carbon capture journal

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Front cover: Canada and Alberta Governments Invest in Major Carbon Capture and Storage Project From left to right: The Honourable Mel Knight, Alberta Energy Minister, the Honourable Lisa Raitt, Canada's Minister of Natural Resources, and Graham Boyle, Shell Canada V.P., at the official signing of a letter of intent for investments in the Quest carbon capture and storage project near Edmonton, Alberta

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Alberta's Quest and Pioneer projects move to grant agreement stage

Alberta, a leading North American energy producer, is emerging as a global leader in advancing the science of large-scale carbon capture and storage projects. The province has recently signed letters of intent with two proponents for funding from its $2B (Cdn) CCS commitment.

By The Honourable Mel Knight, Minister of Energy, Alberta

Prime Minister Stephen Harper is joined by TransAlta CEO Stephen Snyder and Alberta Premier Ed Stelmach as he looks at schematics for Project Pioneer

Shell's Quest project – which is owned by Shell Canada, Chevron Canada and Marathon Oil Sands L.P. – signed a letter of intent in October to receive $745 million from the province of Alberta.

The Government of Canada is also investing $120 million through its Clean Energy Fund in the $1.35 billion project.

The Quest project is expected to capture 1.2 million tonnes of carbon dioxide annually starting in 2015 from Shell's Scotford upgrader and new expansion east of Edmonton.

A letter of intent has also been signed with TransAlta Corporation and its partners Capital Power and Alstom for Project Pioneer at the Keephills 3 plant west of Edmonton. Alberta's investment in the retrofit of this coal-fired electricity plant is $431 million from the CCS fund and an additional $5 million will be provided to support front-end engineering and design.

The Government of Canada is also contributing $343 million for this project through the Clean Energy Fund and the federal econENERGY Technology Initiative.

Prime Minister Stephen Harper and Alberta Premier Ed Stelmach recently made the joint announcement at the plant.

TransAlta's Project Pioneer is expected to sequester one million tonnes of CO2 annually starting in 2015 and could be a catalyst for CCS implementation at coal-fired electricity plants around the world.

It is clear that both the province of Alberta and the Canadian federal government see carbon capture and storage technology as a leading solution to greenhouse gas emission reduction. It is also clear that CCS technology has application in a variety of industries. The Quest project will help with upgrading emissions of oil sands bitumen while Project Pioneer will be one of the world's first retrofitted coal-fired electricity plants.

Both of these projects plan to use some of the captured CO2 for enhanced oil recovery projects (EOR), which is ideal for Alberta and for Albertans. Enhanced oil recovery helps produce oil from conventional wells drawing from tapped-into reservoirs. EOR uses pressure to help increase production during secondary or tertiary recovery and for Alberta, it means increased production and increased revenues.

Alberta's investment in the technology is also an investment in our economy as it will provide many jobs during the construction phase and will provide many people with a specialized knowledge that can then be shared with others.

It's important to note that the project proponents are also making a tremendous financial investment in these projects. Our funding formula provides up to a maximum of 75 per cent of the total incremental costs to capture, transport and store the CO2.

A maximum of up to 40 per cent of the approved funding will be distributed during the design and construction stage based on achieved milestones and up to an additional 20 per cent of the approved funding will be granted once commercial operation begins. The remaining 40 per cent of the funding will be paid as CO2 is captured and stored over a maximum period of 10 years.

The next step in the process is for the project proponents to sign funding grant agreements.

We are in discussion with other project proponents for letters of intent to access the remaining funds from the $2-billion commitment made in the summer of 2008. I am confident announcements of those projects will be made in the very near future.

Alberta, like every other jurisdiction in the world, has not been immune from the global economic downturn. You may have heard that for the first time in more than a decade our province ran a deficit budget .That has not stopped us from pursuing our commitment to clean energy and we see CCS as one of many technologies which will help us on the path forward. We are committed to the science of solutions.

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Enhance Energy – ACTL Project

Enhance Energy's Alberta Carbon Trunk Line (ACTL) will be the first commercial, large-scale carbon capture and storage project in the province, which is expected to store more carbon than any other CCS project in the world.

Enhance Energy's founder and president, Susan Cole, P. Eng., has almost a decade of CCS and enhanced oil recovery experience making her highly qualified to lead Enhance on their ACTL project.

"Prior to starting up Enhance Energy, I was the manager of the Weyburn CO2 Development project for five years and I spent three years at EnCana managing their Athabasca Oil Business Unit where we focused on water flooding and polymer flooding of the Pelican Lake heavy oil pool," says Cole.

Overview of the ACTL project

The ACTL project will incorporate carbon dioxide capture, transportation, enhanced oil recovery, and storage in Alberta's Industrial Heartland and south-central Alberta.

Enhance will construct and operate the ACTL, which is part of a larger project involving the storage of CO2 and EOR projects. The system will gather, transport, and distribute CO2 from the Alberta Industrial Heartland, just east of Edmonton and south of Redwater, to the oil production fields just east of Clive, Alberta.

The ACTL project will consist of constructing a pipeline distribution system that will encompass drying and compression facilities at the north end in the Industrial Heartland; delivery facilities at the south end of the system, which will distribute the CO2 to conventional oil and gas fields in the area; and a high vapour pressure pipeline between the source and the delivery points.

Enhance Energy specialises in enhanced oil recovery using CO2

The initial leg of the ACTL will be 240 kilometres in length and the pipe will be 40.6 centimetres in diameter. Over time, lateral legs extending south, west, and east will allow for multiple entry and exit points throughout the system.

The system will initially gather, compress, and store 15,000 tonnes of carbon per day. At full capacity, it will gather, compress and store 40,000 tonnes of carbon per day or 14.6 million tonnes per year. "The project could potentially store more than 2 billion tonnes of carbon," says Cole.

Enhance says it will ramp up additional supplies over time. "We expect it will take anywhere from ten to 15 years to get to full capacity because of the current shortage of pure CO2," explains Cole.

"Our current supplies of CO2 are pure however, subsequent supplies will need to be cleaned up because they will be coming from different types of industry like power, petrochemicals, and oilsands upgraders and we are reliant on more CO2 supplies becoming available over time."

Enhance says the combined total cost of the trunk line and the associated EOR projects is in the range of CAD $600 million; the initial cost of capturing and transporting the CO2 will be CAD $300 million with the EOR storage component costing another CAD $300 million.

The initial suppliers of high purity CO2 to the ATCL are expected to be North West Upgrading Inc. and Agrium Inc. NWU is an independent merchant upgrader using gasification technology which is fully permitted and approved for construction and is expected to be fully operational in 2013.

Agrium, a fertilizer facility which produces CO2 as a by-product from its ammonia production, is located just outside of Redwater. The total volume from NWU and Agrium is expected to be 5,100 tonnes of carbon per day. Enhance will construct and operate the capturing facilities at NWU and Agrium where these pure carbon streams will be compressed and build the pipeline system.

"Everyone at Enhance Energy is looking forward to working on this first-of-its-kind CCS project and to becoming part of the CCS movement in Alberta" - Susan Cole, Enhance Energy's founder and president

Fairborne Connection and EOR

In Alberta, one of four provinces in the Western Canadian Sedimentary Basin in western Canada, many reservoirs have been depleted such that production is at a minimum and abandonment might well be the next step unless enhanced oil recovery methods can revitalize them.

Enhance has signed an agreement with Fairborne Energy Trust to jointly develop a CO2 EOR project at two of their oilfields near Clive. Where Enhance will operate the pipeline, Fairborne will operate the EOR facilities.

EOR with injected CO2 is a common practice in oilfields, having been used for more than 30 years. However, Cole says there is currently a shortage of high purity CO2 needed for EOR. "When the required supplies of high purity CO2 become available, approximately 1.1 billion barrels of incremental oil reserves could be recovered primarily through CO2 injection in southern Alberta."

Environmental Benefits and Benefits to the Oilsands Sector – The capture and transmission of CO2 through the ACTL will contribute to decreasing overall emissions in Alberta by storing CO2 after EOR operations are complete. "A typical car emits 5.6 tonnes of GHG emissions per year. With the

amount of CO_2 that we will be storing, it will be the equivalent of removing 2.6 million cars off the road in Alberta annually. That's about a third of all registered vehicles in the province," says Cole.

CCS in the oilsands

The benefits of the ACTL to oilsands operators will be immense. Cole says these Large Final Emitters will finally have a viable option to store their CO_2 emissions which will dramatically help them lower their emissions and meet Alberta's new emissions targets.

"We are fortunate we have the right geology in Alberta to produce oil and manage the CO_2 emissions from upgrading oilsands in the same place. So we can develop our oilsands in a sustainable manner with a low CO_2 footprint while also increasing conventional oil production."

"It is an economic and environmental win for Alberta when we are able to store CO_2. Studies show the CO_2 footprint of the Alberta oilsands with a CCS solution would be in line with any conventional light oil production that we have in this region," says Cole.

Building the pipeline

Enhance is also working with Canadian Pacific so the company can construct the pipeline along the right of way of CP's railroad. "By constructing our pipeline alongside CP's railroad right of way, we minimizing disturbance of the land and avoid environmentally sensitive areas," says Cole.

Enhance submitted its application to construct the pipeline to Alberta's Energy Resources Conservation Board on March 23, 2009 and is expecting to receive approval by sometime in the first quarter of 2010.

Depending on the timing of regulatory approval, construction of the pipeline and facilities could begin in 2010 with start-up sometime in 2012.

www.enhanceenergy.com
www.fairborne-energy.com

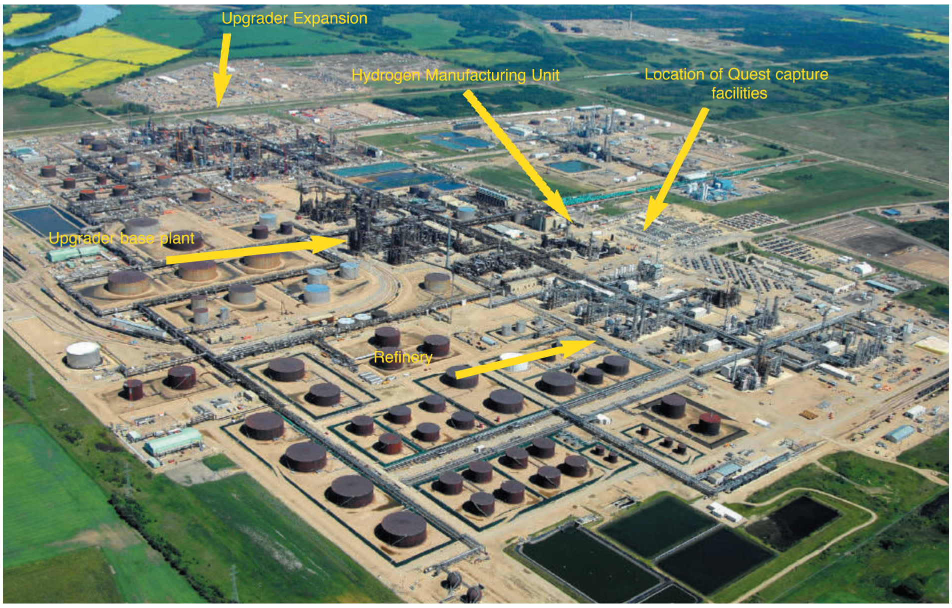
Shell Quest Project - CCS in the oilsands

Shell, on behalf of the Athabasca Oil Sands Project, a joint venture among Shell Canada (60 per cent), Chevron Canada Limited (20 per cent) and Marathon Oil Sands L.P. (20 per cent), is advancing the Shell Quest project, which would capture, transport and store CO_2 from the Scotford Upgrader in Alberta.

Shell Quest is a fully integrated CCS project. It would capture and store up to 1.2 million tonnes of CO_2 per year from the Scotford Upgrader and from the Scotford Upgrader Expansion, now under construction.

The CO_2 would be captured from the Scotford steam methane reformer units, which produce hydrogen for upgrading bitumen.

The CO_2 would then be transported by pipeline to an injection location near the Scotford Complex and stored approximately 2,300 metres underground in a deep geological formation. The CO_2 could also be made available for use in enhanced oil recovery projects on a commercial basis.



Aerial view of the Quest site

Project Status

In late 2008 and early 2009, Shell drilled two test wells near the Scotford Upgrader as part of a CCS appraisal program co-funded by the Alberta Energy Research Institute. The results of this program will help determine potential locations for Quest CCS Project CO_2 injection sites.

Several additional years of work are still needed to inform a final capital investment decision on Quest. That investment decision will ultimately depend on a range of factors, including the outcome of a structured consultation process, the results of appraisal activities and detailed integrated studies, as well as the ability to meet all regulatory requirements.

Construction would only begin after all of these aspects have been addressed successfully, with the aim to start operations in 2015.

Development plan

Shell is developing Quest in four stages:

Preliminary project development

This includes locating deep, sub-surface geological formations in which injected CO_2 can be stored.

Project development

Shell will continue to advance development work, consult with the public and prepare detailed engineering designs and plans, incorporating public input.

Regulatory and internal approvals

Shell will seek regulatory approvals from the Government of Alberta, investment approval from the Athabasca Oil Sands Project owners and satisfy its own internal governance process.

Construction

If all approvals are received with satisfactory conditions, construction would take approximately three years, and could be followed by project commissioning and start-up approximately three to five years later.

Project components

Capture:

Shell is proposing to install facilities at Scotford that would capture CO_2 from all three of the Upgrader's hydrogen plants. The hydrogen plants combine steam and natural gas

(methane) to produce hydrogen used for upgrading, and concentrated CO2, which is ideal for CO2 capture.

Transportation:

The liquid CO2 would be transported by pipeline from the Scotford Upgrader to the injection location(s), which have yet to be selected but which would be at a distance of between 10 kilometres and 60 kilometres from Scotford. The pipeline would run northeast from Scotford and would follow existing right of ways to the greatest extent possible and would be designed and constructed to the latest technical and safety specifications.

The pipeline system could be extended to supply CO2 for third-party enhanced oil recovery depending on the outcome of commercial discussions.

Storage:

Shell proposes to inject the CO2 deep underground into a geological formation known as the Cambrian Basal Sands at a depth of 2,000 – 2,500 metres. This for mation is deeper than the oil and gas deposits in the area and is roughly 2,000 metres below any freshwater aquifers.

The injection sites are anticipated to be within 60 kilometres of the Scotford Complex.

Monitoring and Verification:

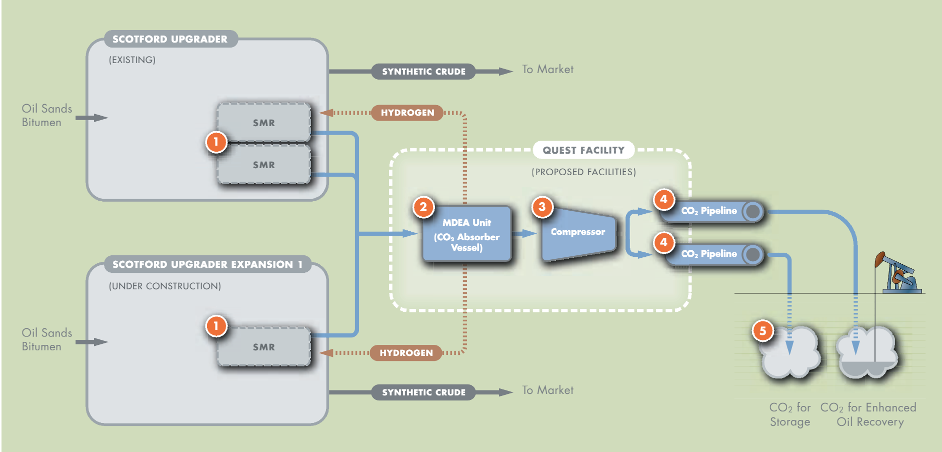
Shell Quest would use new technology measuring, monitoring and verification systems to observe the CO2 storage wells and geological formations.

This would provide assurance that the injected CO2 had remained deep below ground in the target formation.

Enhanced Oil Recovery Opportunities:

CO2 captured from the Scotford Upgrader could be made available for use in EOR projects in Alberta depending on the outcome of commercial discussions. The

CO2 would be stored permanently in these oil fields, which would also be required to use sophisticated measuring, monitoring and verification systems.



1 The Shell Quest CCS project will capture CO_2 from three hydrogen-manufacturing units (two existing and one now under construction) at the Scotford Upgrader. These are called steam-methane reformation units, or SMRs.

2 An absorber vessel will use chemical amines (called activated MDEA) to capture the CO_2 from the process stream; the CO_2 will be released from the amine through steam stripping.

3 In a compressor unit, CO_2 will be compressed into its dense phase (a super critical liquid) for safe pipeline transport.

4 The liquefied CO_2 will travel by pipeline to nearby storage sites.

5 The CO_2 will be injected into deep underground formations for storage and could be used for enhanced oil recovery.

Quest process schematic

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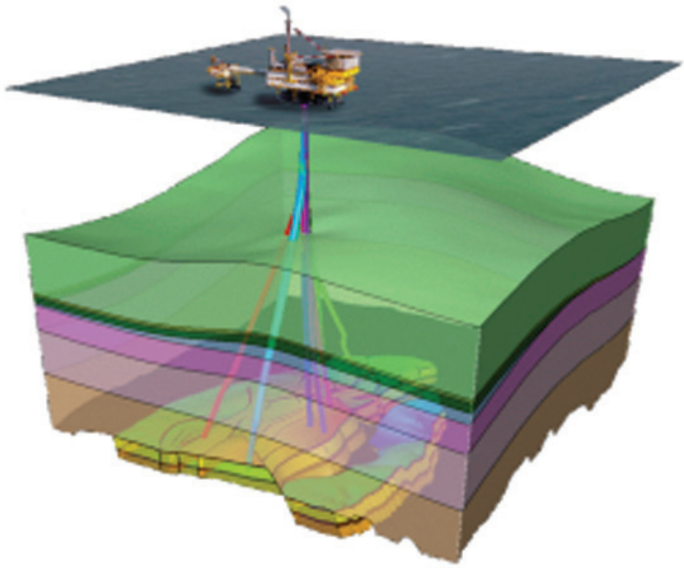

Carbon capture and storage has the potential to be the size of North Sea oil and gas industry and be worth more than £2bn/yr and sustain more than 30,000 jobs by 2030. North Sea CO^2 storage space is estimated at more than 22 billion tonnes which is 180 years' emissions from the UK's 20 largest point sources. But what are the geological factors affecting how this space can be used? How will geology inform the regulators and the public and what are the risks and opportunities for the private sector?

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CCSA - what next for CCS?

2009 has been an important year for Carbon Capture and Storage (CCS), and the attention given to the importance of the technology has certainly stepped up a notch, with developments both on the regulatory and funding side, as well as a growing number of announcements to develop large-scale projects around the world. Even in a time of economic crisis there have been new opportunities and prospects for CCS and significant progress has been made that will hopefully lay the foundations for the development a long-term CCS industry.

By Stephanie Squire and Judith Shapiro, Carbon Capture and Storage Association (CCSA)

What has 2009 brought us?

The Carbon Capture and Storage Association (CCSA) began the year by becoming a founding member of the Global Carbon Capture and Storage Institute (GCCSI) that was launched in April, amid much excitement over the role that this new organisation could play.

The GCCSI has since become an independent legal entity and has really hit the ground running and with a commitment of AUD$100million per year from the Australian Government, the Institute has set ambitious plans to support the aim of accelerating commercial deployment of CCS.

Recent achievements include completion of two initial important reports; "strategic Analysis of the Global Status of CCS" and "An Ideal Portfolio of CCS projects and Rationale for Supporting Projects" We look forward to continued involvement as the organisation grows.

Perhaps the most significant progress to date on regulation came earlier this year when the EU CCS Directive was finalised and came into force in June (as part of the EU Climate and Energy package that was adopted in December 2008).

The CCS Directive establishes an essential legal framework for storing CO2 in Europe, and Member States now have less than two years to transpose the Directive into their own legal systems. The UK has been a leader in the area of regulation and the CCSA continues to be actively engaged with the Department of Energy and Climate Change (DECC) on details of how this legislation will work.

At the same time revisions to the EU Emissions Trading Scheme (ETS) for Phase III were also finalised as part of the Climate and Energy package. This Directive has introduced a crucial source of funding for CCS in the form of 300 million allowances (EUAs) set aside from the New Entrants Reserve in phase III (2013-).

The background to this funding is the EU aim to have 10-12 CCS projects in operation across Europe by 2015 – as agreed at the 2007 EU Spring Council. Depending on when these EUAs are auctioned, this could lead to support for both CCS and innovative renewables of up to €9 billion.

Details of how to distribute this funding are, however, proving to be controversial, particularly as it is likely that Member States will also need to provide additional support to the projects.

The issue of Member State versus EU Commission project selection is proving to be a difficult problem to resolve and discussions, which the industry is engaged in, are ongoing. It is hoped that the mechanism for distribution will be finalised soon.

Interestingly, the economic crisis has presented some opportunities for CCS – this has come in the form of recovery packages. Staying in Europe, €1.05 billion of funding for CCS was announced as part of the European Energy Programme for Recovery.

Thirteen projects across seven European countries were originally shortlisted as potential beneficiaries of the support and of those six have now been presented to the EU Parliament. The final announcement of the winners is expected imminently.

Further afield, the U.S. has made several funding announcements this year including $2.4 billion for CCS as part of the American Recovery and Reinvestment Act – in terms of projects, Hydrogen Energy has received a $308 million grant for its IGCC project in Kern County, California. Canada announced C$650 million for large-scale CCS as part of its clean energy fund and Australia also has its own CCS 'Flagships Program'.

These examples clearly show that the race for CCS is now on and the UK will have to work hard if it is to remain amongst the leading countries in this suite of technologies. In under a year the province of Alberta has selected its three winning projects to benefit from $2 billion, whereas the UK announced its competition in 2007 and a winner has yet to be chosen.

Having said that, there have been exciting announcements in the UK throughout this year and the Association has certainly been very busy, with membership continuing to grow. Activities have included engaging with Government, in particular on the recent consultation 'A framework for the development of clean coal', which was launched in June, and also more generally on funding and regulation.

We were pleased to see the announcement earlier this year as part of the consultation that the UK would support up to four CCS demonstration projects through a levy mechanism. We now urge the Government to commit to four (rather than up to four) and consider how to address support that might be needed for further roll out, particularly if (as the Committee on Climate Change has recommended) we are to decarbonise electricity by 2030.

The UK published its Low Carbon Transition Plan in July this year, setting out how to meet the first statutory carbon budget of 34% cut in emissions by 2020, as recommended by the Climate Change Committee. As part of this plan, it is encouraging to note that the Government has emphasised the trinity of renewables, nuclear and clean fossil fuels (CCS) to contribute 40% of UK electricity from low-carbon sources by 2020.

At present the investment climate for CCS in the UK is challenging. The uncertainty over the number of UK CCS projects to be funded in total (announced as "up to four" including the current competition project) also translates to increased investment risk.

To achieve the objective of wide-scale CCS deployment from 2020 will require a significant number of CCS projects before 2020, and a commitment to four projects by 2020 (rather than up to four) will enable the majority of the energy industry in the UK to undertake important learning and build sufficient supply chains for further roll out.

This will enable CCS to move down the cost curve at an early stage and bringing forward the point at which CCS can be deployed commercially.

Aside from engagement with Government, other activities of the CCSA have included jointly holding a dialogue on CCS with Green Alliance in September. The event brought together industry, NGOs and other

stakeholders to discuss policies and regulation relating specifically to CCS.

It was exciting to see over two days that whilst there are areas where different stakeholders disagree on how to progress, there were also many areas of broad agreement and much enthusiasm about the need to roll out this important climate change mitigation technology.

The Carbon Sequestration Leadership Forum (CSLF) held its ministerial meeting in October in London. The CSLF is an international initiative of 24 countries, focussed on facilitating the development and deployment of CCS technologies.

A CSLF stakeholder meeting, co-hosted by the CCSA, took place alongside the ministerial meeting and the International Energy Agency (IEA) also published its ambitious CCS roadmap at the ministerial meeting, setting out the role of CCS in meeting a global 50% reduction in emissions by 2050.

Statements that came out of both the CSLF meetings and the Major Economies Forum (that followed not long after) were encouraging and an important contribution to building momentum and underlining the importance of CCS in the run up to Copenhagen. This year has, in fact, seen new impetus to international activities on CCS and this has become a large focus of our work.

What will the coming months bring us?

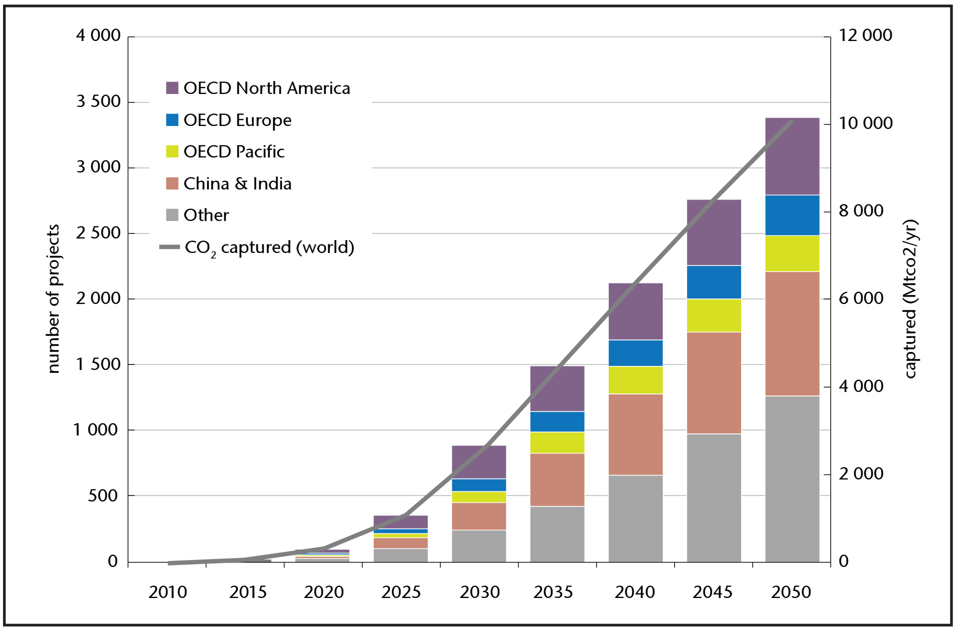
The UNFCCC meeting in Copenhagen in December is, of course, the major event for the climate. The expectations are high, but what outcomes can we really hope for? The Association is pushing hard for CCS to be recognised and supported in any future post-2012 agreement as an essential technology to addressing climate change.

Indeed, without CCS it may prove extremely expensive, and perhaps even impossible to avoid dangerous climate change whilst the inevitable use of fossil fuels continues.

The major issue for CCS will be the need to develop a mechanism to finance CCS projects in developing countries, whether this be as part of a reformed Clean Development Mechanism (CDM) or a new mechanism altogether.

Developing countries will be unable to finance CCS on their own and it is therefore imperative that a post-2012 agreement includes a mechanism that enables these countries to deploy CCS whilst continuing to develop their economies in a low-carbon manner.

The IEA estimates that, in order to meet our required mitigation pathway, 100 CCS projects will need to be operating worldwide by 2020 and more than 3000 by 2050 (see Figure above). The IEA calculates that this level of development by 2020 will require $130 billion of extra capital, 73% of this from OECD Governments.



Global deployment of CCS 2010–2050 (CO2 captured and number of projects) (Source: CCS Technology Roadmap, © OECD/IEA, 2009)

The UNFCCC agreement at Copenhagen must therefore allow for both large-scale public financing and ongoing market incentives to provide support for CCS development. On a wider point, the issues of knowledge sharing and technology transfer are proving difficult in the discussions leading up to the meeting.

It is likely that details of actions and agreements may well be negotiated beyond the Copenhagen meeting, and we expect further progress in this area in 2010.

Next year we also hope to see some important announcements on CCS from the UK Government. In particular the Association is looking forward to seeing the winner of the current competition announced.

The Committee on Climate Change recommended in their recent report that the next competition for the further one to three (or as we hope, three at least) demonstration projects should be announced, with the aim of seeing these projects coming online in 2015 or 2016, (perhaps just a year after the deadline for the current competition project).

We would urge the Government not to run further competition for the additional one to three projects as a series of individual competitions, as such an approach will only delay the development of CCS in the UK.

Instead we recommend holding one open competition for these projects as soon as possible, allowing as many projects as possible to bid across a variety of capture technologies, transport systems and storage options.

Funding remains the major barrier to CCS development and deployment and whilst the EU ETS is considered the long-term mechanism to incentivise low-carbon technologies, the current carbon price is insufficient and too uncertain to provide investment certainty to CCS project developers.

Once the first CCS projects are built, costs can begin to come down and further projects will also benefit from technology improvements. However, additional funding must be found in the period until CCS will be economically viable under the EU ETS and this is particularly the case for first-of-a-kind projects, which will be faced with the added burden of investing in the infrastructure that will support a long-term CCS industry.

Finally, one major issue is now beginning to have an impact on the development of CCS projects in several European countries – namely public perception.

The lack of awareness, but more importantly, the lack of public acceptance for CCS projects, has the ability to represent one of the major barriers to the deployment of CCS and Governments around the world must work together to tackle this issue as early as possible.

Important activities are happening around the world to develop guidelines for public engagement and these must be promoted and disseminated effectively, so that project developers can include a public engagement process that ensures successful project implementation.

Overall progress this year has been positive for CCS, and 2010 could be even better. The Association looks forward to another busy and exciting year in the world of CCS.

Global CCS Institute releases two major studies

The Global Carbon Capture and Storage (CCS) Institute has released a report, 'Strategic Analysis of the Global Status of Carbon Capture and Storage,' which shows that despite progress more demonstration projects are urgently needed. It also engaged L.E.K. Consulting to research and propose a theoretical 'Ideal Portfolio' of CCS projects, as well as a rationale for supporting projects.

In May 2009, a consortium led by WorleyParsons and comprising Schlumberger, Electric Power Research Institute and Baker & McKenzie was engaged to undertake the Strategic Analysis of the Global Status of Carbon Capture and Storage.

The consortium was tasked to undertake a comprehensive survey of the status of CCS and to develop a series of reports analysing CCS projects, the economics of CCS, policies supporting CCS development and existing research and development networks. A fifth report - the Synthesis Report - was also developed and this summarises the findings of the first four reports, and provides a comprehensive assessment of the gaps and barriers to the deployment of large-scale CCS projects, including strategies and recommendations to address these issues.

CCS global status

'Strategic Analysis of the Global Status of Carbon Capture and Storage' shows that the majority of advanced projects are focussed on coal-fired power generation, recognising the need to implement solutions that address the world's current and future use of coal in a carbon constrained environment.

It says that there is growing action being taken to achieve the G8 objective of deploying at least 20 commercial scale CCS projects globally by 2020. Despite this progress the report also showed that due to commercial, technical and regulatory hurdles there is the urgent need to rapidly identify and advance a larger and more diverse portfolio of projects to ensure success.

The study reveals that in order to accelerate the deployment of CCS projects the world must exploit cost advantages that exist in advancing projects in developing countries such as China and India, and industries such as natural gas processing and fertiliser production in which CO_2 capture is inherent in their design.

The study also confirms that greater efforts towards CCS need to be made within the cement, aluminium, iron and steel industries, given their significant contribution towards CO_2 emissions.

Global CCS Institute CEO Nick Otter said, "We know that many of the CCS technologies are available today to be applied across a range of industries to help reduce emissions. This report demonstrates the need to not only deploy more projects, more quickly, but to deploy more types of projects, and in more places, so that we can learn how to design the best possible facilities, bring down costs and create a valid business case for CCS."

The Global CCS Institute – an initiative to accelerate the worldwide commercial deployment of at-scale CCS – commissioned a WorleyParsons-led consortium to undertake what is the most comprehensive review and analysis of the world's current CCS projects.

The research was undertaken to advance the understanding of the status of CCS projects, the costs involved, the status of supporting policy initiatives, the research and developments efforts being pursued, and the gaps and barriers to deployment at scale.

Key findings of the report which demonstrate the depth of the action currently being taken include:

• There are 213 active or planned projects with 101 of commercial scale – demonstrating the existence of a significant pipeline of potential projects being investigated around the world.

• There are 62 fully integrated, commercial scale projects each of which demonstrates every stage of the CCS process chain of CO_2 capture, transport and storage. Seven of these projects are already operating and 55 are at various stages of progress making them potential candidates for contributing to the G8 objective.

• The leading developers of fully integrated, commercial scale projects include participants in the Europe (37%), USA (24%), Australia (11%) and Canada (10%), with distribution throughout Asia, South America and Africa relatively low.

The report highlights that widespread take-up of CCS is faced with the stark risk of high project failure rates typical with the adoption of new technologies, but that this can be overcome by targeted project support, and appropriate incentives for development. Recommendations put forward by the report call for governments to partner with industry to address the challenges facing project success.

The recommendations suggest urgent action on three major fronts:

• Actively working with the 55 active or planned fully integrated projects to improve their likelihood of success.

• Developing national strategies where absent to provide incentives to innovate or invest in CCS technology.

• Establishing a regulatory framework that assigns a value to carbon

The ideal portfolio

The world needs to broaden the commercial development of CCS projects across industries, geographies and technologies in order to accelerate deployment, according to the Global CCS Institute's second key report.

The portfolio study consists of two sections: the Ideal Portfolio which describes the range of projects that would address different hurdles to CCS deployment; and the Rationale for Supporting Projects which describes possible ways in which the Global CCS Institute can identify and support CCS projects as they relate to an Ideal Portfolio.

Global CCS Institute CEO Nick Otter said "The iron and steel, and cement industries are responsible for over 20 per cent of the world's CO_2 emissions. If CCS is to contribute to the deep cuts in emissions the world needs, then industry must be part of the solution."

The report naturally prioritises the Power Generation sector, given its own contribution to global emissions and the scale and effort it is putting into CCS, recommending a minimum of 17 projects types but spreading them across different fuel and technology combinations.

The report recognises that some industry sectors, including gas extraction and processing, while representing only a small share of global emissions, already carry out CO_2 separation. These industries can provide early opportunities for CCSdevelopment, and are also prioritised in an Ideal Portfolio due to their ability to accelerate deployment.

It is recommended that the majority of projects in an Ideal Portfolio be located in North America, Europe and China due primarily to their share of global emissions. Australia and Japan are also classified as priority regions with an allocation of approximately 15 per cent of projects, due to their favourable policy and regulatory environments.

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

CCP publishes research conclusions

The CO2 Capture Project (CCP), a partnership of eight oil & gas majors, recently presented the findings from the last five years of work to world energy and environmental ministers attending the Carbon Sequestration Leadership Forum in London (12-14 October).

By Iain Wright, CO2 Capture Project (CCP)

The CCP is an industry wide effort to develop the technologies and operational approach to accelerate the deployment of carbon capture and storage. In acknowledgement of its contribution to the advancement of CCS the group received the prestigious CSLF Recognition award. Established in 2000, the CCP has built a reputation as a technical authority on CCS.

The CCP's findings, published in a book entitled 'Advances in CO2 Capture and Storage Technology', represent five years of research and more than 150 exploratory projects. They are the result of a collaborative effort between its members: BP, Chevron, ConocoPhillips, Eni, Petrobras, Shell, StatoilHydro and Suncor. These oil & gas majors worked alongside governments (including the US Department of Energy, the EU and the Norwegian Research Council) and 60 academic institutions and leading environmental and industry groups.

A summary of the findings from 'Advances in CO2 Capture and Storage Technology' and details on how to obtain a copy can be found on www.co2captureproject.org

Highlights from the Results Book 'Advances in CO2 Capture and Storage' include:

CO2 Storage

CO2 Capture Project (CCP) studies have addressed outstanding issues and confirmed that CO2 can be stored underground safely and securely.

Development of a Certification Framework: Providing a simplified workflow protocol for assessing CO2 storage sites.

The CCP developed a Certification Framework for the geological storage of CO2 to provide a simple, transparent guide to site certification, essential to help decision makers to manage the CO2 storage process.

This simple, transparent and comprehensive framework was developed in partnership with three leading institutions in CO2 storage and addresses the need for a consistent and accessible approach to understanding risks associated with CO2 storage. It consists of three parts:

1) platform for input of geological data

2) specialized tools that predict the behaviour of CO2 in the subsurface and

3) risk calculation.

A Well Integrity Field Study – Addressing critical issues for CO2 storage

Conflicting data has existed on the long-term well integrity – a crucial issue for CO2 storage. The CCP's ambitious Well Integrity Field Study addressed the risks that the presence of injected and stored CO2 would have on the containment integrity of existing and newly drilled wells.

The field study, at a natural CO2 production well in Colorado, reached a number of crucial conclusions. A chief finding was that cement placement was actually more significant in resisting CO2 migration along the barrier system than the choice of cement itself.

It proved that a well's barrier performance is not necessarily compromised by CO2 alteration, and that good drilling and installation practices are more important than material choice for long term well stability – a crucial finding. A second study is underway at the Buracica Field, Brazil, and continued research is planned.

CO2 Capture

The CO2 Capture Project (CCP) has made crucial progress in identifying technologies with the highest potential. Around ten potential capture technologies, spanning the range of techniques: post-combustion, pre-combustion and oxy-fuel were identified from more than 200 capture technologies reviewed. These technologies have been developed further and are now being evaluated before being taken forward for demonstration.

Identification of a preferred CO2 capture method for oil refineries

Significant progress has been made towards CO2 capture from the oil refining process. As the second largest industrial emitters of CO2 oil refineries face specific and considerable challenges. Oxy-fuel combustion has been shown to offer the greatest potential, both technically and economically, for capturing CO2 emitted by the largest source in oil refineries, the Fluid Catalytic Cracking unit (FCC).

A pilot test in an industrial scale refinery is scheduled for next year. The CCP is also working to extend oxy-firing technology to other CO2 emitting units of the refinery, namely process heaters and boilers.

Potential for CO2 capture from extraction of heavy oil

A novel advanced oxy-firing technology - chemical looping combustion (CLC) - has been developed, which has the technical and economical potential in the mid-term for scaling up to capture CO2 from heavy oil steam extraction processes. Significant development challenges remain, but the potential rewards are huge.

Post-combustion - most likely short-term option for gas fired power stations

The lower concentrations of CO2 in gas fired power station flue gas make this a challenging – but important – area for capture technology development. Post-combustion identified as most likely short-term option for capturing CO2 from gas fired power stations, although pre-combustion may be more viable in the long-term. The CCP has the challenge of identifying and further developing significantly lower costs for CO2 technology.

What next for the CO2 Capture Project?

The CCP will now enter its third phase – using insights from the first two phases to further test and trial high potential technologies. The third phase will provide practical solutions to the need of the oil & gas industry to reduce its own CO2 emissions from both traditional and unconventional operations, without incurring considerable extra costs.

It is clear that with the right encouragement, carbon capture and storage is capable of playing a significant role in CO2 mitigation, and the oil & gas industry is well placed to make a significant contribution to its development.

The CO2 Capture Project has made significant progress over the last eight years towards addressing the remaining technical questions surrounding carbon capture and storage. It has provided an example of how public-private partnerships can work to rapidly close technical gaps.

If CCS is to become part of the solution for managing climate change, governments and industry will not only collaborate on technology development but also on deployment. CCS will need to receive a clear signal that it has the support of government.

UK policy - on the pathway to clean coal?

The UK government has released a series of policy statements designed to speed up planning permissions and clarify the requirements for CCS in coal fired power plants. Is it enough?

Six draft National Policy Statements (NPS), one overarching and one for each of the following areas: fossil fuels, nuclear, renewables, transmission networks and oil and gas pipelines, have been released to guide planning decisions on energy infrastructure.

Alongside the NPSs, a 'Framework for the Development of Clean Coal' was published, setting out the requirements for new and existing coal plant. Following a consultation in June, the document confirmed:

No new coal without Carbon Capture and Storage (CCS): With immediate effect, to gain development consent all new coal plant will have to show that they will demonstrate the full CCS chain from the outset on at least 300 MW net of their total output.

A programme of up to four commercial-scale CCS demonstrations, including both pre-combustion and post-combustion capture technologies, will be funded by a new CCS Incentive. Legislation to introduce this has been proposed for the forthcoming Parliamentary session.

A long term transition to clean coal: The demonstration plants are expected to retrofit CCS to their full capacity by 2025, with the CCS Incentive able to provide financial support for their retrofit.

A rolling review process, which is planned to report by 2018, will consider the case for new regulatory and financial measures to further drive the move to clean coal.

Also confirmed is that the Government has received two bids - from E.ON and Scottish Power - to proceed to the next stage of the current CCS demonstration competition. It is expected that contracts for the detailed design stage will be concluded early next year.

The UK Government also published its guidance on carbon capture readiness, which is intended to give practical advice on the type of information Section 36 applicants need to submit to the Secretary of State to demonstrate that a proposed new combustion plant can be built carbon capture ready (CCR).

The CCR requirements only apply to new combustion plant which have an electrical generating capacity at or over 300 MW and which are of a type covered by the Large Combustion Plant Directive.

Doosan Babcock urges more ambition from UK Government

Doosan Bacock issued a response to the DECC consultation on the development of clean coal following the meeting of key energy industry representatives at the Institute of Chemical Engineers.

The response calls for action to enable CCS to be introduced more rapidly than the proposed timeline, and for a more extensive demonstration programme to be put in place.

According to the company, unless the current policy details are changed there is a risk that the DECC proposals will fail to meet objectives and no new coal-fired power plants or CCS demonstrations will be built.

Doosan Babcock believes that clean coal will be less expensive than other low carbon options, much cleaner and more secure than unabated gas-fired power, more reliable and less expensive than intermittent wind, and more relevant to global needs.

Doosan Babcock proposes a "Middle Way" which should satisfy both electricity companies and NGOs while delivering all four government objectives, plus a large contribution to carbon dioxide reductions by 2020.

A 'Middle Way' approach would include a commitment by Government to at least four clean coal projects (not just up to four) covering at least three capture technologies and two or three options for storage in time to announce this in the run up to the Copenhagen meeting.

"A more ambitious programme of demonstrations funded by a contract for difference levy scheme could provide almost 5GW of CCS capacity by 2020," said Iain Miller, CEO, Doosan Babcock Energy Ltd.

"This would generate reliable, low carbon electricity at an acceptable cost. The 'Middle Way' is central to achieving the objectives set out in the DECC Consultation and urgent action is needed to ensure plans for CCS in the UK remain on track."

UK lagging on CCS - ICE report

The Institution of Civil Engineers (ICE) report, "Carbon Capture and Storage – Time to Deliver" outlines the steps needed to deliver CCS not only domestically but also on a global scale. The UK has the potential to be a world leader in CCS technology, creating a major export opportunity, but needs Government to provide a clear strategic overview to avoid unnecessary delays, the report says.

"The UK was quick on the uptake in the global race to deploy CCS but now we have fallen behind other nations. If we want to keep a competitive lead and take advantage of the export opportunity it presents, progress needs to be greatly accelerated," said ICE Vice President Geoff French.

"We have the skills and the expertise to deliver global solutions - all we're waiting on is Government to take the lead and provide the steps to get us there. In the current climate there is no incentive for utility providers to sink billions of pounds into projects that have no certain future."

The ICE report features papers from six leading experts on different aspects of CCS including regulation, storage, transportation, investment, pre and post combustion alternatives and its role in creating a low carbon economy.

The six papers are:

1. Carbon capture and storage – an essential part of our low carbon economy, Dr Jeff Chapman, The Carbon Capture & Storage Association

Globally, energy generation still relies largely on fossil fuels. Capturing and storing the emissions from this process is going to be fundamental in the global fight against climate change.

2. Carbon Capture and Storage – the technologies, Peter Whitton, Progressive Energy Ltd

There are currently several carbon capture technology alternatives ready for commercial use. The fundamental division is between 'pre-combustion' and 'post-combustion capture technologies.

3. Carbon capture and storage – moving to implementation, Alastair Rennie, AMEC

Carbon capture and storage can offer big benefits but it is costly and requires political will. Transport and storage solutions could offer international dividends but further planning is needed.

4. Geological Storage of Carbon Dioxide, Steve Murphy, Co2 Deep Store

The major issue remaining unresolved in the CO2 storage debate is how to tackle the long-term possibility of leakage.

5. Winners, losers, China, NPV and self-service check-outs: the role of policy in carbon capture and storage investment decisions, Ian Templeton, head of Advisory team, Climate Change Capital

Investment in CCS is crucial. Unfortunately the rush to make quick political decisions means thus far incentives have not been an integral part of the policy-making process.

6. Carbon capture and storage regulation, Andrew Raingold, deputy director, Aldersgate Group

A clear regulatory framework for the deployment of CCS is essential to ensure its effective implementation.

Policy, company and regulation news

Alstom and AEP formally commission Mountaineer CCS demonstration

www.power.alstom.com

Federal and state officials joined Alstom and American Electric Power (AEP) at AEP's Mountaineer Plant to formally commission the world's first project to both capture and store CO2 from a coal-fired power plant.

AEP's Mountaineer plant is a 1,300-megawatt electrical (MWe) coal-fired unit that was retrofitted earlier this year with Alstom's patented chilled ammonia CO2 capture technology on a 20-MWe slipstream of the plant's exhaust flue gas.

The slipstream of flue gas is chilled and combined with a solution of ammonium carbonate, which absorbs the CO2 to create ammonium bicarbonate. The ammonium bicarbonate solution is then is pressurized and heated in a separate process to safely and efficiently produce a high-purity stream of CO2.

The CO2 will be compressed and piped for storage into deep geologic formations, roughly 1.5 miles beneath the plant surface. Approximately 90 percent of the CO2 from the 20-MW slipstream will be captured and permanently stored.

AEP has applied for federal stimulus funding to scale-up the Alstom chilled ammonia technology to 235-MWe at Mountaineer Plant. The proposed commercial-scale demonstration will capture and geologically store approximately 1.5 million metric tonnes per year of CO2.

The Mountaineer CCS demonstration project began capturing CO2 Sept. 1 and storing it Oct. 2, and is designed to capture at least 100,000 metric tonnes of CO2 annually.

AEP's 1300MW Mountaineer coal-fired power plant in New Haven, West Virginia, is using Alstom's chilled ammonia technology to capture CO2 from a 20MW slipstream and store it underground

Alstom and Schlumberger in CCS partnership

www.slb.com

Alstom and Schlumberger have signed an agreement for mutual collaboration in the joint offering of CCS-ready studies.

The studies will consist of a technical analysis of a power plant to identify how it should be adapted to accommodate an Alstom CCS system. The studies will also include an evaluation of potential CO2 storage sites for the power plant, as well as an evaluation of required investments for future CO2 transport and storage.

This is designed to facilitate the future conversion of power plants to CCS and the securing of environmental permits as well as optimising time-to-market periods and associated costs.

"Our customers are increasingly demanding full support, from the flue gas outlet to the downhole, to ensure that their new power plants are CCS ready. Assessing this readiness will be a mandatory requirement for all large fossil-fuelled power plants in Europe by 2011. Similarly, the State of Queensland in Australia recently announced that no new coal fired power station will be approved in the state unless it is CCS ready" said Andreas Lusch, Senior Vice President, Alstom Power Thermal Systems.

The first wave of large-scale CCS demonstration projects, such as AEP's Mountaineer in the United States or Vattenfall's Schwarze Pumpe in Germany, also requires an integrated approach along the value chain. This agreement is designed to offer this type of comprehensive service, both for new and existing power plants.

Global CCS Institute provides project deployment funding

www.globalccsinstitute.com

The Global Carbon Capture and Storage Institute has announced the injection of AUD $3.6 million towards ensuring the creation of the right level of knowledge and expertise to accelerate the deployment of CCS projects globally.

Of the funding, AUD $1.2 million will be directed towards the CSLF's Capacity Building Program, with the aim to identify capacity building activities in key developing countries, and to deliver both technical and non-technical workshops globally.

In conjunction with a significant contribution from the Norwegian Government, the Global CCS Institute has also provided AUD $2.4 million to the World Bank CCS Trust Fund in further support of CCS capacity building. This funding will be aimed at creating opportunities for developing countries to explore CCS potential, realise the benefits of domestic technology development and progress and facilitate appropriate policy initiatives.

CSLF begins capacity building program

www.cslforum.org

A new Capacity Building Program will assist the 24 members of the Carbon Sequestration Leadership Forum (CSLF) in implementing CCS demonstrations and help accelerate commercial deployment.

The Program will assist all CSLF members in developing the "information, tools, skills, expertise and institutions required to implement CCS demonstrations and then move rapidly into commercial operation," the Program Plan's Mission Statement says.

CSLF said the Capacity Building Program will address the fact that CCS is "new and the capacity to widely implement it is not yet adequate in either emerging or industrialized economies."

The Program Plan said while specific needs vary by nation, four basic tasks are required to implement CCS:

• Identifying and characterizing CO2 sources and potential reservoirs, and then matching sources to potential reservoirs;

• Analyzing and formulating policy and legal/regulatory frameworks;

• Conducting pre-feasibility, feasibility, and regulatory studies to evaluate and support decisions about proposed projects;

• Implementing projects through planning, financing, construction, operation, and monitoring.

Four capacity building program initiatives will accelerate the deployment of CCS, CSLF said:

(1) disseminating practical information; building capacity in emerging economies; (3) assisting activities by government and regulatory agencies; and (4) the building of academic and research institutions for CCS.

The Program Plan said greater levels of funding than previously committed are needed to support the new initiative, and anticipates expenditures of $5 million annually for the remaining four years of the CSLF term.

First CCS project in Portugal

www.tejoenergia.com
www.bellona.org

Tejo Energia will assess the feasibility of applying CCS at its Pego coal power plant, according to Bellona.

The project is co-funded by the National Strategic Reference Framework (NSRF), through the EU-funded Operational Agenda for Competitiveness Factors (COMPETE) and will be jointly developed by the University of Évora and the National Laboratory for Energy and Geology (LNEG), Tejo Energia (the plant owners) and Pegop (plant operators).

The Pego coal-fired power plant is owned by Tejo Energia, a joint venture between International Power (50%), Endesa (39%) and Energias de Portugal (EDP) (11%). The power plant, located near the river Tejo in central Portugal, has a capacity of around 600 megawatt (MW) electricity and emits around four megatonnes of CO_2 per year.

Tejo Energia has also begun to build a new combined cycle gas turbine plant. The 530 million euro project will use natural gas as fuel and is expected to fully operate in the first quarter of 2011. By 2011 and with an installed capacity of 1,430 MW (600 MW produced by the coal-fired power plant and 830 MW by the new gas plant), the Pego area will be the most important electricity producing region in Portugal.

(Source: Martina Novak, The Bellona Foundation, an environmental NGO based in Norway.)

DOE funds joint training and research projects

Forty-three research projects that will advance CCS technologies while providing graduate and undergraduate student training opportunities at universities across the country will be supported by $12.7 million in U.S. Department of Energy funding.

Spread over three years, the regional sequestration training projects and funding will be managed by the Office of Fossil Energy's National Energy Technology Laboratory.

The projects are funded through the 2009 American Reinvestment and Recovery Act and are aimed at the broad objectives of advancing CCS scientific, technical, and institutional knowledge while simultaneously producing the expertise and workforce needed for the emerging carbon capture and storage industry.

Projects have been selected across the US and collectively they will focus on providing advanced research training in simulation and risk assessment; monitoring, verification, and accounting; geological related analytical tools; methods to interpret geophysical models; and carbon dioxide capture.

Twelve projects to be selected for major US CCS funding

fossil.energy.gov

U.S. Energy Secretary Steven Chu has announced the first round of funding from $1.4 billion from the American Recovery and Reinvestment Act.

The funding will be for the selection of 12 projects that will capture CO_2 from industrial sources for storage or beneficial use.

The first phase of these projects will include $21.6 million in Recovery Act funding and $22.5 million in private funding for a total initial investment of $44.1 million. The remaining Recovery Act funding will be awarded to the most promising projects during a competitive phase two selection process.

The initial duration of each project selected is approximately seven months. Projects will be subject to further competitive evaluation in 2010 after successful completion of their Phase 1 activities. Projects that best demonstrate the ability to address their mission needs will be in the final portfolio that will receive additional funding for design, construction, and operation.

The projects include:

* Air Products and Chemicals Inc. (Allentown, Pa.)— A state-of-the-art system to concentrate CO_2 from two steam methane reformer waste streams will be designed, constructed, and demonstrated at Port Arthur, Texas. More than one million tons of CO_2 will be delivered per year via pipeline for sequestration into the Oyster Bayou oilfield for enhanced oil recovery by Denbury Onshore LLC. (DOE Share: $961,499)

* Archer Daniels Midland Corporation

(Decatur, Ill.)— Archer Daniels Midland Company, a member of DOE's Midwest Geological Sequestration Consortium, will partner with other research organizations to demonstrate Dow ALSTOM's advanced amine process to capture CO2 from industrial flue gases and sequester the CO2 in the Mt. Simon Sandstone reservoir. (DOE Share: $1,480,656)

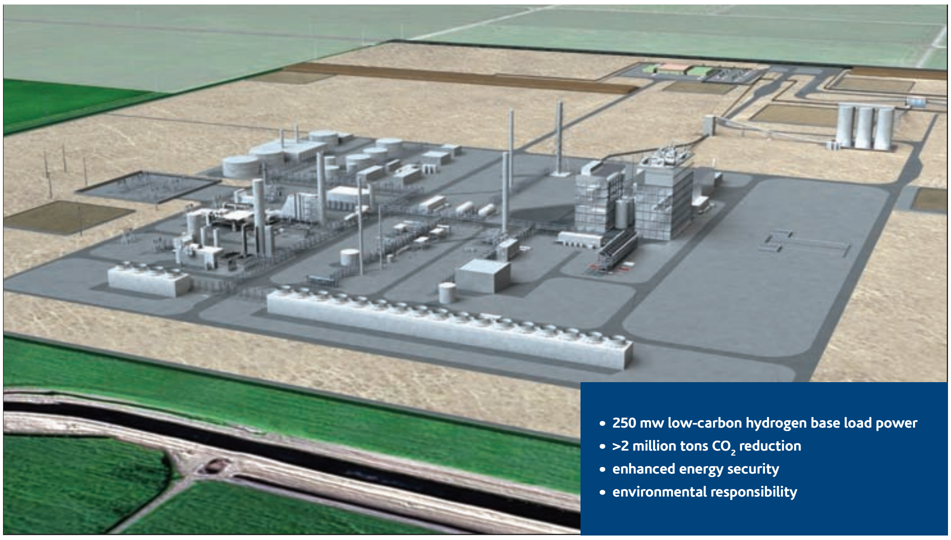
* Battelle Memorial Institute, Pacific Northwest Division (Richland, Wash.)— Battelle researchers will partner with Boise White Paper LLC and Fluor Corporation to demonstrate geologic CO2 storage in deep flood basalt formations in the State of Washington. Fluor Corporation will design a customized version of its Econamine Plus™ carbon capture technology for operation with the specialized chemical composition of exhaust gases produced from combustion of black liquor fuels. (DOE Share: $500,000)

* C6 Resources (Salno, California)— Objective is to capture and transport by pipeline approximately one million tons per year of CO2 streams from facilities located in the Bay Area, Calif., to be injected more than two miles underground into a saline formation. C6 Resources, an affiliate of Shell Oil Company, will conduct the project in collaboration with Lawrence Berkeley National Laboratory and Lawrence Livermore National Laboratory. (DOE Share: $3,000,000)

* CEMEX Inc. (Houston, Texas)— CEMEX USA will partner with RTI International to demonstrate a dry sorbent CO2 capture technology at one of its cement plants in the United States. CEMEX will design and construct a dry sorbent CO2 capture and compression system, pipeline (if necessary), and injection station. This commercial-scale carbon capture and sequestration demonstration project will remove up to one million tons of CO2. (DOE Share: $1,137,885)

* ConocoPhillips (Houston, Texas)— ConocoPhillips will demonstrate new advancements that improve conversion efficiency and economies of scale for carbon capture systems at a petcoke-based 683-megawatt integrated gasification combined cycle (IGCC) power plant adjacent to its existing refinery in Sweeny, Texas. About 85 percent of the CO2 from the process stream will be captured and over five million tons sequestered into a depleted oil or gas field. (DOE Share: $3,014,666)

* Leucadia Energy LLC (New York, N.Y.)— Partnered with Denbury Onshore, Leucadia Energy will demonstrate advanced technologies that capture and sequester more than 4 million tons of CO2 emissions at the Lake Charles co-generation petroleum coke-to-chemicals (methanol) project to be located near Lake Charles, La. The project will transport compressed CO2 through a 12-mile pipeline that connects to Denbury's Green Line pipeline system in Louisiana so that it can be used for enhanced oil recovery in the Hastings and Oyster Bayou oilfields in Texas. (DOE Share: $540,000)



Hydrogen Energy California's proposed IGCC plant in Kern County, California (image: HECA)

* Leucadia Energy LLC (New York, N.Y.)— Leucadia Energy and Denbury Onshore will demonstrate advanced technologies that capture and sequester CO2 emissions from an industrial source. Mississippi Gasification LLC, a Leucadia affiliate, is building a petcoke-to-substitute natural gas plant in Moss Point, Miss., to demonstrate large-scale recovery, purification and compression of 4 million tons per year of CO2. (DOE Share: $840,000)

* Praxair Inc. (Danbury, Conn.)— Praxair will partner with BP Products North America, Denbury Resources, and Gulf Coast Carbon Center to demonstrate capture and sequestration of CO2 emissions from an existing hydrogen-production facility in an oil refinery into underground formations for CO2 enhanced oil recovery. This demonstration will be performed at the BP refinery, and a lateral pipeline will be built to connect to Denbury's Green Pipeline to transport one million tons of CO2 per year. (DOE Share: $1,719,464)

* Shell Chemical Capital Company (Houston, Texas)— The objective of this project is to capture, condition, and transport by pipeline approximately one million tons per year of by-product and off-gas CO2 streams from facilities located along the Mississippi River between Baton Rouge and New Orleans for geologic storage. (DOE Share: $3,000,000)

* University of Utah (Salt Lake City, Utah)— More than one million tons of CO2 per year will be captured from various industrial sources, compressed, and transported via two new intra-state pipelines for CO2 enhanced oil recovery and deep saline sequestration research in Kansas. Beneath each enhanced oil recovery target, a major saline aquifer spanning most of the State of Kansas will be used for CO2 injection. (DOE Share: $2,696,556)

* Wolverine Power Supply Cooperative Inc. (Cadillac, Mich.)— Investigators will demonstrate advanced amines and additives supplied by Hitachi and Dow to capture 300,000 tons of CO2 per year. Wolverine Power Supply Cooperative will be building a 600-megawatt circulating fluidized bed power plant near Rogers City, Mich. (DOE Share: $2,723,512)

DOE and Hydrogen Energy sign IGCC agreement

www.hydrogenenergycalifornia.com

The U.S. Department of Energy (DOE) has signed a cooperative agreement with Hydrogen Energy California (HECA) to build and demonstrate an IGCC plant with CCS in Kern County, California.

HECA, which is owned by Hydrogen Energy International, BP Alternative Energy, and Rio Tinto, plans to construct an advanced integrated gasification combined cycle (IGCC) plant that will produce 250 megawatts of electricity using a blend of 75 percent coal and 25 percent petroleum coke.

Approximately 90 percent of the CO2 produced from the gasification process, or about 2 million tons per year, will be transported via pipeline to the Elk Hills oilfield, less than four miles away, where it will be used for enhanced oil recovery.

The project is part of the Clean Coal Power Initiative (CCPI), a cost-shared collaboration between the federal government

and private industry to increase investment in low-emission coal technology by demonstrating advanced coal-based power generation technologies prior to commercial deployment. The project will be cost-shared and administered by DOE's Office of Fossil Energy and the National Energy Technology Laboratory.

The estimated capital cost for the project is approximately $2.3 billion. The federal cost-share is limited to $308 million, or just under 11 percent of the total project costs. The project consists of three phases: project definition (phase I), design and construction (phase II), and demonstration (phase III). Sequestration of 2 million tons per year of CO2 is due to begin by 2016.

Toshiba completes CCS pilot plant

www.toshiba.co.jp

Toshiba Corporation has completed construction of a pilot plant to support development and validation of its carbon capture technology.

The pilot plant is located in Sigma Power Ariake Co. Ltd.'s Mikawa Power Plant, in Omuta City, Fukuoka Prefecture, Japan.

At the Mikawa pilot plant, Toshiba will deploy and validate its latest separation and capture technology. The Mikawa pilot plant is designed to capture 10 tons of CO2 a day from actual live flue gas of the boiler of the coal-fired thermal power plant.

The pilot plant will be used to verify the performance and operation of the system when practically applied to thermal power plants, including but not limited to the verification of the effects of flue gas contents on system operation.

The knowledge will then be used to help design systems and equipment for utility-scale power plants, which will finally be optimally integrated with other power plant equipment, such as turbines and boilers.

Toshiba initiated its R&D into CCS in 2006, focusing on an amine based chemical absorption system that consumes less energy in the CO2 separation and capture process, and has verified through small scale testing that its performance matches the leading levels in the industry.

The company established a new CCS development and promotion organization in October 2008, and is seeking to further accelerate practical application and commercialization of its technology.

Toshiba's goal is to establish a business able to meet emerging needs for commercial scale CCS systems for thermal power plants by 2015. The company targets net sales of 100 billion yen in 2020 in CCS-related business.

The Fortum and Teollisuuden Voima Oyj (TVO) Meri-Pori power plant in Finland where Siemens' capture technology will be used (Image ©Fortum)

Siemens, Fortum and TVO cooperate on Finnish project

www.siemens.com/energy
www.fortum.com

Siemens Energy has been selected as the capture technology partner for the FINNCAP - Meri-Pori CCS project by the owners of Meri-Pori power plant, Finnish utilities Fortum and Teollisuuden Voima Oyj (TVO).

The coal-fired power plant is located at Pori in Western Finland and has an installed capacity of 565 MW. The CCS demonstration is planned to treat approximately 50 percent of Meri-Pori's flue gas and to capture 90 percent of the CO2 it contains.

Meri-Pori's CCS demonstration is among the largest post-combustion capture projects yet announced in Europe. Fortum and TVO plan to apply for the European Flagship Programme with Siemens capture technology combined to a ship transportation and geological storage solution.

The selection for the first tranche of the Flagship Programme is expected to take place in 2011 and the final investment decision in 2011-2012. The plant is scheduled to be in operation in 2015.

"We have selected Siemens post-combustion carbon capture technology for our CCS plant, out of several other technologies," says Tapio Kuula, President and CEO of Fortum. "The Siemens technology seems especially promising in terms of energy efficiency and emissions control. Meri-Pori CCS plant is one of the key projects in Fortum's CO2-reduction programme."

The development of Siemens' post-combustion capture technology is funded by the German Federal Ministry of Economics and Technology and part of the COORETEC initiative.

UK Centre for Low Carbon Futures created

www.yorkshire-forward.com

The Centre for Low Carbon Futures, a £50 million virtual project, will combine the expertise of universities in Hull, Leeds, Sheffield and York to research issues relating to climate change.

The centre has two main aims - to create a sustainable regional economy and to research ways of coping with climate change. It is supported by Yorkshire Forward, a regional development agency.

Researchers will provide practical solutions for ways in which Yorkshire organisations and businesses can reduce their carbon emissions. It is hoped that suitable methods and technologies could be used across the country and the rest of the world.

It's first four pilot projects will be focused on climate change, low carbon supply chains, biorenewables and carbon capture technology.

CCS cannot significantly reduce tar sands emissions - WWF report

www.co-operative.coop

A study produced by The Co-operative Financial Services and WWF-UK claims to debunk the idea that CCS will significantly counter the high levels of greenhouse gases emitted in the production of oil from tar sands deposits in Alberta, Canada.

The report, 'CCS in the Alberta oil sands – a dangerous myth,' examines the potential for CCS to prevent CO2 from entering the atmosphere as a result of tar sands production and concludes that the process could not possibly achieve what has been claimed.

The study says that:

* Whilst the amount of CO_2 emitted during production needs to be reduced by around 85% to make tar sands oil comparable with conventional oil, even the most optimistic forecasts for CCS see production emissions reduced by 10 to 30% at selected locations by 2020 and 30 to 50% across the industry by 2050.

* Even under the most optimistic scenarios for the application of CCS, the projected production emissions from tar sands developments would be greater than the whole of Canada's 2050 carbon budget were it to reduce emissions by 80% compared with 1990 levels, as the climate science requires.

* The maximum potential of CCS would be insufficient to reduce lifecycle emissions of tar sands oil to levels needed to meet emerging international low carbon fuel standards such as those in California and the EU.

Paul Monaghan, Head of Social Goals at the Co-operative Financial Services said, "Last year we published a report which found that Canada's tar sands could increase atmospheric CO_2 by more than 10 parts per million, which would take us right to the edge of runaway climate change. The industry's response was that CCS would address this threat. Today's report shows that even the most wildly optimistic scenarios for the development of CCS fail to bring emissions down to those of today's conventional fossil fuels."

International award for SINTEF CCS project

www.sintef.no

SINTEF's DYNAMIS project received the "CSLF Recognition Award" at the Carbon Sequestration Leadership Forum's (CSLF) ministerial meeting in London for its contribution to CCS research.

The DYNAMIS project is the first phase of the EU's HYPOGEN programme, which is intended to lead to the construction of an advanced full-scale power station that will generate both hydrogen and electric power, and will be fitted with CO_2 capture and storage technology. The facility will be operational by 2015.

DYNAMIS has already carried out a thorough evaluation of the potential for full-scale hydrogen and electricity generation complemented by CO_2 capture and storage, and the project has focused on the technological, economic and societal aspects of the process. International collaboration is a prominent feature of the project, which is supported by industrial companies and organisations from all over Europe.

GE Oil & Gas secures $400M Gorgon contract

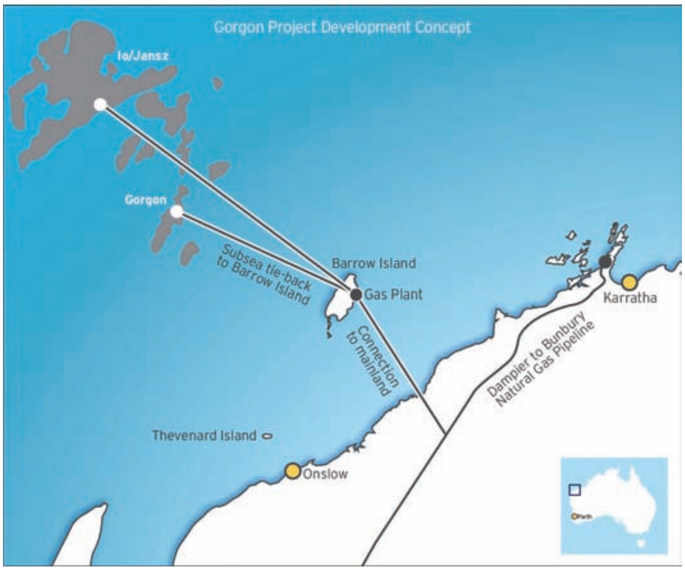
www.ge.com

GE Oil & Gas has been awarded a competitive bid worth over $400 Million to deploy equipment for LNG production along with CO2 storage at Gorgon in Australia.

GE will supply Chevron with:

• Three Main Refrigerant Compression Trains required for Gorgon's production of 15 million tonnes per annum (MTPA) LNG – equating to three shipments a week leaving Gorgon's purpose-built LNG loading jetty;,

• Six Compression Trains required to drive Gorgon's carbon C02 project, the world's largest - injecting up to four times more carbon dioxide than any other project worldwide.



Map of the Gorgon Project (image ©Chevron)

The Gorgon natural gas fields are located at Barrow Island, around 130km off Western Australia. Gas will be extracted and delivered via subsea and underground pipelines to gas treatment and liquefaction facilities on Barrow Island's south east coast.

Three 5-MTPA GE Main Refrigerant Compression Trains, each comprising two GE Frame-7 Gas Turbines plus liquefaction compressors, will be used for the production of liquefied natural gas by chilling to –160°C, ready for shipping, before re-gasification and pipeline transportation for use by domestic and industrial customers.

Prior to liquefaction CO_2 will be stripped out and injected into the depleted natural gas wells 1,300-meters deep to ensure its safe storage and the reduction of emissions. Six surface operating, 15 MW electric-motor driven GE Compression Trains will be used.

The GE Main Refrigerant Compression Trains and the GE Compression Trains for CO_2 sequestration will be manufactured and tested in Florence and Massa, Italy, then shipped in 2011 and 2012.

ITF secures contract for UK new energy technology transfer network

www.innovateuk.org

ITF, the oil Industry Technology Facilitator has secured a three year, six figure sum contract to deliver a new energy network for the UK industry.

Part of a consortium appointed to run the network on behalf of the UK government's Technology Strategy Board (TSB), the new energy knowledge transfer network (KTN) was unveiled at Innovate '09 in London.

At the meeting Dr Brian Cane, Director of the Energy Generation and Supply KTN, hosted a workshop on 'Supporting and Enabling Innovation in Energy'. The session included representation from the Technology Strategy Board, the Energy Technology Institute, the Research Councils and The Carbon Trust, and attracted over 100 people.

A UK-wide network, the Energy KTN was established to open up opportunities for collaboration and knowledge sharing across all energy sectors.

ITF's KTN role is to focus on maximising oil and gas resources The network will also deliver opportunities for developing new technologies in offshore wind, wave and tidal, carbon abatement technologies, including carbon capture & storage and biomass, hydrogen and fuel cells and future emerging opportunities.

Membership of the Energy KTN will be free of charge and open to the entire energy community, including industry, investors, academia, innovators, government bodies and regulators.

Registered members will benefit from access to services such as research and development funding, project financing, supply chain opportunities and market and policy information. The KTN's services will be delivered through a range of networking events and via an interactive web portal and enquiry help desk.

Calix – a carbon capture breakthrough

Calix Limited has developed a new Calcium Looping technology that may capture carbon dioxide at less than €15/tonne. Applications are being developed for power station or cement works retrofit, hydrogen generation from coal or lignite, and for new power generation plant based on an IGCC cycle.

By Brian Sweeney and Mark Sceats, Calix

This article describes the history of the technology and the Endex reactor which is the key to its practical implementation. It outlines the main applications and the development path of the company.

The History

Making lime from limestone is the oldest industrial process; with the possible exception of the fermentation of alcohol! The decomposition of calcium carbonate, limestone, to produce lime in fires produced the first fertilizers in pre-history, and its production in kilns was a well established pre-Roman technology.

Today, the calcination of lime is a basic process in the production of Portland cement, and lime itself is one of the most common chemicals, used in about eighty substantial markets. The reverse process to calcination, called carbonation, uses lime to capture CO2 and has been widely studied over the last century.

Modern kilns operate close to equilibrium, and the direction of the reaction – calcination or carbonation - varies in a kiln depending on the local partial pressure of the CO2 and the temperature. These both vary across the kiln depending on the heat and mass flows, and within the stones as they calcine. The reactions are well understood.

Calcium Looping for carbon capture was first patented in 1994 as a temperature swing reactor[1]. This process separates the calcination and carbonation processes into two separate reactors – a Calciner and a Carboniser, and then loops the lime particles between the reactors for a continuous extraction process.

In the Carboniser the lime, as CaO, captures the CO2 from an input flue or fuel gas to produce CaCO3, and when transported to the Calciner the sorbent is regenerated and the CO2 is released in a pure gas stream, for compression, transport and sequestration.

By 2004, the IEA had singled out Calcium Looping as a potential candidate for CO2 capture, but noted that the major problem to be resolved was the sintering of the CaO sorbent[2]. Sintering is the loss of the CO2 capture capacity of the lime as the surface area is reduced, and numerous laboratory and pilot plant studies worldwide had demonstrated that the sintering was severe, with the sorption capacity being reduced from about 70% to 17% in the first 10 or so cycles.

[1]A.B.M.Heesink and H.M.G.Temmink, "Process for removing Carbon Dioxide Regeneratively from Gas Streams", PCT WO94/01203 (1994)
[2]International Energy Authority, "Prospects for CO2 Capture and Storage", 2004

The sintering problem has been the subject of intense research in the past seven years, and continuous improvements have been reported using a number of strategies. However, the large throughputs of lime are such that Calcium Looping in 2009 has been relegated to technology of interest to remediation of emissions from cement plants[3], where the lime can be consumed.

Calix has solved the sintering problem, and is confident that Calcium Looping will find major applications in all areas of both fossil fuel and biofuel emissions.

A second issue in Calcium Looping has been the high energy flux required to drive the process. In the conventional approach to CaO Looping, a large amount of energy must be supplied to the high temperature Calciner (at 850-950 °C) and this is released in the lower temperature Carboniser (at 650-800 °C). This heat required is about 30-40% of the thermal power of a power plant.

While the heat released in the Carboniser can be used to generate power, the capture plant is too large to warrant the investment. The conventional CaO Looping Cycle is shown in Figures 1 and 2 to illustrate these points.

The Breakthrough

Scientific breakthroughs often happen when two disciplines come together and an old problem is viewed from a new perspective. Calix scientists, with their knowledge of active sorbent preparation techniques, realized that the problems of the conventional Calcium Looping could be eliminated by:

- adjusting the pressures and temperatures in the Calciner and Carboniser so that the exothermic carbonation reaction occurs at a higher temperature than the endothermic calcination.

This means that the heat is retained within the reactor. The carbonation reaction increases the temperature by some 50 deg C as the sorbent flows through the carboniser. And it falls again through the calcining step.

[3]"CO2 Capture Technologies for Cement Industry", A.Boaoaga, O.Masek and J.E.Oakey, Energy Procedia, 1, 133-140 (2009)

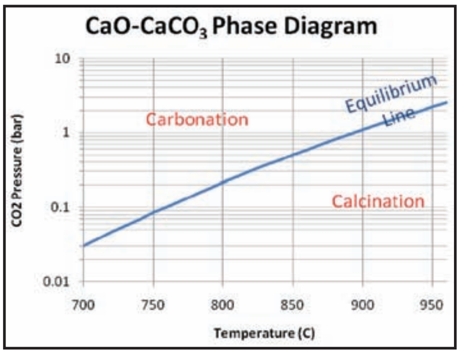


Figure 1: The CaO:CaCO3 Phase Diagram

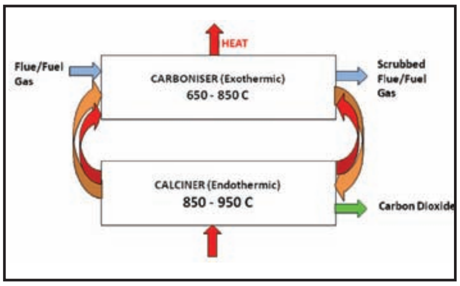


Figure 2: The Conventional Calcium Looping Reactor

The heat flows spontaneously from the carboniser to the cooler calciner. The heat is carried by the sorbent transfer and through the reactor walls. In principle, the separation of CO2 can be realized without any external thermal energy.

- using the high initial reaction rates on the surface of the particles, which give 2-3% carbonation in 2 or 3 seconds for particles less than 150 microns.

This is sufficient to capture 90% of the CO2 and avoids sorbent sintering. The residence time is so small that the size of the reactor is very compact – essentially pipes about 10-30 m high and 1-3 m in diameter.

The Endex reactor

Calix calls this configuration the Endex reactor – for a coupled endothermic-exothermic reactor. This class of chemical reactors was first described by Australian researchers, Rowena Ball and Brian Grey in 1999[4].

Endex reactors are non-linear systems, and when applied to CaO Looping, the reactor operates as a gas switch. Calix has shown

[4]B.F.Gray and R.Ball, "Thermal Stabilisation of Chemical Reactors. The mathematical description of the Endex reactor" Proc.R.Roc.Lond. A, 455, 163-182 (1999)

that the stability regime for the Endex CaO Looping reactor is very wide, with the switching occurring at low temperatures.

The Endex configuration for CaO Looping is shown in Figures 3 and 4. Ideally, the Endex reactor operates as a pressure swing reactor with continuous solids flow.

The primary outcome of the Endex reactor is that the dominant barrier to adoption of Calcium Looping, namely sorbent sintering, is overcome. This is done by holding the Calciner at a low temperature to minimise thermal sintering; by minimizing the carbon dioxide pressure in the calciner so that CO2 catalysed thermal sintering is minimised; and by holding the degree of carbonation to be small so that irreversible mesopore filling is negligible.

The Implementation

The implementation challenges of CaO Looping in the Endex configuration are no longer associated with the sorbent, but are now typical engineering challenges such as minimizing heat losses and transporting solids at high temperature between the reactors.

However, maintaining the CO2 pressure in the Calciner low requires that it must be evacuated and this requires mechanical energy. This energy penalty is relatively small, about 3-6%, and Calix is working to minimise it.

The most immediate consequence is that the flue or fuel gases preferably should be compressed for efficient CO2 capture. This means that the use of pressurized fluid bed (PFBC) combustor reactors is preferred for post-combustion capture, while fuel gases such as natural gas and Syngas are already pressurized and can be used directly.

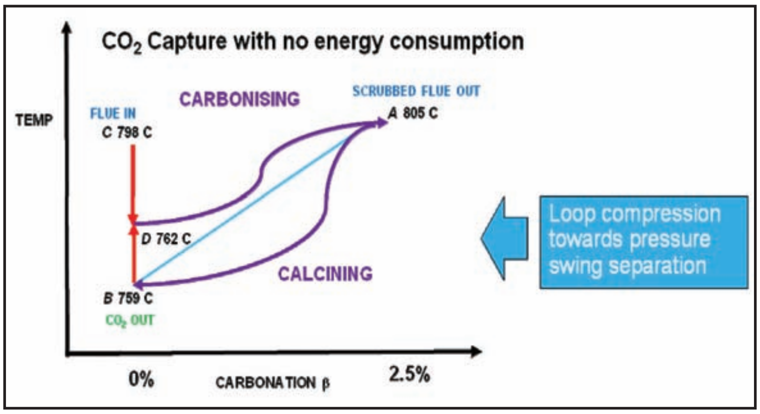


Figure 5: The Endex Calcium Looping Cycle

Atmospheric combustors are currently used for power plants and industrial processes such as cement, and iron and steel production. Calix has identified an approach to atmospheric capture by substituting the excess air intake into gas turbine plants by flue gas, and extracting the CO2 at high pressure after the combustor. This compression comes at no cost because it is a replacement for excess air.

In the separation of CO2 from fuel gases, the Endex reactor becomes an integral part of the fuel processing, because the high temperature of the CaO Looping causes the fuels to decompose at high pressures.

In a simple example, if syngas is injected into a Calcium Looping Endex reactor with steam, the extraction of CO2 through the formation of CaCO3 spontaneously drives the reactor to produce hydrogen, in a process known as the Sorbent Enhanced Water Gas Shift (SEWGS).

In general terms, the Carboniser of the Endex reactor can be used to transform chemically the fuel gas to produce CO2. In the conventional IGCC process, the WGS and CO2 Capture processes occur in separate reactors at low temperatures, resulting in high capital costs and inefficiencies.

The WGS-Endex reactor is able to separate the CO2 and produce hydrogen from Syngas and steam without thermal energy inputs. Other fuel gases, such as natural gas and LPG can also be used to produce hydrogen through variants of this theme.

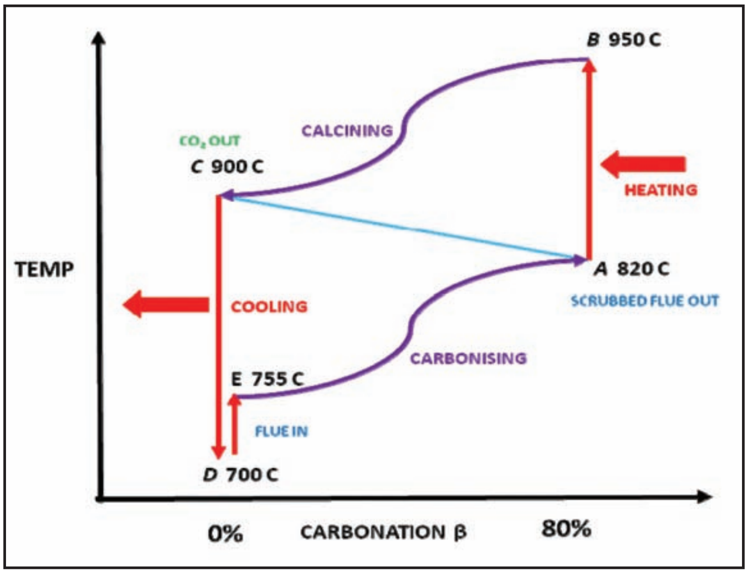


Figure 3: The Conventional Calcium Looping Cycle

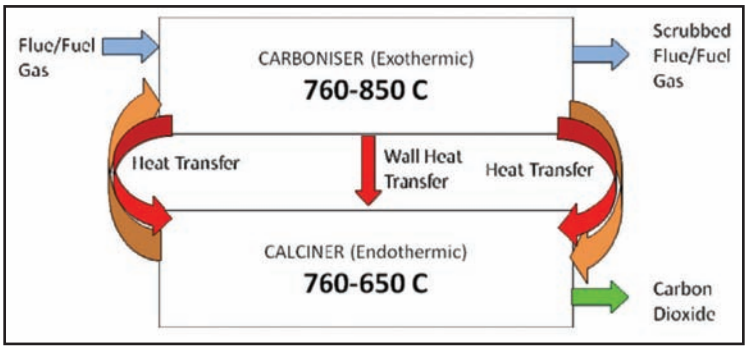


Figure 4: The Endex Calcium Looping Reactor

The Cost

The cost of CCS is the critical number that will determine whether the Endex technology will be economically viable. With a negligible thermal energy penalty and a small mechanical energy penalty discussed above, the cost of CO2 capture is most likely determined by the capital costs.

Provided that the Endex reactor can be matched to the temperature and pressure of the input gas without penalty, then the capital costs of an Endex reactor is expected to be relatively small.

The cost of the Endex reactor is expected to scale simply with the gas input flow rate. In the low carbonation limit considered above, the dominant heat transfer between the reactors occurs by the transport of the sorbent between the reactors, so that the wall heat transfer can be small. Thus the reactors can be substantially thermally insulated, and carbon steel can be used.

The reactors will be compact – with cross-sections of the order of metres and the height being a 20 to 30 meters. Because of the thermal coupling, the reactors operate autothermally and have an intrinsic stabiltily, so the control systems are expected to be relatively simple.

Estimates of several configurations are that the capital cost for large plants, exceeding 500 MWe, will be less than €200 per MWe, the energy penalty for capture and compression will be 6%, to give a cost of CO2 capture less than €15 per tonne. Initially, the

systems will be smaller, and the first-of-a-kind factor will be significant.

The development of Calix

It is widely agreed that there is no solution to climate change which does not include extensive application of carbon capture and storage. CCS is a major global industry in gestation.

While the political issues are being debated, and the remuneration mechanism for carbon sequestration is being resolved, Calix is developing its technology, fine tuning the applications and preparing for commercialisation.

No matter how good our technology breakthrough, there is a considerable task to catch up with the suite of first generation technologies and their incremental improvements current in demonstration. In a prudently conservative industry processes must be proven before they will be adopted.

Calix has demonstration plants planned worldwide at increasing scale in which Endex reactors can be developed and tested for particular applications – pre- and post combustion capture, with various fuels including coal, lignite, natural gas and syngas.

About the authors

Brian Sweeney is the Director of Business Development commercialising the carbon capture technology of Calix (Europe) Limited. He has an extensive background in the energy industry having worked with Shell and Rolls-Royce Industrial Power Group.

Mark Sceats is the Chief Scientist of Calix Limited, Australia. He is a materials scientist with a background in technology commercialization.

www.calix.com.au

Capture news

E.ON and Siemens begin CO2 capture pilot in Germany

www.eon.com

www.powergeneration.siemens.com

E.ON and Siemens are starting up a pilot CO2 capture plant at the E.ON power plant Staudinger in Grosskrotzenburg near Hanau, Germany.

A lab-proven post-combustion capture process developed by Siemens is to be employed under real operating conditions at the power plant's hard-coal-fired Staudinger Unit 5. The pilot plant will be operated with part of the flue gas from Unit 5.

E.ON and Siemens intend to run the facility until the end of 2010. The results achieved and the operating performance of the pilot plant will serve as the basis for large-scale demonstration of the technology, which is scheduled to start operation in the middle of the next decade.

It will test the cleaning agent's long-term chemical stability and the efficiency of the process under real power plant conditions. In parallel, the technology will be further optimized in terms of energy consumption.

The project is being sponsored by the German Federal Ministry of Economics under the terms of the COORETEC Initiative. It is part of the federal government's 5th Energy Research Program "Innovation and New Energy Technologies" and promotes research and development in the field of low-CO2 power plant technologies.

Alstom and Dow open CO2 capture pilot plant

www.alstom.com

www.dowoilandgas.com

Alstom and The Dow Chemical Company have begun operation at a pilot plant to capture CO2 from the flue gas of a coal-fired boiler at the Dow-owned facility in South Charleston, West Virginia, USA.

The pilot plant uses proprietary advanced-amine technology jointly developed by Alstom and Dow to capture approximately 1,800 metric tons of CO2 per year.

The pilot will operate for the next two years, generating reliable, long-term data that can be used to optimize this technology for implementation at coal-fired power plants across the globe.

In 2008, the two companies entered into a Joint Development Agreement to develop this technology. In March 2009, the companies announced their plans to design and construct the plant.

"This pilot plant is designed to evaluate the technology operating under power plant conditions, test proprietary innovations jointly developed by Dow and Alstom and provide data necessary to finalize the design of large-scale demonstration plants that will apply this technology," said Philippe Joubert, Alstom Executive Vice President and President of Alstom Power.

"Integrating this process with new advanced coal and gas fired power generation equipment will allow customers to minimize CO2 emissions while generating electricity as cost effectively as possible."

E.ON's Staudinger plant in Grosskrotzenburg near Hanau, Germany (Source: E.ON AG)

Alstom acquires Lummus Global engineering unit

Alstom has acquired the former engineering office of Lummus Global, a leading provider of technology for the hydrocarbon processing industry, in Wiesbaden, Germany.

The unit, renamed ALSTOM Carbon Capture GmbH, will be integrated into Alstom's CO2 Capture Systems activity.

The unit consists of over 100 employees with the full set of skills and capabilities required for the design and delivery of CO2 capture plant.

Alstom says the acquisition will enable it to make its CO2 capture technologies available to its customers with greater responsiveness and efficiency. It will support the increasing demand for studies, FEED packages, pilot plants and demonstration units driven by the need to accelerate the commercialisation of effective and efficient large scale CCS facilities.

Towards a framework for CCS risk assessment

The main objective of this paper is to present a systematic and conceptual framework of risk assessment methodology for underground CO2 storage.

By F.Lahaie and R.Farret, Ineris, France and P.Bumb, Indian Institute of Technology, Kharagpur

Project Objective

Various risk assessment methods have been tentatively applied in recent years to the context of geological carbon storage. The main objective of this paper is to present a systematic and conceptual framework of risk assessment methodology for underground CO2 storage.

We have used the so-called event-tree analysis method in identifying all the possible events and their corresponding causes which might can occur due to the underground CO2 storage and try to relate them by event-tree charts.

Risk Analysis consists in identifying relevant scenarios, and to describe them in order to give a full image of the risk inherent to a CCS system. In this respect, we first need to identify all relevant and plausible scenarios. In a second step, we need to rank these scenarios, or to characterise them in terms of severity S and probability P: this is the risk analysis (or risk estimation).

S and P are the 2 two criteria that are relevant, according to ISO/CEI 73 guide, where risk is described as the combination of probability of occurrence of damage and its severity. This characterisation in S and P is not fulfilled in this paper, only the principles are described here.

After this risk analysis, the level of risk can be compared to the acceptable level, this is the risk evaluation (or risk assessment): if the risk is too high, appropriate management measures can be suggested in order to lower the S or the P. This entire process, the management of risk, is outside the scope of this paper, however some relevant measures for managing risks are listed here as described in literature.

The experience of INERIS in risk analysis (both on industrial systems and on underground sciences) suggests that:

a. The identification of risk scenarios necessitates a systematic approach, that gathers the scientific knowledge about phenomena and events, and that ensures that all sub-systems are considered, as well as all possible events.

To be systematic, we have to be sure that all relevant events are considered, even if their probability is low; the best way to achieve this is to consider (i) a pre-determination of the targets at stake as well as the pre-definition of the relevant sub-systems with their intrinsic characteristics, (ii) a logical classification of hazardous events that are likely to cause damages, (iii) a check-list of possible events, that are likely to initiate or to prolong risk scenarios.

b. Once this exercise is completed, an event tree is the best way to represent the results (even if it was not used formally in step (a): this kind of representation is a risk model of the system, that illustrates the cause-consequence relationship, includes the interactions between sub-systems and between events, and shows the result in a meaningful way to other experts (or stakeholders). This will help the experts to eventually identify the relevant top scenarios that are representative of the whole risk model.

c. It is necessary to complete this method with modelling and with probabilistic data, in order to estimate the S and P (either in a quantitative or in a qualitative way). For instance, modelling will generate quantitative data in order to estimate the severity of some phenomena, hence modelling can be seen as a specific step of a generic risk assessment

Review of risk assessment methodologies applied to co2 storage

To evaluate the potential risks associated with geological carbon sequestration various risk assessment methodologies are developed which are carried out to select the promising sites from a number of candidate sites and lead to the evaluation and potential certification of particular sites as safe and effective geological carbon sequestration sites.

There is a growing body of work in risk assessment in the areas of geological carbon sequestration screening and ranking and single-site certification. In the area of screening and ranking, three approaches have been described in the literature.

1. Bowden and Rigg (2004) invoke a quantitative probabilistic approach that involves risk measures applied to key performance indicators. This approach uses the RISQUE method which involves assembling an expert panel to develop and rank potential scenarios and events.

2. The second approach (Oldenburg, 2008) is a spreadsheet-based approach that focuses on near-surface risk of CO2 leakage called the Screening and Ranking Framework (SRF). The SRF was designed to require minimal site characterization data and provide a simple and uniform way to rank several sites based on expected performance and the certainty of the information available. The SRF approach is too qualitative to certify sites for which more site characterization data and associated modelling are needed.

3. The third approach is the Vulnerability Evaluation Framework (USEPA, 2008) useful for guiding the development of regulations, for educating stakeholders about potential risks, and for delineating regions with better or worse potential for safe and effective geological carbon storage.

For assessing sites, several approaches have been developed or adapted from other applications such as:

1. The FEP approach involves the generation of a comprehensive list of FEPs that are codified in a database. The user can rank the importance or relevance of given FEPs and associated scenarios for performance failures, such as excessive leakage and seepage.

2. In the PRA approach of Rish (2005), developed for UIC Class I hazardous waste injection wells, probabilities of events and distributions of formation and well properties are used as input for probabilistic calculations of the likelihood of various detrimental events.

In the next phase of the assessment, the consequences of a scenario or of an event are expressed in terms of impact of long-term high concentrations of CO2 at key receptors. The consequences are evaluated by modelling and simulation. The product of this probability and the consequence estimate from the simulation enables the risk to be calculated.

3. The system modeling approach (e.g., CO2 PENS, Stauffer et al., 2009) takes a much broader view and analyzes the entire system from the point of capture of CO2 from flue gas, through transportation by pipeline, to injection and trapping in the reservoir and includes economic aspects. The system modeling approach is designed to use probabilistic methods for modeling uncertainty.

4. Certification framework approach is use to evaluate the degree to which a geological carbon sequestration site is expected to be safe and effective in a risk-assessment

context. Certification framework approach relate effective trapping to CO_2 leakage risk which takes into account both the impact and probability of leakage. Certificate framework uses:

a. Wells and faults as the potential leakage pathways,

b. Compartments to represent environmental resources that may be impacted by leakage,

c. CO_2 fluxes and concentrations in the compartments as proxies for impact to vulnerable entities,

d. Broad ranges of storage formation properties to generate a catalog of simulated plume movements, and

e. Probabilities of intersection of the CO_2 plume with the conduits and compartments.

5. Evidence support logic (ESL) analysis framework enables to represent evidence and uncertainty in the sub-decisions that contribute to the overall decision. This framework also addresses uncertainty that arises as a result of lack of knowledge or incompleteness of data and is applied to a range of problems that arise in assessing the performance and safety of underground storage of CO_2.

6. The Performance & Risk (P&R™) assessment approach for Well Integrity: Quantitative Performance & Risk (P&R™) assessment methodology for well integrity based on a regular assessment and prevention of potential CO_2 leaks.

This methodology gives the operators a decision-making tool and a strong support for demonstrating safety to regulators. This methodology focuses on the Risks of both contamination of subsurface formations and hazardous releases on surface. The following aspects are considered in the proposed Performance & Risk (P&R™) assessment methodology:

a. Predicting the evolution of the well integrity over short, medium and very long time scales (up to 10,000 years);

b. Optimising the potential CO_2 storage site. Different options of the conversion strategy of an existing field or development of a new CO_2 storage site could be considered;

c. Mitigating risks and planning safety control.

7. MOSAR method (Organized and Systemic Method of Risk Analysis) analyses the technical risks of a human plant and to identify the prevention means to neutralize them. This methodology creates a typology grid of under-systems danger sources adapted to a CO_2 geological storage site. Risk scenarios can then be built and organized hierarchically in a grid by means of gravity based on probability and leads to the identification of prevention and protection means.

8. Multi Criteria Assessment (MCA) is a useful tool for characterising and better understanding differences in stakeholder assessments of CCS and its implications. Multi-criteria analysis can be used as a heuristic to reveal some of the more arcane but important scientific uncertainties. The multi-criteria evaluation of CCS was conducted in two stages:

a. The first stage explores in detail the various carbon storage reservoirs included in the study; a set of evaluation criteria to assess the alternative storage reservoirs independently of the scenarios was defined for this purpose.

b. In the second stage assessment is conducted using a set of criteria relating specifically to the scenarios.

9. The Swift Technique: The structured What-If Technique (SWIFT) is a systematic team-oriented technique for hazard identification. The following protocol was used for the SWIFT review of CO_2 sequestration.

a. Define reservoir types.

b. Brainstorm possible hazards.

c. Structure the hazards into a logical sequence for discussion. Start with the major ones, and prioritize selection of others.

d. Consider each hazard in turn. Consider possible causes of the event. Consider possible consequences (in terms of rate and quantity of CO_2 released) if the event occurs. Consider safeguards that are planned to be in place to prevent the event occurring. Consider frequency and consequence relative to natural gas production. Record discussion on SWIFT log sheets.

e. Reconsider whether any hazards have been omitted. Use checklists and previous accident experience to check for completeness.

f. Consider possible impacts of the releases on human and environmental resources.

10. CQUESTRA (A risk and performance assessment code for geological sequestration of carbon dioxide): A computationally efficient semi-analytical code, CQUESTRA, is used for the probabilistic risk assessment and rapid screening of potential sites for geological sequestration of carbon dioxide. The rate of dissolution and leakage from a trapped underground pool of carbon dioxide is determined.

The program considers potential mechanisms for escape from the geological formations such as the movement of the buoyant phase through failed seals in wellbores, the annulus around wellbores and through open fractures in the caprock. Solubility, density and viscosity of the buoyant phase are determined by equations of state. Advection, dispersion, diffusion, buoyancy, aquifer flow rates and local formation fluid pressure are taken into account in the modelling of the carbon dioxide movement.

All methods used for risk analysis or risk assessment are based on a data base of events and scenarios that are formalized (e.g in FEPs) or not (e.g in the mind of the experts).

There exists a series of methods that are very relevant, but cannot be considered systematic either because they focus on a given kind of scenario (e.g. near-surface such as SRF, or well-integrity such as P&R, or CO_2 leakage through faults or wells such as the certification framework, etc. or because they entail a very specific type of analysis that necessitates detailed data and hence cannot consider all types of events: e.g. probabilistic analysis, or detailed modelling such as CO_2 PENS or CQUESTRA.

As already said, models are very useful to characterise more precisely the severity of risks (e.g. extent of migration or leakage), but are not themselves a full method for systematic risk analysis. Besides, specific tools like Screening and Ranking Framework (SRF) focus on technical risks but give a generic frame in order to end up with a global indicator-hence they derive from our objective of systematic, generic, analysis of a risk model.

Other methods such as MCA and Vulnerability Evaluation Framework are related to social consideration more than technical risk assessment. They include the decision makers (and the way they take their decision) and the perception of risk, hence they are outside our scope.

Some systematic methods enable us to consider all kinds of scenarios and often insist on cause-consequence relationships: e.g. MOSAR, PRA, SWIFT. Most of them are driven from the experience of industry in assessment of technological risks, and were not applied to the whole CCS yet.

The approach we develop here is close to the What-If or PRA methods, completed by a so-called event-tree analysis method. It therefore consists in (i) identifying all the possible events and their corresponding causes which might can occur due to the underground CO_2 storage, through a systematic approach, and (ii) try to relate them by event-tree charts.

Methodology used (event tree analysis)

The basic goal of the risk analysis and assessment method discussed in this paper is to identify all the possible events and their associated caused which may occur due to geological carbon storage. It is applicable in

principle to any part of the CCS chain.

However, in a preliminary step, we decided to apply it on the injection and storage parts of the system.

The methodology used to construct these trees is as follows:

1. Collection of a series of articles about the risks of storing the CO2 underground.

2. Analyzing and reading the article one by one. Once a undesired event is discussed in the article, a line in the excel spreadsheet is fulfilled detailing about:

a. Possible event that might occur because of underground storage of CO2.

b. Storage compartment concerned with the possible event i.e. cap-rock, reservoir, well etc.

c. The individual (s) cause (s) of the undesired event.

d. Favourable conditions for the occurrence of undesired event (if the evidence on this point are provided in the article).

e. The methods or model to quantify the likelihood or intensity of such undesired event (if the evidence on this point is provided in the article).

f. Prevention or monitoring technique can be implemented to avoid (or limit the effects of) the undesired event (if stated in the article).

3. By aggregating all possible undesired events and their corresponding causes, working to relate them by the event-tree analysis technique.

An event tree analysis technique is a visual representation of all the events which can occur in a system (underground storage of CO2). This tree analysis technique provides a highly effective structure within which we can explore undesired events which might occur due to underground CO2 storage, and investigate the possible outcomes of choosing those events.

We have classified the scenarios of risks associated with underground storage of CO2 on the basis of the 7 impacting phenomena (IP) (see Table 1) and relate them with the 5 potentially different effects on the defined 3 targets described below. The entire storage site and its surroundings are divided into various compartments to distinguish the leakage through wells, environment and cap-rock, reservoir etc.

For constructing event-tree analysis, we have defined 3 specific targets that will be affected directly or indirectly by the CO2 leakage. The first and most important targets is humans, CO2 leakage affects the safety and health of the humans. The second target is plants and animals; which are adversely affcted by the underground leakage of the CO2. The third target is human activities such as oil/gas production, mining etc. which are greatly affected by the underground leakage of CO2.

No	Impacting phenomenon	Potential effects
1	Massive emission of CO2 mixture at the surface (emission is proposed to be defined as —massive as soon as its flow rate is sufficient for CO2 mixture concentration to exceed the minimal threshold of lethal effects on humans)	Toxic and ecotoxic
2	Slow emission of CO2 mixture at the surface (emission is proposed to be defined as —slow as soon as its flow rate is not sufficient for causing lethal effects on humans but sufficient for causing lethal effects on other species)	Ecotoxic
3	Pollution by CO2 mixture: CO2 concentration in one compartment of environment (subsurface, soil, water, sea, except air), exceeding the minimal impact threshold of lethal effects for a defined species.	Ecotoxic Disturbances of human activities
4	Pollution by brine	Ecotoxic Disturbances of human activities
5	Disturbance of the regional hydraulic regime	Disturbances of human activities
6	Ground movement	Deformation or acceleration of the earth surface
7	Pollution by CH4	Overpressure Thermic

Table 1 - Seven impacting phenomena (IP)

Depending on the impact on these targets we have again classified 5 different types of effects which includes toxic effects on human and ecotoxic effect on plants and animals; Thermic effects on human, plants and animals; Overpressuring effect on human, plant and animals; Deformation and acceleration of the earth surface on human, plants, animals and human activities; and disturbances of human activities.

Finally, we have classified the scenarios of risks associated with underground storage of CO2 on the basis of the 7 impacting phenomena (IP) which includes their associated potential effects; (a) Massive emission of CO2m (mixture of CO2 and impurities) at the surface; (b) Slow emission of the CO2m at the surface; (c) Pollution by CO2m; (d) Pollution by brine; (e) Disturbance of the regional hydraulic regime; (f) Ground movement; (g) Pollution by CH4.

In this paper we have worked to classify the scenarios of risks for the IP # 2: Slow emission of CO2 mixture (CO2m) at the surface to illustrate the methodology, the detailed scenarios of risks for IP # 2 can be found in Appendix # A of the full paper.

We have considered the events: Slow upflow of CO2m from the lower overburden rocks up to the surface; and lateral leakage of CO2m up to the surface. We have further classified the specific event of the basis of the excel spreadsheet (acting as a detailed database) which is fulfilled by the analyzing and reading the series of articles one by one on risks of storing the CO2 underground. A complete flow sheet is formed in the same way for all other impacting phenomena.

Conclusion

We have focused on the systematic and detailed approach for risk assessment methodology of underground CO2 storage through event-tree analysis technique. Most of the events shown are based on the detailed literature survey and the excel sheet database which has been developed prior to the tree construction.

In this study we have mainly focussed on the injection and the underground storage system of CO2 respectively on the basis of the various compartments that includes well system, cap-rock and reservoir system, overburden and suface environment system.

This methodology is a systematic approach and includes the majority of the events on the basis of the prior literature survey. But, it is obvious that the current risk description methodology, in the shape of the events and their causes description is not sufficient.

In order to make the CO2 storage technique valid, a consistent and rigorous risk study has to be carried out before storage of CO2.

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Transport and storage news

New research at CO2CRC Otway Project

www.co2crc.com.au

New research on deep saline storage will soon be underway at the CO2CRC Otway Project, Australia's only CO2 geosequestration research and demonstration facility.

While final corporate and Government approvals are required, a new stage is planned to research the ways carbon dioxide is trapped in deep reservoir rocks (saline formations), the most promising types of rock formation for large-scale storage.

Plans include drilling a second injection well later this year. Depending on the results of smaller injections (under 10,000 tonnes), a larger scale injection could be part of future plans.

ETI launches UK carbon storage capacity appraisal

www.energytechnologies.co.uk

The UK Energy Technologies Institute has launched a project which could see the UK as the first country with a comprehensive assessment of national CO2 storage capacity.

The project started in October 2009 and will be completed by March 2011. It will complement planned activities around the assessment of sites for CCS demonstration projects in the short to medium term by providing a picture of the long term UK capacity.

It will cost in excess of £3.5 million, and will carry out a review of potential sites suitable for storing CO2 offshore and help to answer the question of exactly how much storage capacity is practically available in the UK.

The UK is potentially well served with offshore CO2 storage capacity in depleted oil and gas reservoirs and saline formations and, although various estimates have been made of the total amount available, those figures vary widely.

Obtaining a more accurate estimate of storage capacity will enable the Government, CO2 emitters, storage operators and developers to make more informed choices on the realistic extent and roll out of carbon capture and storage in the UK.

The United Kingdom CO2 Storage Appraisal Project (UKSAP) is led by Senergy Alternative Energy Ltd and also involves technical contributions from the British Geological Survey, the Scottish Centre for Carbon Storage (University of Edinburgh, Heriot-WattUniversity), Durham University, GeoPressure Technology Ltd, Geospatial Research Ltd, Imperial College London, RPS Energy and Element Energy Ltd.

DOE Mississippi project injects one million tons of CO2

fossil.energy.gov

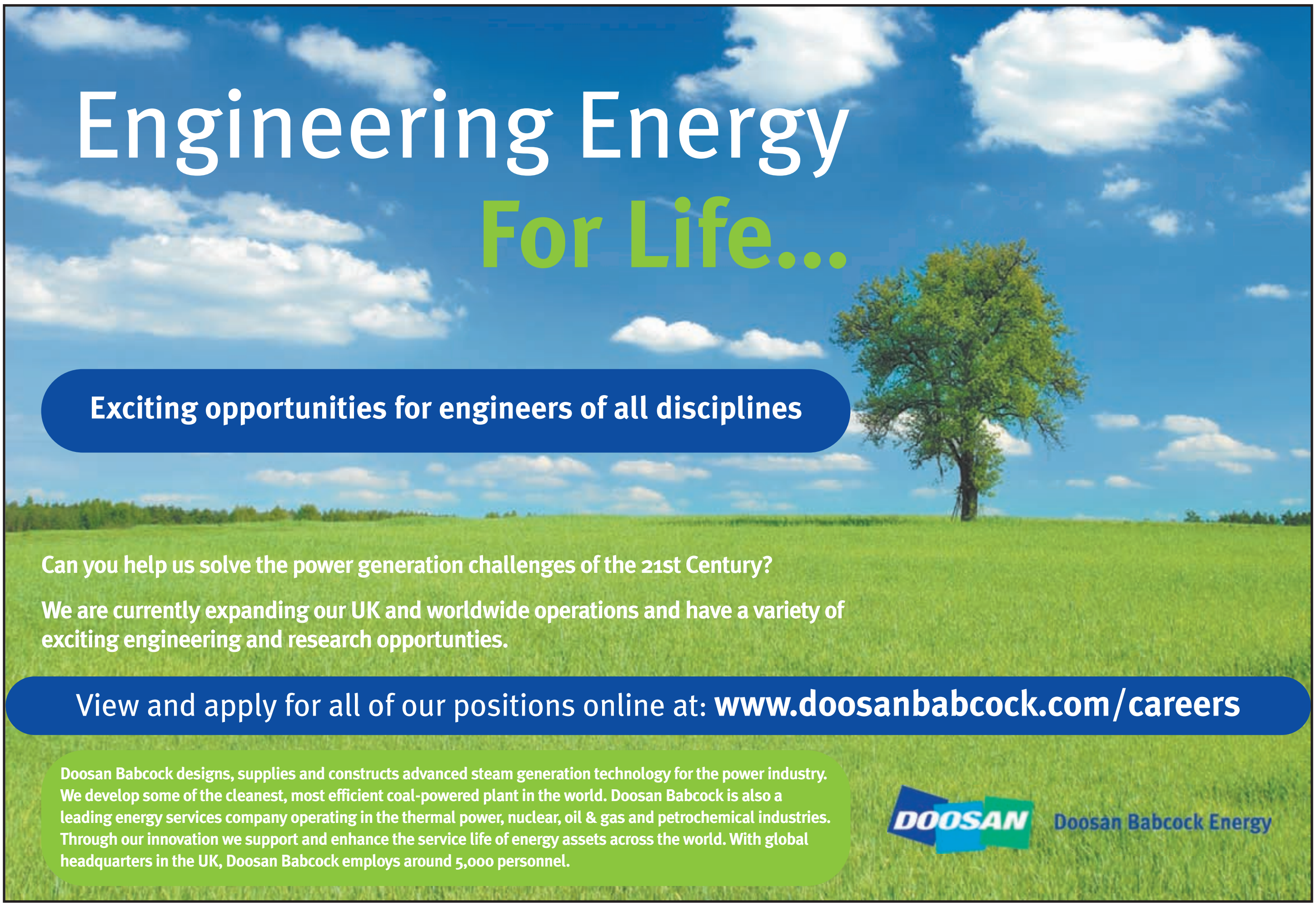
The CO2 storage project in Mississippi has become the fifth worldwide to reach the milestone of more than 1 million tons.

The project, sponsored by the U.S. Department of Energy's (DOE) Office of Fossil Energy (FE), is located at the Cranfield site in Southwestern Mississippi. It is led by the Southeast Regional Carbon Sequestration Partnership (SECARB). The Cranfield site is operated by Texas-based Denbury Resources Inc., the project's host.

The Cranfield project combines the use of CO2 injection with enhanced oil recovery (EOR), followed by CO2 injection into deeper and larger-volume brine, or saline, formations.

A major accomplishment of the Cranfield project has been successful deployment of "in-zone" (in the injection zone) and "above zone" (above the injection zone) pressure-response monitoring techniques, said the DOE.

Real-time data collected since July 2008 has demonstrated these techniques are cost-effective methods for CO2 monitoring, verification, and accounting (MVA) that can be deployed nationwide.

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