility.

With CO2 injection planned for 2015, the Quest Project would join a handful of CCS projects around the world that are injecting CO2 at a commercial scale. Shell is working with governments and other experts globally on both political and technical levels to facilitate the development and wide-scale deployment of CCS and is involved in progressing a number of projects around the world, across a wide range of sectors.

The Quest Project is being advanced on behalf of the AOSP, a joint venture among Shell Canada (60 per cent) Chevron Canada Limited (20 per cent) and Marathon Oil Canada Corporation (20 per cent).

Three European research institutes form CCS alliance

www.sintef.no

The research institutes SINTEF in Norway, TNO in the Netherlands and IFP Energies nouvelles (IFPEN) in France are joining forces in the newly established "Tri4CCS Alliance".

Tri4CCS aims to make the capture, transport and storage of CO2 (CCS) safer and more cost-effective.

The three institutes are supporting the efforts of energy utilities, equipment suppliers and authorities via their research and innovation efforts related to CCS - i.e. the future capture, transport and underground storage of CO2 from fossil-fuelled power stations and process industry.

The three institutes employ a total of 450 scientists in these fields, with a R&D portfolio in CCS of some €60 million a year.

"As a group, we are large enough to tackle the scientific challenges that will emerge when in the course of a few years Europe commissions its planned demonstration and full-scale CCS plants," says alliance spokesman Dr. Nils A. Røkke, Vice President Climate Technologies, SINTEF.

Røkke points to the International Energy Agency's estimate that energy conservation and renewable energy alone will not be enough to prevent a global temperature rise of more than two degrees Celsius.

"The IEA makes it perfectly clear that CCS will be an important weapon in the armoury we need to win the climate fight. But there are still many challenges ahead of us before CCS will be a feasible technology, and it is in this perspective that the establishment of the "Tri4CCS Alliance" will make a difference," says Dr. Røkke.

According to Dr. Røkke, the expertise of the alliance will be of particular importance as a means of ensuring that carbon capture plants will be environmentally friendly and as cost-effective as possible, and just as important when it comes to monitoring the stored CO2.

"Research results will play a decisive role in gaining the public's acceptance for underground storage of CO2, and there too, the work of the alliance will be important," says Dr. Røkke.

Each of the three partners in the alliance operates important laboratory and test facilities.

"All in all, these facilities are a major asset as we integrate our R&D efforts in CCS," says Dr. Røkke.

The facilities cover all main elements in the CCS chain.

The alliance members are participating in follow-up projects on full-scale CO2 storage from the Sleipner and Snøhvit gas fields off the coast of Norway, and the onshore CO2 storage projects of In Salah in Algeria and Lacq in France.

"The alliance as a group knows a great deal about the "storage geology" of several geographical regions. With this knowledge, we can offer our services in many parts of the world," says Røkke.

"The TRI4CCS Alliance is based on a shared vision of the development of carbon capture and storage technology. IFPEN, SINTEF and TNO have joined forces to deliver more rapidly the technologies needed for worldwide deployment of CCS. I really appreciate the trustful and constructive relationship among the three of us and I am confident in the strength of our alliance," says Pascal Barthélemy, IFPEN Executive Vice-President.

Brad Page, CEO of the Global CCS Institute

Global CCS Institute Appoints CEO

www.globalccsinstitute.com

Brad Page has been appointed Chief Executive Officer of the Global CCS Institute. He will take up the position during August 2011.

Page comes to the Institute from the Energy Supply Association of Australia (ESAA) where he has been CEO for the past 7 years. During this time he has become an authoritative spokesperson for the electricity and downstream natural gas industries. He has also been an active member of the Australian Government Business Roundtable on Climate Change; the CSIRO Energy Transformed Flagship Advisory Committee; the Australian Government Energy White Paper High-Level Consultative Committee; and has Chaired the CSIRO Energy and Transport Sector Advisory Council.

Before joining the ESAA, Page has led a successful career in the public service where he has filled senior appointments since 1997. These positions include, General Manager of Innovation Programs at AusIndustry; Head of Secretariat at the Council of Australian Government (COAG) Energy Market Review; Director of Industry Policy

and Regulation in the Australian Capital Territory (ACT) Government Department of Urban Services; and Manager of Electricity Reform in the Australian Department of Industry, Science and Resources.

During his career Page has worked extensively with governments and industry in the United States, Japan, the United Kingdom and Europe in relation to energy and climate change.

In 2009, Page was awarded the British Council, Chevening Fellowship to study the economics of climate change at Cambridge University.

The updated US National Carbon Sequestration Database and Geographic Information System (NATCARB) website offers key CCS information in a graphical format

AEP cancels CCS demo plans at Mountaineer plant

www.aep.com

American Electric Power is terminating its cooperative agreement with the U.S. Department of Energy and placing its CCS plans on hold, citing the current uncertain status of U.S. climate policy and the continued weak economy as contributors to the decision.

"We are placing the project on hold until economic and policy conditions create a viable path forward," said Michael G. Morris, AEP chairman and chief executive officer. "With the help of Alstom, the Department of Energy and other partners, we have advanced CCS technology more than any other power generator with our successful two-year project to validate the technology. But at this time it doesn't make economic sense to continue work on the commercial-scale CCS project beyond the current engineering phase.

"We are clearly in a classic 'which comes first?' situation," Morris said. "The commercialization of this technology is vital if owners of coal-fueled generation are to comply with potential future climate regulations without prematurely retiring efficient, cost-effective generating capacity. But as a regulated utility, it is impossible to gain regulatory approval to recover our share of the costs for validating and deploying the technology without federal requirements to reduce greenhouse gas emissions already in place. The uncertainty also makes it difficult to attract partners to help fund the industry's share."

In 2009, AEP was selected by the Department of Energy (DOE) to receive funding of up to $334 million through the Clean Coal Power Initiative to pay part of the costs for installation of a commercial-scale CCS system at AEP's Mountaineer coal-fueled power plant in New Haven, W.Va. The system would capture at least 90 percent of the carbon dioxide (CO_2) from 235 megawatts of the plant's 1,300 megawatts of capacity. The captured CO_2, approximately 1.5 million metric tons per year, would be treated and compressed, then injected into suitable geologic formations for permanent storage approximately 1.5 miles below the surface.

Plans were for the project to be completed in four phases, with the system to begin commercial operation in 2015. AEP has informed the DOE that it will complete the first phase of the project (front-end engineering and design, development of an environmental impact statement and development of a detailed Phase II and Phase III schedule) but will not move to the second phase.

US NATCARB CCS website updated

www.natcarbviewer.com

An updated and redesigned National Carbon Sequestration Database and Geographic Information System (NATCARB) website offers key CCS information.

NATCARB is an interactive virtual encyclopedia of CCS information, including locations and information on field projects, a map of all publically announced worldwide CCS projects and their status; and the complete latest edition of NETL's assessment of carbon storage resource potential in the United States and portions of Canada.

The updated site integrates new features and was specifically designed to make it easily accessible for public viewing and use. Among the highlights presented in a tabbed format:

- Location and links to CCS projects undertaken by the Energy Department's seven Regional Carbon Sequestration Partnerships (RCSPs). The partnerships form a nationwide network that is determining the most suitable technologies, regulations, and infrastructure for CCS deployment in different areas of the United States and portions of Canada.

- An interactive version of data contained in the 2010 Carbon Sequestration of the United States and Canada – Third Edition. Released in November 2010, this edition among other things documents up to 5,700 years of carbon storage resource potential in the United States and portions of Canada. The layers in the NATCARB viewer show the unmineable coal areas, oil and gas reservoirs, saline formations, and sedimentary basins that provide this storage potential, as well as the locations of CO_2 stationary sources.

- The locations of small- and large-scale CCS field projects with links for more information, including the 10 site characterization projects funded by the Department of Energy as part of the Recovery Act. CCS field projects are designed to demonstrate that geologic formations in the United States and Canada have the capability to store thousands of years of CO_2 emissions and confirm that CO_2 capture, transportation, and injection can be achieved safely, permanently, and economically.

- A user-friendly world map with pinpoints for all publically announced CCS projects and their status. Clicking on a point in the Worldwide Carbon Capture and Storage (WCCS) database provides a link for more information about a project. This database is also available as a Google Earth layer on NETL's website.

NATCARB was created by NETL with input from the seven RCSPs in the Carbon Sequestration Program. The information contained in NATCARB is current as of March 31, 2011, and will be updated quarterly as changes occur.

Capturing CO2 from the air

In the search for potential approaches to tackle climate change policy makers have to-date largely ignored the contribution that could be made from the implementation of methods that directly extract greenhouse gases (GHGs), particularly carbon dioxide (CO2), from the atmosphere. This article examines the role that such an approach, known as air capture, can play in tackling the challenge of global warming and makes recommendations for climate change policy developments in this area.

Dr Tim Fox, Institution of Mechanical Engineers

At the core of international climate change mitigation policy is the notion that a global legally binding emissions reduction agreement can be reached, which in the case of CO2 would drive worldwide carbon pricing to incentivise investment in low-carbon technologies and behaviours.

Through this approach it is hoped that global mean temperature rise will be kept below the 2°C threshold that many in the science community tell us is necessary to avoid dangerous climate change.

There is however growing recognition that this approach is not producing the necessary action on the required timescale and in the meantime global emissions continue to rise. It is therefore important that policy makers seek ways of accelerating emissions reduction while simultaneously utilizing the full range of mitigation approaches available to them.

Climate change mitigation policy worldwide in relation to CO2 is based on three commonly accepted methods for reducing the accumulation of emissions in the atmosphere. These are:

1. Reduce demand for CO2 emitting energy and processes through energy conservation, increased energy efficiency and behavioural change;

2. Substitute technologies characterised by lower CO2 emission levels in place of carbon-intensive industrial processes and energy sources;

3. Capture the CO2 emitted from power generation and other industrial processes utilising fossil fuels and sequestrate the gas by storing it in suitable underground geologies; carbon capture and storage (CCS).

These approaches are however missing a mitigation opportunity, as they do not allow for the contribution that could be made by the removal of CO2 directly from the atmosphere.

This method, known as air capture, can be achieved through a number of technologies (McGlashan, Shah & Workman 2010) including air capture machines.

Carbon Engineering Ltd's Air-Contactor device which could be used to remove CO2 passing through the machine

Air capture for mitigation

Air capture offers two mitigation possibilities:

1. 'negative emissions' through capture and sequestration;

2. 'carbon recycling' through the capture and processing of CO2 for onward use in industrial or energy applications that result in 'closed loop' carbon cycles.

Both approaches take advantage of the fact that direct capture of CO2 from the atmosphere can take place at any geographical location regardless of the point at which the gas is emitted. This would enable difficult to tackle CO2 sources to be accounted for in the mitigation process, including non-stationary and dispersed sources such as aircraft, ships and industrial processes that are not amenable to CCS.

It could also facilitate the participation of countries with low GHG emissions in the carbon economy and global mitigation effort. This would be achieved for example through the development of a direct CO2 capture and sequestration activity trading in the world's carbon markets, or a carbon recycling industry driving localized fuel manufacture for energy security. These development routes could be particularly attractive for those countries with low industrial development costs and abundant 'stranded' or 'excess' sources of renewable energy, which can be used to drive the machines cost-effectively.

From an international policy perspective, it is the fact that a negative emissions approach can be used to establish a rational 'ceiling' (or cap) price on CO2 emissions globally that is potentially of most significant benefit. In this regard, if all CO2 emitters were subject to a mandatory international requirement to apply an alternative abatement method or pay for the negative emissions necessary to balance their CO2 emissions account, the cost of air capture with onward sequestration would represent the ultimate limit on the price to the polluter for putting the CO2 in the atmosphere.

This simple approach would drive worldwide carbon pricing to encourage cost reduction in competing low-carbon technologies and incentivize both deployment

and large-scale behavioral change, thereby removing the need for a complex global legally binding emissions reduction agreement.

If ultimately required, legacy emissions can be removed from the atmosphere using a negative emissions approach, thereby enabling CO2 concentrations to be returned to acceptable levels (as defined by the climate science community).

Air capture machines

Machines that will enable air capture are at an advanced stage of engineering design, reaching pilot demonstration potential, and represent a promising technology for early deployment of this approach. The two principal proponents of these machines are Prof Klaus Lackner (Lackner 2009) and Prof David Keith (Keith, Ha-Dong & Stolaroff 2006) both of whom have active air capture R&D programmes with designs based on the use of some form of chemical scrubbing to extract CO2 from air passing through the device.

However, though broad descriptions of the technologies are available, the early stage proprietary nature of the work means that many details are not in the public domain. It must therefore be noted that although the technique appears feasible from an engineering perspective (IMechE 2009) there is considerable uncertainty as to future cost levels.

For artificial trees Lackner (Lackner 2009) states that in the process of moving beyond prototypes to mass production and operation, the price of air capture could drop from around US$200/tCO2 to as low as US$30/tCO2 for machines delivering 1-3tCO2 /day.

It should however be acknowledged that although these 'target' air capture costs have been shown to be plausible (McGlashan, Shah & Workman 2010) they are considered by some to be overly optimistic and that, based on current technology in the public domain, a starting point might be nearer US$430/tCO2 (APS 2011).

Though it would not be sensible to use air capture to account for emissions from large stationary sources that are amenable to CCS, these figures compare with recent estimates for CCS costs in the range US$30-90/tCO2 (Florin & Fennell 2010), including the transportation and storage component of around US$1-12/tCO2.

In the context of the uncertainty of future technical developments and localized prices for equipment, finance, maintenance and energy, the cost of air capture and CCS emissions capture appear to be potentially of broadly similar magnitude. However, regardless of any difference between the two, both CCS and air capture machines with onward sequestration represent technologies at the most expensive end of the abatement cost curve (McKinsey 2009). It is therefore clear that the development and deployment of air capture machines alongside CCS will define the 'ceiling' carbon price.

Application of approach

To apply a negative emissions approach it will be necessary to engineer CO2 transportation and sequestration infrastructure in a similar way to that required for CCS. On the other hand, the application of carbon recycling would use the directly captured CO2 in industrial processes to avoid the 'new' CO2 emissions that would otherwise result from those processes. In this regard the approach provides mitigation through stabilization with the potential added benefit of buying us time while we transition to a low carbon economy.

CO2 already has a number of industrial uses in which the gas is supplied as a chemical feedstock to the product manufacturing process and ultimately released to the atmosphere; examples include Urea, Inorganic Carbonates, Polyurethanes and food and drink applications. Currently these uses are largely supplied by the well established commercial gas handlers from sources in which the CO2 is a by-product, or waste stream. Taken overall, they are cumulatively small in comparison with annual global CO2 emissions (100-200Mt versus 28,000Mt), but nevertheless the substitution of the one-way waste streams by 'recycled' CO2 obtained using air capture would prevent further accumulation in the atmosphere of CO2 from these products.

Ideally, in such cases the air capture plant would be located adjacent to the CO2 demand, thereby potentially saving pipeline or surface transport costs and GHG emissions. The displaced CO2 by-product or waste stream previously utilized as feedstock by the product manufacturer would need to be abated by the source owner in-line with the principle of polluter pays. However, in a future carbon constrained world the manufacturer would no longer need to be liable for the carbon cost of the CO2 emitted by their product when it later enters the atmosphere, as a closed loop carbon cycle will have been established.

In addition to existing processes, major new industrial uses for CO2 are emerging through R&D which have the potential to provide wider sustainability benefits, as well as consume large volumes of the gas. One such innovation is the use of CO2 to manufacture synthetic fuels. The basic process; obtaining hydrogen from water via electrolysis and combining this hydrogen with CO2 to create methanol or other hydrocarbons, is well known and has been shown to be amenable to a closed loop carbon recycling approach based on the use of air capture technology (Pearson & Turner 2011). Despite concerns raised regarding the efficiency of the process, which will require careful engineering to address, synthetic fuels have many benefits, including:

- provide high energy densities comparable with conventional hydrocarbons;
- do not require a change in the current liquid fuel infrastructure or consumer behaviour;
- can buy time in the low-carbon transition of ground transportation;
- are not subject to the land-use issues affecting biofuels (they can be used in combination with biofuels where appropriate);
- help tackle the difficult challenges of mitigating air and ship transport emissions and have the potential to enhance fuel security.

Poly tree designs are another approach

Summary

Given the slow progress to-date on climate change mitigation using current policy approaches, it is critical that we avoid wasting time and urgently assess alternatives that

may help in meeting the challenge of decarbonisation. Air capture technology is one such alternative in an early stage of development and, as with CCS, needs intervention to drive pilot testing, demonstration at scale and detailed cost assessment. Governments should therefore provide development and assessment support through research budgets and the addition of air capture to existing CCS strategy and policy.

In common with many generally accepted technology based methods for mitigating GHG emissions, negative emissions and carbon recycling will result in an additional cost to society and are unlikely to make economic sense without market intervention. Appropriate changes in policies and mechanisms will therefore be needed to drive their adoption, deployment and utilization. In this regard Governments should recognise the important contribution that these approaches can make to climate change mitigation and engage in developing national and international policy framework models for their adoption.

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www.imeche.org

The Institution's Policy Statement on Air Capture can be downloaded from:

www.imeche.org/knowledge/policy/environment/policy/Geo-engineeringpolicystatement1101

Capture news

CO2CRC tests new CO2 capture technology

www.co2crc.com.au

An innovative system for capturing carbon dioxide from power stations will be developed for field-scale testing by the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC), following a grant from Brown Coal Innovation Australia (BCIA).

International Power's Hazelwood power station in Victoria, Australia will be the site of a new CO2 capture test by CO2CRC

The three year $4.2 million project will allow CO2CRC to further develop the system, UNO Mk 3, by modifying and relocating an existing capture plant to International Power's Hazelwood power station in Victoria. In a separate project, a CO2CRC small to medium enterprise partner, Process Group, will use the new plant for testing a new state-of-the-art WES Absorber™ Technology absorption column.

The CO2CRC project will develop a computer model of the process to facilitate scale-up, along with large-scale designs and costs for equipment items, with the aim of making the system "power station ready'.

"The capture process is generally the most expensive part of a carbon capture and storage (CCS) system," said Professor Dianne Wiley, CO2CRC Capture Program Manager.

"CO2CRC's UNO process has been shown to potentially reduce capture costs by 15 to 20 per cent, thereby saving millions of dollars a year and substantially lowering the costs of the whole CCS system."

The UNO Mk 3 system, developed by the CO2CRC solvent team at The University of Melbourne, uses potassium carbonate, an environmentally benign compound similar to baking soda, to capture CO2 from large industrial sources for storage. The solvent used is non-volatile (will not evaporate) and oxygen-tolerant (will not break down over time).

The new system not only promises significant energy efficiencies and environmental benefits but also features removal of SOx and NOx impurities, producing a by-product that can potentially be used in fertiliser man-

ufacture. A worldwide provisional patent is pending.

"A major accelerator for the project has been the ability to trial the new solvent and refine the process under industrial conditions," said Professor Wiley. "That research has been supported by the Victorian Government through their ETIS program and CO2CRC industry and government partners."

In addition, the solvent technology research will create training opportunities for PhD students, post-doctorial research fellows, a research assistant and a site engineer in cost-effective design and operation of solvent-based CO2 capture.

Statoil starts technology qualification at Mongstad

www.statoil.com

Statoil and Gassnova are inviting suppliers to take part in a technology qualification programme for full-scale carbon capture at Mongstad.

The project is now extending an open invitation to potential suppliers of capture technologies, and will sign a framework contract with one or more suppliers.

The purpose of the technology qualification programme is to document that the chosen technology can be used at the Mongstad plant, and that it meets all health, safety and environmental requirements.

"It's important to be fully confident that there will be no health or environmentally hazardous emissions in connection with operations at the capture facility. It must be safe for all who live in the area and who will be working at the plant," says Statoil's Kurt Georgsen, who is head of the full-scale project at Mongstad.

The forthcoming technology qualification process has been split into three phases:

- A feasibility study to show whether the technology can be used at Mongstad

- A technology qualification programme to show that the process will work and that the emissions will meet stipulated criteria, one in which the suppliers will test their chemical and process technologies

- A concept phase for the design of a full-scale carbon capture facility customised for Mongstad

"Participation in the programme will give technology suppliers a very good opportunity to document their technologies against the competition through the building of a full-scale facility at Mongstad. The aim is to make an investment decision by 2016 at the latest, in line with the government's plans," says Gassnova managing director Bjørn-Erik Haugan.

Technology Centre Mongstad. Photo: Helge Hansen / Statoil

Aker and Kvaerner complete Mongstad amine plant

www.akercleancarbon.com

Aker Clean Carbon (ACC) and Kvaerner have competed construction of an amine plant at Technology Centre Mongstad for TCM DA in Norway.

The plant is now ready for commission and testing.

Kvaerner's industrial know-how gained in the petroleum sector has been used in deploying Aker Clean Carbon's technology on the project. The plant was constructed using a modular design, with modules being prefabricated at Kvaerner Stord and shipped to Mongstad.

"This is cost-efficient and an HSE friendly method, since it limits the construction time at Mongstad", says Kvaerner's Project Manager Janne Rasten.

Although amine technology for carbon capture is a proven technology, the amine plant design is a scale-up which brings the deployment of CCS technologies one important step forward, says ACC. TCM brings the next and final scale-up to full scale commercial capture plants considerably closer.

Aker Clean Carbon will benefit from the coming commissioning and testing and later operational experience in its continued effort to compete for and win major CCS projects.

The TCM plant will capture 78,000 tonnes CO2 per year through a 62 m tall absorber tower. The test plant is unique, flexible and very well instrumented, enabling thorough testing of the amine technology. Following commissioning and performance testing, ACC will supervise operation and be in charge of the test programme for the first 14 months. Demonstration of proprietary amine advantages and innovative process solutions are essential to build confidence in technology.

Mitsubishi begins CO2 capture at plant Barry

www.mhi.co.jp

Mitsubishi Heavy Industries Ltd. (MHI) has launched operations at a 25 megawatt coal-fired carbon capture facility at Southern Company's Plant Barry, owned and operated by Alabama Power.

The facility uses the KM CDR Process® capture technology, jointly developed by Mitsubishi Heavy Industries, Ltd. and The Kansai Electric Power Co., Inc.

Built in collaboration with Southern Company, construction of the facility in Alabama commenced in May, 2009. Upon completion, it became the world's largest carbon capture and sequestration (CCS) facility attached to a coal-fired power plant using a proven capture technology. It will capture approximately 150,000 tons of CO2 annually (500 tons/day) at a successful CO2 capture rate of over 90%. The CO2 will then be permanently stored underground in a deep saline geologic formation.

The facility consists of a flue gas scrubber, CO2 capture and utilization technology, CO2 compression machinery, and electrical components, among other features. MHI's role in the project includes licensing the KM CDR Process technology, project engineering, provision of core components, and technical support of operations.

MHI's KM CDR Process technology

uses an advanced solvent called KS-1 to capture the CO2 from a flue gas stack. The flue gas is directed to the KM CDR Process where the KS-1 solvent reacts with and captures the CO2. CO2 can then be separated from the KS-1 and compressed for pipeline transport. Compared with other CO2 capture technologies, the KM CDR Process uses significantly less energy, claims MHI.

The project is an initiative associated with the U.S. Department of Energy's Regional Carbon Sequestration Partnership Phase III program. Captured CO2 will be supplied to the Southeast Regional Carbon Sequestration Partnership for injection underground. The CO2 will remain underground, permanently trapped in the geologic formation.

MHI has received orders for ten natural gas-fired CO2 capture facilities, with eight of the facilities currently in operation, representing a world-class CO2 capture lineup. In contrast, while coal-fired CO2 capture facilities are currently at the commercial feasibility testing stage, since 2006 MHI has partnered with Japan's Research Institute of Innovative Technology for the Earth (RITE) in demonstrating a 10 ton/day scale coal-fired CO2 capture facility.

With the experience gained from stable, continuous operations of a CO2 capture facility in Japan, along with the know-how gained from the CO2 capture project in the United States, MHI intends to verify the economic feasibility and reliability of coal-fired CO2 capture.

US National Carbon Capture Center opens post-combustion test center

www.nationalcarboncapturecenter.com

The recent successful commissioning of an Alabama-based test facility is another step forward in research that will speed deployment of innovative post-combustion CO2 capture technologies for coal-based power plants, according to the U.S. Department of Energy (DOE).

Technologies tested at are an important component of Carbon Capture and Storage, whose commercial deployment is considered by many experts as essential for helping to reduce human-generated CO2 emissions that contribute to potential climate change.

The Post-Combustion Carbon Capture Center (or PC4) facility is part of the larger NCCC, a testing and evaluation center established by the U.S. Department of Energy in 2009 and operated and managed by Southern Company.

The NCCC works collaboratively with technology developers worldwide to test and evaluate both pre- and post-combustion carbon capture technologies under realistic conditions, accelerating development of cost-effective CO2 capture technologies and ensuring continued use of coal for power generation.

The PC4 is located at the Alabama Power Gaston power plant Unit 5, an 880 MW supercritical pulverized coal unit. Initial testing at the PC4 began recently when researchers used a solvent called monoethanolamine (MEA) to capture CO2 from a slipstream of flue gas from the plant. To date, the MEA solvent has exceeded the expected 90 percent CO2 capture, and the unit is now in steady operation capturing about 10 tons of CO2 per day. Data from these initial tests will be used as a baseline to evaluate the performance of emerging CO2 capture technologies.

The NCCC has entered into testing agreements with Aker Clean Carbon AS and Babcock & Wilcox Power Generation Group Inc. for evaluation of their advanced CO2 capture processes at PC4. Both companies plan to conduct testing of their respective technologies at the NCCC later this year.

In addition to DOE and Southern Company, participants in the NCCC include American Electric Power, Arch Coal, EPRI, Luminant, NRG Energy, Peabody Energy, and RioTinto.

Aker Clean Carbon cooperates with Norcem

Norcem and Aker Clean Carbon (ACC) have announced a cooperation agreement for capture of CO2 in the cement industry.

The cement industry is a major emitter of CO2 and as part of an ongoing sustainable strategy on climate protection, Norcem and its parent company HeidelbergCement Group, in cooperation with the European Cement Research Academy (ECRA) have decided to enter into a partnership agreement with ACC.

Under the agreement ACC will perform studies to enable Norcem, through ECRA, to assist the European cement industry in understanding the use of technology for future CO2 capture.

Norcem will execute a Concept study and a pre-engineering study for later trials with ACC post-combustion capture technology at Norcem’s plant in Brevik, Norway. Any ensuing trials will be given industrial environment testing by using ACC’s Mobile Test Unit (MTU).

ACC has run its MTU now with more than 14,000 hours industrial operation, providing unique support for Norcem.

“The Cement Industry is a major emitter of CO2 and we are delighted to be able to work with Norcem, HeidelbergCement and ECRA in this important forward-looking project” says Liv Monica B Stubholt, Chief Executive Officer of Aker Clean Carbon.

“HeidelbergCement and Norcem have already taken major steps in reducing the emissions of CO2 from the production of cement. The next important step is CO2-capture. We assume that a cement plant is a favorable location for capturing of CO2. We look forward to test the technology together with Aker Clean Carbon”, says Per Brevik, Director Alternative fuels of HeidelbergCement Northern Europe.

The cement industry develops strategies, conducts practical testing and gains project experience through ECRA, whose mission is to advance innovation in the cement industry within the context of sustainable development and to communicate the latest knowledge and research findings in cement and concrete technology.

ECRA members have chosen Norcem Brevik as the site for ECRA operational CO2 capture test projects.

Structural safety in CO_2 transport pipelines

Although CO_2 pipelines will be the primary means for transporting CO_2 for storage, it is often considered as an 'available technology' and so discussed less. There is a need for structural integrity-based model for the assessment of pipeline safety, says Dr Amir Chahardehi, Offshore Renewable Energy Group, Cranfield University

The demand for carbon capture and storage (CCS) in recent years as a viable solution to the problem of CO_2 emissions from power plants has led to an increase in interest in research in certain associated areas of technologies. Among these, the transport process has usually been taken for granted as 'available technology', and is therefore discussed less.

While there is considerable experience in the transport of natural gas by pipelines, experience in the transport of CO_2 through pipelines is relatively limited and far less than that required for a thorough understanding of the pertinent details for the design and analysis of pipelines for CO_2. This article discusses the current issues in the field of CO_2-transporting pipelines and highlights the need for a structural integrity-based model for the assessment of safety and for the design of CO_2 pipelines.

CO_2 Emissions and Global Warming

The need to reduce the emission of CO_2 and other greenhouse gases into the atmosphere as a result of industrial development has been the driving force behind the development of CCS technologies. There is overwhelming scientific evidence, as shown in the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), that climate change will threaten economic growth and long-term prosperity [1, 2]. The IPCC suggests that to avoid the most catastrophic impacts of climate change, greenhouse gas emissions need to peak in the next 10 to 15 years and be reduced by the order of 50–80% below 1990 levels by 2050.

CCS is considered a key solution to the problem of anthropogenic CO_2 emissions. However, as the Congressional Research Service Report on CO_2 pipelines indicates [3] the general focus of CCS and related legislation is on the capture and storage of CO_2 and not its transportation. As the report suggests: "this reflects the perception that transporting CO_2 via pipelines does not present a significant barrier to implementing large-scale CCS" [3]. Nevertheless, the truth and the perception are different.

CO_2 Pipelines

The current generation of CO_2 pipelines has been operational for over 30 years, mainly in the US, transporting high-pressure CO_2 for onshore enhanced oil recovery across sparsely populated terrain. However, the next generation of CO_2 pipelines will be directed at climate change mitigation.

Initiatives such as the EU Emissions Trading Scheme, usually requiring companies to limit or reduce greenhouse gas emissions, mean that there will be a serious economic driver for power generation companies to consider CCS technology. Moreover, for the CCS process to be cost-effective and safe, all three main aspects of capture, transport and storage technologies should be developed and possibly standardised.

Carbon Capture and Storage Pipelines

Pipelines seem to be the primary mode of transport of CO_2 in the context of CCS [4, 5]. The expansion of CO_2 pipelines in recent years and safety requirements for pipelines in densely populated areas mean that new legislative and safety considerations should be taken into account for the emerging CCS pipelines.

Compared with hydrocarbon transport pipelines, there is very little experience in the design and maintenance of CO_2 pipelines. Also, since some or most of the storage locations are offshore, the requirements for pipelines in the offshore environment need to be considered. Design and construction of new dedicated pipelines for CO_2 transport, or, in some cases, the conversion of existing infrastructure, both require a thorough understanding of the safety issues associated with the transport of CO_2.

CO_2 as a Hazardous Substance

A significant amount of information has been published outlining the hazards associated with relatively small releases of CO_2 [6]. In water, CO_2 forms an acidic solution, leading to corrosion issues, and is a known asphyxiant [7]. For more information about the hazards and legal status of CO_2 the reader is referred to Harper [8].

Pipeline Failure

Makino et al. highlight the existing issues with the prediction of crack propagation in ultra-high-pressure natural gas pipelines [9]. Whereas the catastrophic failure mode in pressurised pipelines is clearly demonstrated in burst tests as being ductile, crack initiation at low temperatures is more likely to be due to the metal lacking sufficient toughness, i.e. brittle failure mode [10]. Cravero et al. recommend a constraint-modified failure assessment diagram which takes into account both ductile and cleavage (brittle) mode failures [11].

Safety Considerations – Leakage Scenario

Pipeline transmission of CO_2 over longer distances is considered most efficient when the CO_2 is in the supercritical or dense phase [12]. Safety analysis of the pipeline should include the important 'what-if' scenario, where a defect is assumed to be created in the pipeline. The existence of a defect in the pipeline would lead to rapid escape of fluid CO_2 from the hole.

Mahgerefteh et al. have proposed an outflow model which predicts the decompression behaviour of the CO_2 flow through the pipe defect [13]. Starting from liquid or supercritical phases, the saturation pressure – at which liquid and gas phases are in equilibrium – is determined by the initial pressure of the fluid in the pipe; the higher the initial pressure the higher the saturation pressure.

For a pure component, the temperature is a function of pressure and therefore the temperature of the escaping gases is wholly dependent on the depressurisation trajectory. Eldevik et al. [14] argue that, as a result of pipeline failure, rapid depressurisation may cause the CO_2 to cool to the triple point and the low temperatures could cause associated operational and structural problems.

A detailed discussion on the decompression behaviour of CO_2 from a pipeline defect can be found in [13]. In a review article, Eldevik emphasises that the likelihood of solid CO_2 deposition on the pipe as a result of decompression may bring the local temperature as low as - 78°C [15]. This can have a severe impact on the pipeline material's toughness or resistance to fracture.

Metal Embrittlement – Toughness versus Temperature

Pipeline steels show a ductile-to-brittle transition at low temperatures and the toughness value of the material, i.e. the resistance to brittle fracture, is reduced at lower temperatures. Knowledge of the exact behaviour of the material is key in the development of a structural integrity model for the pipeline. As part of the development of the model, a database containing toughness characteristics of the mate-

rial as a function of temperature should be compiled.

Current Testing Methods, Future Outlook and Requirements

Current test standards relevant to the evaluation of pipeline toughness include testing methods such as the Drop Weight Tear Test (DWTT) [16–18] and Notched Bar Impact Test [19]. Some authors have recommended the use of pre-cracked test specimens in the impact test and report a closer correlation with the plane-strain fracture toughness (KIC) [20].

However, there is a considerable amount of uncertainty as to the correlations between the actual fracture toughness value pertinent in the design and analysis of CO2 pipelines and the results from the Charpy impact test or DWTT [21]. The conclusion of the Health and Safety Executive report on the subject is that whereas individual correlations have been introduced and summarised, “no single correlation describes completely the KIC temperature transition although some attempt to do so” [21].

The Det Norske Veritas Recommended Practice [4] rather vaguely suggests that the pipeline should be designed such that any rupture is arrested within a small number of pipe joints. Notwithstanding the fact that the predictive requirements of any structural integrity model demand accurate knowledge of material characteristics at different temperatures, a more rigorous standard practice should be devised for CO2 pipelines considering their growing importance and the potential hazards of pipeline failure and CO2 leakage.

There are currently a relatively large number of test programmes dedicated to developing systematic understanding of the structural integrity issues and requirements of these pipelines. It is the author’s belief that a rigorous, robust structural integrity model for CO2 pipelines can only be obtained after material characteristics tests, such as DWTT, Charpy and fundamental fracture mechanics tests involving the direct determination of KIC, are used in conjunction with component testing, full-scale or otherwise.

Large-scale component testing gives invaluable information about the transferability of the results obtained from specimen tests to the real world. Fundamental tests should include crack initiation and measurements of the onset of unstable crack growth in regions of temperature gradient, where the crack is likely to grow from a region of low temperature in the vicinity of the defect to a region where the temperature is effectively in equilibrium with the environment.

The low toughness value of the metal in the neighbourhood of the defect would mean that crack initiation is likely even though the normal ‘working temperature’ toughness of the metal is sufficient to ensure lack of crack growth [13, 23]. Robertson devised a test to characterise this temperature gradient effect on the propagation of cleavage fracture in steels [24].

This type of test, modified to account for the requirements of CO2 pipelines in terms of steel type, thickness and geometry constraint, can be used as a tool in the generation of the material property database. Validation tests for pipeline weldments [25] allowing for incorporation of residual stresses through the use of weight functions [26] are required in order to construct a robust, predictive structural integrity model for CO2 pipelines.

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New trials begin at Australian Otway Project

A series of research trials into geological storage of carbon dioxide have begun at the CO2CRC Otway Project in Victoria, Australia.

The experiments, led by the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC), are part of the $10 million second stage of the project, which is focused on saline formations, geological structures with the potential to permanently store hundreds of years' worth of carbon dioxide emissions.

An international research team has been assembled by the Centre, with researchers from leading Australian research organisations, Lawrence Berkeley National Laboratory (USA), Korea Institute of Geoscience and Mineral Resources (KIGAM), Canada's Simon Fraser University and New Zealand's GNS Science.

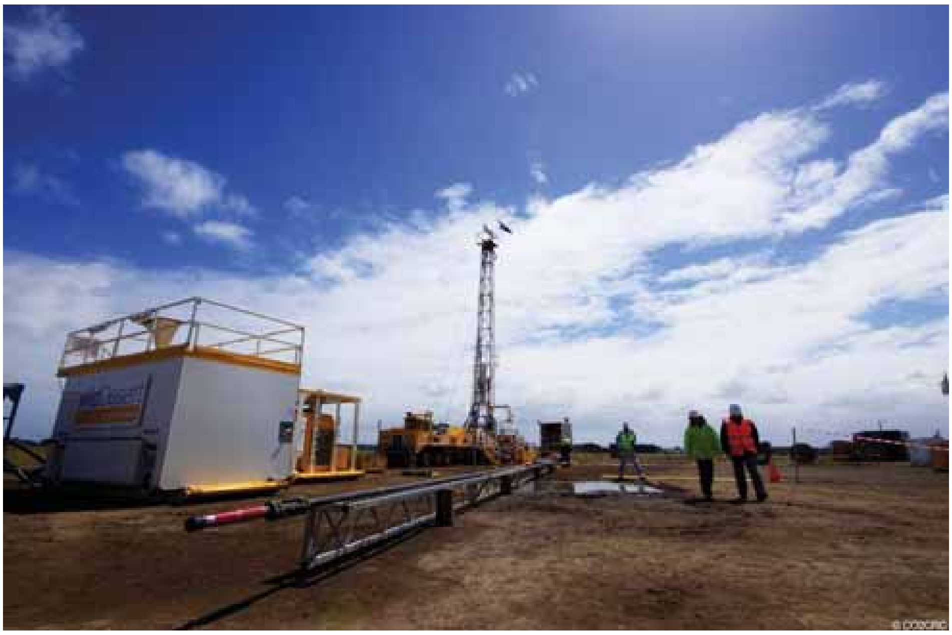
The team will use a new 1565 metre well at the site to undertake a complex series of extractions and injections of carbon dioxide and water over the next two months, evaluating storage capacity and security.

A sophisticated and highly innovative 28 metre instrument array, installed 1400 metres underground in the same well into which the carbon dioxide is injected, will measure pressure, temperature and tracer gas concentrations, while a „U-tube' system allows the team to chemically analyse samples of water and dissolved gas direct from the reservoir, at pressures equivalent to 1400 metres underground.

“The Otway Project has been demonstrating safe storage of carbon dioxide in a depleted gas reservoir since 2008,” says CO2CRC Chief Executive Dr Peter Cook, “and the successful first stage provided a great deal of highly useful information on monitoring, verification and regulation of CCS.

“This second stage involves research aimed at tackling some of the key outstanding research questions regarding storage capacity and security in types of rocks found many parts of the world. It will enable CO2CRC to produce practical tools for commercial CCS projects that will make it easier to evaluate a potential reservoir.”

The CO2CRC Otway Project involves researchers from Australian universities and research organisations as well as from the United States, Korea, Canada and New Zealand. The project has been financially supported by the Australian Federal Government, the Victorian State Government and the US Department of Energy, as well as CO2CRC members.



The 30 metre instrument assembly before installation in the well (Image ©CO2CRC)

Final preparations before the instruments are installed downhole (Image ©CO2CRC)

www.co2crc.com.au

Transport and storage news

DOE funds projects aimed at CCS security and environmental safety

www.fossil.energy.gov

The U.S. Department of Energy's (DOE) portfolio of field projects aimed at confirming that long-term geologic CO2 storage is safe and environmentally secure has been expanded by three projects selected to collectively receive $34.5 million over four years.

Researchers will conduct small-scale injection testing of CO2 into promising geologic formations. Project data will be incorporated in the National Carbon Sequestration Database and Geographical Information System (NATCARB), an interactive online tool that integrates a wealth of information on worldwide efforts to deploy carbon capture and storage (CCS) technology.

The total award value of the new projects is more than $45 million, with approximately $10.5 million provided by the recipients. The work will be managed by the Office of Fossil Energy's National Energy Technology Laboratory (NETL).

Members of the public and industry can use NATCARB to assess future opportunities for developing commercial carbon storage projects throughout the United States.

The projects are:

- Blackhorse Energy, LLC (Houston, Texas) — Blackhorse Energy plans to inject approximately 53,000 tons of CO2 into a geologic formation located in Livingston Parish, Louisiana. The project will assess the suitability of strandplain geologic formations for future large-scale geologic storage of CO2 in association with enhanced oil recovery. Additionally, they will test the efficacy of increased storage using short-radius horizontal well technology to inject supercritical CO2 and CO2 foam into the reservoir.

- University of Kansas Center for Research, Inc. (Lawrence, Kansas) — The University of Kansas will inject at least 70,000 metric tons of CO2 into multiple formations. The project will demonstrate the application of state-of-the-art monitoring, verification, and accounting (MVA) tools and techniques to monitor and visualize the injected CO2 plume and establish best practice methodologies for MVA and closure in "shelf clastic" and "shelf carbonate" geologic formations.

- Virginia Polytechnic Institute and State University (Blacksburg, Virginia) — The Virginia Polytechnic Institute and State University will attempt to reduce uncertainty, test the properties of coal seams, and evaluate the potential for enhanced coalbed methane recovery by injecting approximately 20,000 tons of CO2 into unmineable coalbeds.

DNV CCS well integrity guideline

DNV has released a new guideline for Carbon Capture and Storage projects. The CO2WELLS guideline is the result of a major joint industry project which brought together upstream operators and power utility companies.

Aimed at project developers and authorities, it describes a generic framework process for managing the risks associated with existing wells at carbon dioxide (CO2) storage locations, both onshore and offshore.

DNV has previously published industry guidelines across the full CCS value chain of capture, transport and storage. These guidelines have been implemented by a number of companies for their current and planned CO2 operations, as well as being adopted by authorities as a component in their own regulations.

The CO2WELLS guideline represents the latest addition to this series. Within the field of CO2 geological storage, it supplements DNV's CO2QUALSTORE guideline which was published in 2010 following a similar joint industry initiative.

Together, these two guidelines provide a generic capital value process for CCS projects that is designed to qualify geological storage sites through iterative cycles of risk and uncertainty reducing measures. The integrity of existing wells at CO2 storage sites has been highlighted as a potential concern, and the new CO2WELLS guideline addresses this issue head on.

The guideline describes a risk management framework for existing wells at potential CO2 storage sites, both onshore and offshore. It is aimed at project developers and authorities and includes guidance on:

- Risk assessment of active and abandoned wells during the initial screening of candidate storage sites;

- The qualification of these wells for continued or modified use in a CCS project.

The guideline is consistent with the ISO31000 international standard for risk management and with current and emerging regulations for CO2 geological storage in the US, Canada, Europe and Australia.

Participants of the CO2WELLS joint industry project are DNV, E.On Engineering, GASSCO, GASSNOVA, Global CCS Institute, Health & Safety Executive UK, National Grid, Petrobras, RWE, Shell Canada, Vattenfall

Unified guidelines to speed up CCS implementation

DNV believes that CCS is a strategically important technology for maintaining sustainable growth whilst reducing CO2 emissions. By permanently storing CO2 produced by industrial processes in deep geological formations, it has been highlighted as one of the key technologies that can facilitate a transition to a more carbon neutral world.

For CCS to play a significant role in combating climate change, however, a significant number of commercial scale projects must be initiated around the world within the coming years. To boost the deployment of CCS in a safe and sustainable way, there is a need for unified, recognized and publicly available guidelines that provide the standards that can help speed up innovation.

Mike Carpenter, project manager at DNV, said, "DNV's core philosophy is that technology development and knowledge sharing foster innovation and improvements in safety. So when industry is facing challenges like CCS, the best way of solving them is for the key players to join forces through joint industry projects. In this way we, as an industry, can develop global best practices and standards."

All of DNV's guidelines and recommended practices for CCS have been developed through joint industry projects and are freely available from www.dnv.com/ccs

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 or download a spreadsheet at www.globalccsinstitute.com/resources/data

Project Name	Description	Asset Lifecycle Stage	Country	Volume CO_2	Operation Date
ADM Company Illinois ICCS	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	1 Mtpa	2012
AEP Mountaineer 235MWe CO2 Capture	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	1.5 Mtpa	2015
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	0.55 Mtpa	2012
Air Products 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	1 Mtpa	2015
Belchatow	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	1.8 Mtpa	2015
Bow City	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	1 Mtpa	2016
Browse LNG	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	3 Mtpa	2017
C.Gen Killingholme	C.Gen is proposing this new IGCC plant in north Lincolnshire that would capture around 2 million tonnes per annum of carbon dioxide feeding into the National Grid transport and storage network. The project is part of the Yorkshire Forward initiative.	Define	UNITED KINGDOM	2.5 Mtpa	2015-2016
Cash Creek	The ERORA Group proposes to build a Hybrid IGCC project in Henderson County, Kentucky. It will produce about 565 MW as well as synthetic natural gas. The plant will capture about 2.5 million tonnes per annum of carbon dioxide for enhanced oil recovery.	Evaluate	UNITED STATES	2.5 Mtpa	2015
Coffeyville Gasification Plant	Coffeyville Resources is proposing to build a carbon capture unit at an existing gasification plant in Kansas. The project would capture around 770,000 tonnes per annum of carbon dioxide for urea production and enhanced oil recovery.	Define	UNITED STATES	0.585 Mtpa	2013
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	1.1 Mtpa	2015
Coolimba	Aviva Corporation Ltd proposes the construction of a 400-450MW coal-fired base-load power station using circulating fluidized bed technology and capturing up to 2 million tonnes per annum of carbon dioxide. Suitable storage sites are being sought.	Identify	AUSTRALIA	2 Mtpa	2015
Don Valley	2Co Energy is developing this project to capture nearly 5 million tonnes per annum of carbon dioxide from a new build natural gas-fired power station. The project is part of the Yorkshire Forward initiative.	Evaluate	UNITED KINGDOM	4.75 Mtpa	2015
Dongguan	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	1 Mtpa	2015
Drax	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	2 Mtpa	2015
Emirates Steel Industries	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	0.8 Mtpa	2014
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	1.8 Mtpa	2012

Facility Details	Capture Type	Transport Type	Transport Length	Storage Type	Project URL
Ethanol plant	Industrial Separation	Pipeline	1.6 km	Deep Saline Formations	#http://www.adm.com/#
235 MWe slipstream from 1300 MW net coal-fired power plant	Post-Combustion capture	Pipeline	30 km	Deep Saline Formations	http://www.aep.com/environmental/climatechange/carboncapture/
130,000 Nm3/h hydrogen plant	Pre-Combustion capture	Combination	Not specified	Enhanced Oil Recovery	#http://www.airliquide.com/#
Hydrogen production at oil refinery	Pre-Combustion capture	Pipeline	Not specified	Enhanced Oil Recovery	http://www.airproducts.com/index.asp
260 MW equivalent on 858 MW lignite-fired power plant	Post-Combustion capture	Pipeline	60-140 km	Deep Saline Formations	#http://www.bot.pl/#
1000 MW coal-fired power plant	Post-Combustion capture	Pipeline	6-30 km	Enhanced Oil Recovery	www.bowcitypower.ca
Liquefied natural gas (LNG) plant	Gas Processing	Pipeline	Not specified	Not Specified	#http://www.woodside.com.au/#
430-520 MW net IGCC	Pre-Combustion capture	Pipeline	Unspecified	To Be Determined	#http://www.cgenpower.com/en/projects_killingholme.html#
565 MW IGCC and 130 MSCF/day SNG gasifier	Pre-Combustion capture	Pipeline	Not specified	Enhanced Oil Recovery	#http://www.erora.com/#
Fertiliser plant	Pre-Combustion capture	Pipeline	112 km	Enhanced Oil Recovery	http://www.cvrenergy.com/NitrogenFertilizerOperations/index.html
300 Mwe (Phase 2) coal-fired oxyfuel combustion power plant	Oxyfuel Combustion capture	Pipeline	120 km	Deep Saline Formations	#http://www.compostillaproject.es/#
2x200 MW or 3x150 MW coal-fired CFB power plant	Post-Combustion capture	Pipeline	20-80km	Depleted Oil and Gas Reservoirs	www.coolimbapower.com.au
Natural gas-fired power plant	Oxyfuel Combustion capture	Pipeline	175 km	To Be Determined	#http://www.2coenergy.com/#
800 MW net coal-fired IGCC power plant	Pre-Combustion capture	Pipeline	100 km	Depleted Oil and Gas Reservoirs	#http://www.dgpowerfuel.com/english/profile.asp#
426 MW gross coal-fired power plant	Oxyfuel Combustion capture	Pipeline	Not specified	Depleted Oil and Gas Reservoirs	#http://www.draxpower.com/#
Steel plant	Industrial Separation	Pipeline	50 km	Enhanced Oil Recovery	http://www.esi-steel.com/#http://www.esi-steel.com/#
Fertiliser production and hydrogen production at the oil refinery	Pre-Combustion capture	Pipeline	240 km	Enhanced Oil Recovery	http://www.enhanceenergy.com/projects/clive.html