carbon capture journal

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Front cover:
Skyonic's SkyMine® demonstration project mineralizes CO2 emitted from industrial flue gas stacks into sodium bicarbonate and other marketable chemicals, such as hydrochloric acid, hydrogen chloride, chlorine and hydrogen (see pg. 19)

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Carbon Capture Journal Review of 2010

2010 was a busy year for CCS demonstrations, with several beginning operations and some releasing preliminary test results, however by the end of the year some major projects had been postponed or cancelled altogether. Governments continued to pledge money, with the EU announcing a €4.5 billion fund for clean energy, and the climate talks in Cancun at the end of the year made a landmark decision by opting to include CCS in the Clean Development Mechanism.

January 2010

Total's Lacq project in southwestern France, Europe's first end-to-end carbon capture, transportation and storage demonstration facility is inaugurated. The project uses oxycombustion carbon capture technology developed by Air Liquide and the CO2 is piped 27 kilometers from the Lacq plant to the Rousse geological storage site, where it is injected into a depleted natural gas reservoir located 4,500 meters below ground. The project plans to store around 120,000 metric tons of carbon dioxide over the next two years.

Powerspan releases test results from a one-megawatt pilot unit demonstrating its post-combustion ECO2 carbon capture technology for coal-fired power plants. The 1-MW pilot test unit, located at FirstEnergy Corp.'s R.E. Burger Plant near Shadyside, Ohio, averaged greater than 90 percent CO2 capture from a slipstream of flue gas from the coal-fired power plant in a real world operating environment, at 'less than $50 per ton for CO2 capture and compression.'

February 2010

President Obama creates an **Interagency Task Force on Carbon Capture and Storage**. The task force will seek to develop a comprehensive and coordinated federal strategy to speed the development and deployment of clean coal technologies. The President called for five to ten commercial demonstration projects to be up and running by 2016.

March 2010

A **University of Calgary**-led study coordinated by the Institute for Sustainable Energy, Environment and Economy (ISEEE) concludes that it is technologically feasible to store a huge amount of CO2 in geological formations in central Alberta. They found that around 500 million tonnes of CO2 could be readily injected, which amounts to about half the emissions for 30 years from all of Alberta's centrally located coal-fired power plants.

The UK government publishes a **CCS Industrial Strategy** which outlines how the country can become a centre for CCS innovation and business with an industry worth up to £6.5 billion and sustaining up to 100,000 jobs by 2030. An Office of Carbon Capture & Storage (OCCS) within DECC (Department of Energy and Climate Change) was also set up as a focal point for the facilitation of CCS activities in the UK.

April 2010

Canada opens the **CanmetENERGY CO2 Research Facility** (CanCO2) located at the Natural Resources Canada Ottawa Research Centre. CanCO2 is an integrated pilot-scale carbon dioxide (CO2) capture facility that simultaneously removes pollutants while purifying and compressing CO2 for transport, storage or use. As a portable near-zero emission test platform, the facility is used by industry and research organizations to optimize, reduce costs, evaluate and test technology options for CO2 capture from fossil fuel-fired plants.

DNV develops a comprehensive **guideline for safe and sustainable geological storage of CO2**. The CO2QUALSTORE Guideline for Selection, Characterisation and Qualification of Sites and Projects for Geological Storage of CO2 provides a comprehensive and systematic process that covers the full lifecycle of a CO2 storage project, from screening and site selection to closure and transfer of responsibility from the operator back to the national state.

May 2010

The **International Performance Assessment Centre for Geologic Storage of Carbon Dioxide** (IPAC-C02) establishes a global network linking organizations in eight countries which conduct research into the geological storage of CO2. IPAC-C02 is designed to meet a public and regulatory need in the global CCS chain by providing an independent performance assessment of geological storage of carbon dioxide.

A team including members from NASA Goddard Institute for Space Studies and Columbia University Earth Institute outlines a way to **phase out US CO2 emissions from coal use by 2030**. The paper concludes that elimination of fossil fuel subsidies and a substantial rising price on carbon emissions are the root requirements for a clean, emissions-free future.

Research Scientist Dr. Kourosh Zanganeh (left) shows the Honourable Christian Paradis, Minister of Natural Resources around the CanmetENERGY CO2 Research Facility at its official opening on April 19, 2010

June 2010

A joint International Energy Agency (IEA), Carbon Sequestration Leadership Forum (CSLF), and Global CCS Institute **report presented to G8 leaders** at their June Summit in Muskoka, Canada, concludes that CCS is 'crucial' to mitigating climate change. The report says that two years after the G8 leaders' commitment to the broad deployment of CCS by 2020, significant progress has been made towards commercialisation of CCS technologies.

July 2010

At the world's first **Clean Energy Ministerial**, U.S. Energy Secretary Steven Chu announces that the U.S. is helping launch more than 10 international clean energy initiatives, including one for CCS. The overall aim is to eliminate the need to build more than 500 mid-sized power plants world-wide in the next 20 years. The U.S. announces funding of more than US$1.25 billion for five new projects in the third round of the **Clean Coal Power Initiative** program. Another $106 million is being invested in projects to find ways of converting captured CO2 emissions from industrial sources into useful products such as fuel, plastics, cement, and fertilizers and $67 million on reducing the energy and efficiency penalties associated with applying CCS to existing and new power plants.

August 2010

The **U.S. DOE awards $1 billion in Recovery Act funding** to a revamped FutureGen 2.0 project, which now involves fitting oxy-combustion technology to an existing power plant and a CO2 storage network in Illinois. However the proposed storage site in the original FutureGen location of Mattoon, Illinois is in doubt as the town rejects the new plan. The DOE continues its funding announcements with $21.3 million over three years for 15 projects to develop technologies aimed at safely and economically storing CO2 in geologic formations.

Doosan Power Systems announces a successful first year of testing at its **OxyCoal Clean Combustion Test Facility** at Renfrew, Scotland. The company completes around 100 individual tests for the first time on a full-size 40MWth burner.

September 2010

RWE, BASF and Linde claim a flue gas CO2 capture 'breakthrough'as new technology is shown to save 20 percent on energy input and reduce solvent consumption. The results are from tests for separating CO2 from flue gas in a pilot plant at RWE's Niederaussem power station near Cologne.

The **DOE announces a further $575 million** from the American Recovery and Reinvestment Act for 22 R&D projects to complement the industrial demonstration projects already being funded. This is for research into large scale testing of gasification technologies; turbo-machinery to lower emissions from industrial sources; post-combustion CO2 capture with increased efficiencies and decreased costs; and geologic storage site characterization.

The **EU founds the European CCS Demonstration Project Network**, the world's first network of CCS demonstration projects to foster knowledge sharing and raise public understanding of the role of CCS in cutting CO2 emissions.

$855,000 in additional funding is awarded for two carbon dioxide capture projects developed by the **Cooperative Research Centre for Greenhouse Gas Technologies** (CO2CRC) in Australia. The **CO2CRC/HRL Mulgrave Capture Project** is researching pre-combustion carbon capture from a stream of syngas at HRL Developments Pty Ltd research gasifier. The **CO2CRC H3 Capture Project** is investigating ways to improve post-combustion carbon capture from Hazelwood power station as part of the Latrobe Valley post-combustion capture (LVPCC) project.

Mitsubishi Heavy Industries America (MHIA) begins a collaboration with **Southern Company** to capture carbon dioxide from Georgia Power Plant Yates. The pilot-scale project uses a mobile version of the KM-CDR CO2 capture process developed by Kansai Electric and Mitsubishi Heavy Industries of Japan (MHI).

Vacuum swing adsorption is one of three carbon dioxide separation technologies being evaluated through the CO2CRC H3 Capture Project. (Image: CO2CRC)

October 2010

B9 Coal, based in the UK, develops a novel project involving using syngas from Underground Coal Gasification (UCG) to generate power from alkaline fuel cells. The 500 megawatt (MW) project would achieve CO2 capture upwards of 90% at no extra cost by combining the two technologies.

The **GCCSI announces the first set of projects** to receive support as part of its information and knowledge sharing brokerage efforts to overcome key barriers facing large-scale, integrated CCS demonstration projects. Knowledge will be captured from different stages of project life cycle, across technologies and geographic regions and be shared with the broader industry via workshops, thematic group discussions and one-on-one meetings.

The first tonne of CO2 is captured at the 14 MW pilot plant that **ELCOGAS** has built in its Integrated Gasification Combined Cycle (IGCC) power plant at Puertollano, Spain.

E.ON pulls out of the UK demonstration competition saying its Kingsnorth plan cannot meet competition timescales. This effectively means that ScottishPower's Longannet project in Fife is the winner as the only entrant left.

November 2010

A new **Global CCS Institute paper** helps to define and explain the intricacies around **carbon capture and storage ready policy**, which helps governments prepare power generators for a shift to a low carbon economy and signals future costs to investors.

Finnish energy company **Fortum Oyj discontinues its Finncap project**, due to the technological and financial risks. According to Fortum's updated strategy, coal condensing is not within the core of the company's operations; in light of this the risks grew too extensive, the company said.

Shell cancels its Barendrecht project mainly because of the local opposition to the plan. The delay of the CO2 storage project for more than 3 years and the complete lack of local support were the main reasons to stop a Dutch Minister said.

The **UK Government** opens its extended **CCS demonstration programme** to projects on **gas-fired power plants** as well as coal-fired power plants.

The **EU launches a €4.5 billion fund** for clean energy funded from the sale of 300 million emission allowances in the New Entrants Reserve (NER) of the EU Emissions Trading System (ETS). Eight CCS projects will receive financing of up to 50%.

December 2010

Shell Canada has submitted a regulatory application for its **Quest Carbon Capture and Storage project** located in central Alberta to capture more than one million tonnes of CO2 per year from the Shell Scotford Upgrader and permanently stored it underground 84km away.

CO2 capture begins at a **A$5 million post combustion capture demonstration project in Queensland, Australia**, a partnership between CSIRO and Tarong Energy Corporation Limited. The pilot plant is designed to capture approximately 1000 tonnes of CO2 per annum and evaluate the effectiveness of CO2 capture using amine-based solvents.

The **UN accepts CCS in the Clean Development Mechanism** calling for rules around CCS projects to be finalized at the next climate talks in December 2011 and for issues such as permanence, boundaries and safety to be addressed and resolved.

The **Queensland ZeroGen project** to build a clean coal IGCC power station project in central Queensland will not go ahead in its current form - it may survive as an independent industry-led project.

Pöyry - business models for CCS

This article is the fifth in a series that considers features of the future power markets in which CCS will be competing with a view to understanding the potential implications for the here and now. This article focuses on the various options for structuring contracts between the various participants in the CCS process and the implications for risk and return.

By Andy Houston and Oliver Pearce, Pöyry Energy Consulting

Business models for carbon capture and storage have yet to attract open discussion, yet they are vital to ensure the viability of CCS as they describe how risk and reward will be allocated. For policymakers, getting the business model right may incentivise more companies to enter the market, while for CCS developers it can provide competitive advantage. In both cases, the wrong business model will do the opposite. Given the interlinked and specialised nature of the carbon capture and storage chain, appropriate contracts between partner companies will be critical in creating a viable (and financeable) business case.

In this article, we illustrate the impact that alternative contract models could have on the returns for each of the entities in the CCS chain, and comment on the likely robustness of these models in the face of uncertain market futures.

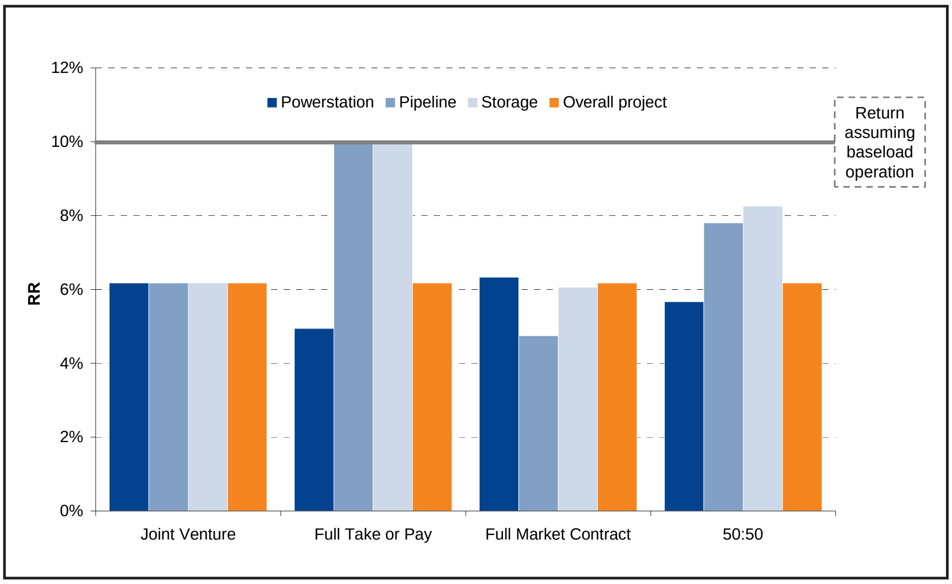

Figure 1 – Investment return ratio (IRR) for different partners in the CCS chain in the case where annual load factor of CCS plant is reduced from base load to 50%

Introduction

CCS creates a new value chain by turning what would have been considered a waste gas into a source of value. Each project will combine several very distinct processes – from generation and CO2 capture to compression, transport and storage. Companies that have the specialist expertise and experience to manage one of the processes are unlikely to have the necessary skill set to operate the others. Therefore CCS projects are to bring together a number of different partners to provide the necessary know-how and access to facilities.

In order for CCS to be successful, the potential for revenue generation from capturing, transporting and storing the gas should be sufficient to incentivise new operators to set up operations in each part of the value chain, based on the reasonable expectation that the owner/operator of each phase will only invest on the basis of expected individual returns.

Successful business models will also need to take into account the inter-dependent nature of CCS chain. In general the downstream components (transport and storage) will be dependent on the upstream components for revenue, while upstream components depend on the availability of the downstream components (to avoid CO2 penalties). This implies that there must be clearly identified value, responsibilities and allocation of risk between the main project partners: the plant operator, the transportation operator and the storage operator and any other involved parties.

Other issues are also important for successful business models. These include liability transfer between phases of the CCS chain as i) CO2 is deemed as a cost and ii) the lengthy period over which it is stored means that at some point liability is likely to be transferred to a governmental body. In addition, there are key questions about how the public funds allocated to support the first tranche of CCS should be distributed along the value chain and, more to the point, how to allocate responsibility for distributing these funds. Therefore governments wishing to incentivise investment in CCS need to understand business models for CCS so they can maximise benefit from any support mechanisms.

As a result, contract structure between partners will have significant implications for each partners risk exposure and expected return. This raises fundamental questions about how to best structure the contractual arrangements between each of the parties and to the type of risk that they are subjected to.

Types of risk

There are many types of risk associated with the CCS chain, including operational risks (e.g. storage site operational difficulties), market risk (e.g. lower market spreads), technology risk, regulatory risks and financial risks – and the structure of the business model will dictate the impact each of these has on partners in the CCS chain.

In our previous articles in this series we have assessed the impact of intermittent generation on CCS. Below we discuss how different CCS business models could perform in a future scenario where the load factor of CCS plant decreases and how risk will be spread among the partners in the CCS value chain.

Different business models will lead to different market risks for participants in the CCS chain

In this illustration, our CCS project consists of a power station from which CO2 is collected, a transport system and storage at a designated site. We have assumed that the power generator receives revenue from electricity sales and dispenses it to the other partners, according to four alternative contractual structures:

- Fully integrated project – where all the partners invest in a single entity, or joint venture, to own and run the project and receive the same return on their investment;
- Take-or-Pay (fixed price) contract – where the contracts specify a fixed payment to each partner;
- Market (variable price) contract – where the contracts specify a price per unit of CO_2;
- 50:50 contract – where 50% of revenue is fixed and 50% variable

The chart (Figure 1) shows IRR's for different partners in the CCS chain in the case where annual load factor of CCS plant is reduced from base load to 50%. While this load factor may be seen as unduly pessimistic, it highlights the importance of the business model, and continues the theme from our previous papers that CCS plant may face a difficult operating environment.

The IRR's can be compared to the IRR assuming base load operation (solid grey line), for which all business models generate the same return on investment. Reducing the load factor highlights the difference between business models, and hence the risk carried by different partners in the CCS chain.

Under a Fully Integrated contract, all participants will achieve lower returns. Each participant receives the same return regardless of whether problems arose in their part of the process.

Under a Take-or-Pay contract each party is directly exposed to their own operational risks and those downstream from them, but they are insulated from the operational problems in upstream processes. In our example, this means that the transport and storage operators receive their fixed payment while the generator receives lower revenue. Conversely, operational problems in the pipeline and/or storage facility may restrict the generator from sending as much CO_2 as initially expected. This model provides the greatest incentive for parties to manage their own operational risks but creates the greatest revenue uncertainty exposure for the power station entity.

Variable Contracts enable generators to pay transport network and storage operators just for the CO_2 they transport and store. Consequently the downstream elements are subject to all of the operational risks across the chain. A decline in power station operating hours results in less CO_2 being transported and stored, and hence revenue passed on to these operators. However, the generator does not have to pay for unused capacity so the IRR for generators increases slightly.

The 50:50 style contract lies somewhere in between the take or pay contract and the full market contract and hence, not surprisingly, so do the results.

As a result, there could be challenges in implementing CCS business models

Different contract structures highlight the risks borne by the partners in the CCS chain. For example, under the fully integrated contract, the transport and storage operators accept the market risk associated with the generation of electricity as well as the financial risk associated with capturing and storing CO_2. The question then becomes: are the parties willing to accept this risk?

There are many ways of segregating the risk along the CCS value chain. One example would be with reference to a fuel and/or carbon price index, to enable the transport and storage operators to shield themselves from some of the risk associated with generation. However, reaching such an agreement could prove to be a significant challenge.

Moreover, it is not clear that all partners in the CCS chain will require the same rate of return to invest. Typically a utility has a pre-tax real hurdle rate of around 10% and a regulated pipeline network may have a rate closer to 6%, but upstream E&P companies typically require returns in excess of 15%. Consequently there may be difficulties in agreeing how to apportion the revenue between the parties.

Governments managing CCS demonstration projects need to be aware of these issues

In the near term, the issue of selecting the right business model applies to the CCS demonstration projects. The key issue here is: how should governments allocate funds to different components of CCS demonstration projects? In making their decision, governments will need to take into account the different risks each business model entails and the return on equity requirements of the different parties. All this must be done while remembering that the ultimate goal is to demonstrate an operational CCS chain for a limited budget.

Should governments allocate all funds to the operator of the power station? If so, who then takes liability for the payment contracts to the transport and storage phases of the project? Alternatively, do governments allocate funds to the each partner on an individual basis? The former would put the operator of a plant in a powerful position compared to those responsible for transport and storage parts of the CCS chain. This may be reflected in a higher investment threshold for other partners, which could be compensated for by additional direct government funding.

Liability for CO_2 as it moves between partners is also a key issue – how can regulation support this and ultimately how does it support the transition of liability for stored CO_2 to the national government?

But what about post-demonstration CCS projects?

If successful, the end of the demonstration phase will, most likely, bring new entrants to the CCS market. As a result, a new set of issues are likely to emerge that could put different constraints on CCS business models.

The key question here is: how can the business models / funding mechanisms set up for demonstration projects be adapted to meet the requirements of the evolving CCS system? Partners will need to decide which elements of demonstration stage business models to incorporate into the new, post-demonstration business model and which to discard in this new environment. For example, how will business models adapt to a CO_2 transport network that serves multiple users; how will third party access rules be implemented and what form will these take? Can CO_2 emitters from other countries use the transport network and if so, once sequestered who is liable for stored CO_2?

In addition, the impact of multiple revenue streams on these business models is also unclear. For example, how will revenue from enhanced oil recovery, or enhanced gas recovery be distributed between the storage owner/operator and other partners in the CCS chain?

The above issues are a small example of many wider implications of different business models on CCS projects. Ultimately, successful projects will be those that learn from past experience and are able to adapt quickly, thereby minimising any competitive advantage new types of business model give new entrants to the market.

More information

Pöyry Energy Consulting is Europe's leading energy consultancy providing strategic, commercial, regulatory, and policy advice to Europe's energy markets.

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Inventys - CO2 capture for $15 per tonne

Inventys has developed a gas separation technology that it claims enables carbon dioxide to be captured from industrial flue gas streams for US $15 per tonne of CO2. Called the VeloxoTherm™ process, it has the ability to recover the heat energy evolved during adsorption and use it to help release the CO2.

Inventys' VeloxoTherm process

The VeloxoTherm™ (velox = fast; therm = thermal) gas separation process is a post combustion carbon dioxide capture technology that has been developed by Inventys Thermal Technologies. The breakthrough gas separation technology enables carbon dioxide to be captured from industrial flue gas streams for 15US$ per tonne of CO2. Inventys is in the process of commercializing the technology for the enhanced oil recovery (EOR) market.

The VeloxoTherm process is an intensified temperature swing adsorption (TSA) process that uses a proprietary structured adsorbent to separate CO2 from almost any industrial flue gas stream. Simply put, a structured adsorbent is a sorbent material which is arranged into a monolithic structure. The structured adsorbent used in the process resembles a honeycomb that preferentially traps CO2 while allowing other gases such as nitrogen and water vapor to pass through it.

The favourable balance between hydraulic and transport properties achieved by structured adsorbents significantly increases the gas throughput of the system for a given amount of adsorbent (the specific productivity of the adsorbent). This intensification enables the VeloxoTherm TSA process to manage the very large volume of gas that must processed from industrial flue gas streams encountered in post combustion CO2 capture applications.

Figure 1: (LEFT) The VeloxoTherm™ structured adsorbents developed by Inventys; (RIGHT) conventional granular adsorbent.

How it works

Fixed bed adsorption processes, like the VeloxoTherm process, can be intensified (made to be smaller and to be more efficient) by increasing the feed rate to the process by decreasing the cycle time of the process. The extent to which this approach can be implemented is limited by the pressure drop, mass transfer, and heat transfer characteristics of the adsorbent reactor, all of which are not favorable for a traditional arrangement of adsorbent – packed beds.

The shortcomings of packed bed reactors inherently limit the performance of conventional sorbent systems and therefore these systems are not considered to be bona fide alternatives for the post combustion capture of carbon dioxide. Properly designed structured adsorbents can overcome the limitations of conventional sorbent-based separation processes and greatly enhance their performance and economics (Figure 1).

In sorbent separation systems, which use packed bed reactors, the reduction in cycle time decreases the working capacity per cycle, decreasing product recovery, and increasing pressure drop. However, structured adsorbents offer the ability to overcome the challenges encountered when the cycle time of the process is decreased.

Structured adsorbents by their nature are immobilized, so fluidization is nonexistent. Also, correctly designed structured adsorbents provide lower pressure drop per unit length than a packed bed of adsorbent, so for low pressure applications, such as post combustion CO2 capture, they are ideal. In addition, structured adsorbents with high cell densities give proportionally better performance than packed beds because of their higher geometrical surface area. Thus structured adsorbents are among the most efficient methods available to pack high adsorbent surface area into a fixed volume while still maintaining low pressure drop.

Numerous studies have been undertaken to evaluate the mass transfer and pressure drop characteristics of monoliths in adsorption applications. However, the effect of thermal management in adsorptive efficiency has not been investigated to the same extent. The enhancement in performance gained by understanding the thermal effects in adsorbent structures is at the heart of Inventys' expertise.

Adsorption is an exothermic (heat producing) process. When CO2 molecules accumulate on the surface of the structured adsorbent, heat is evolved. When CO2 molecules disperse from the surface during regeneration just the opposite occurs - heat is consumed. As the cycle time of adsorption systems is reduced, management of heat flow during adsorption and desorption becomes increasingly important so that the benefits of superior mass transfer and hydrodynamic benefits offered by structured adsorbents can be realized.

Temperature affects adsorption and desorption detrimentally, reducing capacity on adsorption and decreasing it on desorption. Thus the challenge in designing an effective structured adsorbent is to ensure that heat energy is readily dispersed during adsorption to avoid its accumulation and the resulting increase in temperature. During desorption, the structured adsorbent must rapidly transfer heat energy from the regenerate stream to the sorbent to affect its regeneration.

Monolithic, thin walled structured adsorbents are ideally suited for achieving the required rapid heating and cooling requirement in a rapid thermal swing adsorption processes. The structured adsorbent developed by Inventys for the VeloxoTherm process, however, goes one step further – it has the unique ability to recover the heat energy evolved during adsorption and supply this heat energy to the adsorbent during regeneration. This feature is responsible for the low amount of energy required for adsorbent regeneration – less than 1.5 GJ/tonne of CO2 and is an important factor responsible for the very low net energy consumption for the process.

A proven machine for a novel process

The VeloxoTherm process is unlike conventional adsorption processes that have two or more adsorption reactors operating in an adsorption cycle, which is driven by a series of valves. In the VeloxoTherm process the structured adsorbents are fixed in a cylindrical frame which rotates. The frame is divided into at least two zones. In the adsorption zone, flue gas enters and CO2 is captured from the stream. As the frame rotates, the structured adsorbents pass into the regeneration zone where low-pressure steam is used to release the captured CO2 (Figure 2). Because the separation process operates near ambient pressure, a simple sealing mechanism can be used to isolate the adsorption and regeneration zones.

The rotary adsorption machine replaces discrete adsorption vessels and the accompanying complex arrangement of valves and piping. This embodiment has several advantages. The rotary adsorption machine is a simple, inexpensive, and a proven design. Machines of a similar form and function have demonstrated their reliability and simplicity of operation for many years (rotary heat exchangers which have an analogous more of operation are used in the power generation industry for pre-heating combustion air).

Second, the rotary adsorption machine can readily be integrated into new and existing chemical processes (heaters, boilers, crackers, cement kilns, blast furnaces, and gas turbines) because it is not tightly integrated into existing plant operations. Any industrial facility can continue normal operations during the installation, commissioning, and maintenance of the VeloxoTherm plant.

Third, the VeloxoTherm process is readily scalable. Any number of structures can be assembled to construct a VeloxoTherm plant of nearly any capacity; a plant capacity of 100 tonnes per day of CO2, which would be emitted from a typical process heater in a refinery, would be approximately three meters in diameter whereas a 80 meter diameter VeloxoTherm plant would be capable of processing 5 megatonnes of CO2 annually. Having a projected capital cost of US$132-million, a VeloxoTherm plant of this capacity would be suitable for installation on a 500-megaWatt pulverized coal fired power plant.

CO2 Enhanced Oil Recovery

After applying primary and secondary extraction techniques, a considerable amount of oil remains trapped in the geological formations of oil reservoirs. In some instances, more than sixty percent of the original oil in place (OOIP) remains stranded at the conclusion of conventional production. Enhanced Oil Recovery (EOR) using CO2 provides a means to extract further oil from otherwise depleted oil assets. CO2 injected into a mature well acts as a solvent that enables the trapped oil to flow to the production well, typically enabling the extraction of an additional 20% of OOIP (Figure 3). In the United States alone, CO2-EOR would produce approximately 85-billion barrels incremental oil production.

Natural sources of CO2 are limited both in quantity and geography. The largest natural CO2 sources in the United States are located near the Permian basin whereas opportunities for EOR projects exist in various places across North America. However, there is an abundance CO2 contained in industrial flue gases originating from point sources that are distributed across the North American continent. CO2-EOR offers a compelling opportunity to use the CO2 contained in flue gas streams for enhanced oil extraction while circumventing costly transportation of CO2 from a centralized CO2 source (Figure 4).

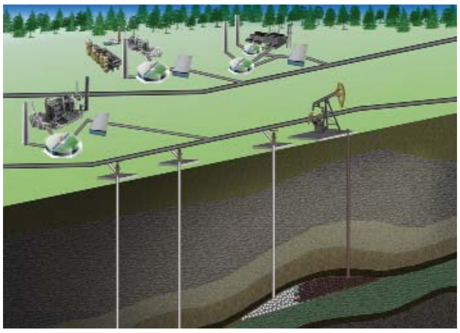

Figure 4: Enhanced oil recovery using the VeloxoTherm process. Carbon dioxide is captured from a flue gas generated from a variety of industrial sources is injected into oil reservoirs to facilitate tertiary extraction of oil

The VeloxoTherm process is able to capture CO2 from nearly any industrial flue gas stream for a total cost (operating + capital) of 5 US$ per barrel of oil recovered, which is equivalent to a capture cost of 15 US$/tonne of CO2. The VeloxoTherm™ process presents purified CO2 at low pressure so compression and transportation are required for use in EOR applications. This will translate into a field-delivered price of approximately 35US$/tonne of CO2, depending, on the nature of the EOR project (the cost for compression and transportation are, of course, application and EOR site specific).

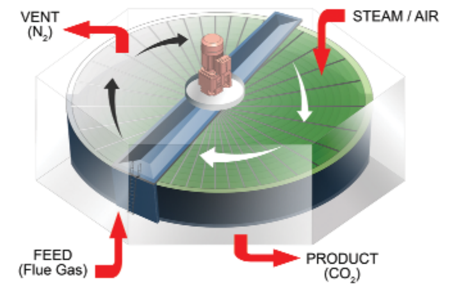

Figure 2: Unlike conventional adsorption processes the proven design rotary adsorption machine does not use reactor vessels which makes the VeloxoTherm process compact, simple, and cost effective.

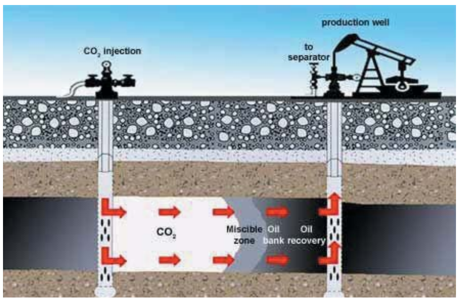

Figure 3: Enhanced oil recovery using carbon dioxide. CO2 is injected into a well site, which helps to mobilize the residual oil so that it can be extracted using conventional processes and existing infrastructure

More information

Inventys Thermal Technologies is located in Vancouver, British Columbia and the company is working with some of the world's largest energy companies to demonstrate the VeloxoTherm™ process. The company was recently awarded 1.9M$ Sustainable Development Technology Canada (SDTC) to demonstrate the VeloxoTherm™ process with its consortia partners, which include Suncor Energy, Doosan Babcock, and British Petroleum.

www.inventysinc.com

CCS legal and policy – Jan / Feb 2011

Several of the component parts of the proposed reforms under the UK Government's Electricity Market Reform Consultation carry the potential to radically alter the outlook for CCS projects, says Calum Hughes, principal consultant in CCS regulation and policy at Yellow Wood Energy.

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One of the UK coalition government's early publications upon coming to power was its first Annual Energy Statement to Parliament, a large part of which addressed the urgent need for electricity market reform in GB. Towards the end of 2010 market modification proposals were issued by DECC in the form of the Electricity Market Reform Consultation. Several of the component parts of the proposed reforms carry the potential to radically alter the outlook for CCS projects. These include, in particular, the introduction of: a carbon price support mechanism; capacity payments for flexible generating plant; and an Emissions Performance Standard (EPS) for electricity generation.

Carbon Price Support Mechanism

It has long been clear that the CO2 emissions reduction commitments made by Parliament via the Climate Change Act 2008 would not be met by the UK's participation in the EU Emissions Trading Scheme (ETS) alone unless the objectives of the ETS were aligned with the targets set out in the Act. With moves towards such an alignment looking increasingly unlikely, and withdrawal of the UK from the ETS practically unfeasible, a mechanism to reduce the UK's CO2 emissions in isolation and ahead of the EU ETS curve is required. The consultation proposes a mechanism aimed at achieving this.

The proposal is to reform an existing piece of climate change related legislation: the Climate Change Levy (CCL) in a way that specifically targets the carbon price to which those generating electricity from fossil fuels are exposed without directly affecting the carbon price of other ETS participants. The intention is that this would increase the wholesale price of electricity (which is typically set by gas, and occasionally coal, fired generation plant) in order to increase both the magnitude and certainty of the electricity price signals going to those considering the development of low-carbon power generation investments.

Currently, fossil fuels used for electricity generation are exempt from the CCL. However, where there are environmental policy reasons, EU law allows member states to tax fuels used for electricity generation and the proposal is that, for fossil fuels used for power generation, the CCL exemption should be removed and CCL rates levied based upon the fuel's carbon content. This additional levy is to be dubbed the 'CCL carbon price support rate'. Therefore, if the reforms are introduced as proposed then, from April 2013, the total carbon price for electricity generators using fossil fuels will be the EU ETS price plus the new CCL carbon price support rate.

How the new scheme will be applied to CCS plants is not yet entirely clear but the Treasury has proposed that, once CCS technology is considered proven and commercially available, the Government should make an application to the European Commission for approval under the state aid rules for a partial relief from CCL for fossil fuels used in CCS plants to reflect the proportion of CO2 abated.

This approach would potentially put early CCS projects at a significant disadvantage to other low-carbon generation projects as they would apparently be liable to pay the CCL carbon support rate, and would therefore not benefit from the carbon price support mechanism, until such time as the technology generally had been proven.

Capacity Payments for Flexible Generating Plant

When considering investment in fossil fuel fired generating plant, generators assess a number of risks. These include operating risk: the risk that the plant will not be run for an economically viable proportion of its design life and/or its design capacity, i.e. that the actual load factor of the plant will be below that assumed in the economic model upon which project sanction is based.

Until relatively recently, load factor risk for a new fossil fuel fired plant was relatively low because it was very likely that an efficient new plant would run continually for a large proportion of its design life. However, with the potential for an increasing amount of low operating-cost renewable plant to come on-line over the next few years, the risk that relatively high operating-cost fossil fuel fired plant would be displaced from the grid at times of low demand is increasing. This is because once winds farms are constructed and commissioned the marginal cost of wind generated electricity is very low and, with the subsidies provided through the Renewable Obligation scheme, may even at times be negative. This leads to increased operational risk for fossil fuel fired power plant, a major factor currently stalling investment decisions.

Calum Hughes, Yellow Wood Energy

For a number of reasons the current market arrangements are failing to overcome this problem and satisfactorily encourage investment in new flexible, fossil fuel fired, power plant. This is threatening to reduce capacity margin (the level to which installed generating capacity exceeds actual peak electrical demand) to unacceptably low levels. Whilst this is clearly a security of supply issue, it also threatens to adversely affect the development of the CCS industry as new fossil fuel fired plant would require CCS in some form and therefore, without new developments of this type of plant there will be less CCS.

The consultation includes proposals to address the issue: a targeted capacity mechanism, administered by a central body with an obligation to maintain a set capacity margin. The body would forecast the level of spare capacity likely to be provided through the energy market and then run tenders for the additional capacity needed to make up any shortfall. The generation type making up this spare capacity is very likely to be flexible, fossil fuelled, plant.

At first view then, the capacity mechanism proposal appears to be beneficial for CCS and, on the whole, I think it is. But it is notable that the rationale for the proposed capacity mechanism does not address the need for any particular level of coal fired plant in the energy mix. Indeed it is general-


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ly noticeable, that there is a reduction in the apparent appetite for support specifically targeted at encouraging the development of coal fired plant and the general impression given is that an increased reliance upon gas fired plants for capacity margin and generation flexibility may be acceptable to the current Government.

Emissions Performance Standard

The introduction of an Emissions Performance Standard (EPS) for fossil fired power plant has long been advocated as a method of targeting this type of plant without unhelpfully interfering with the general operation of the EU ETS. The main point of disagreement amongst EPS proponents has been the level at which an EPS should be set as this governs the type of plant affected by the EPS. The current consultation proposes the use of an EPS at levels which effectively mandate CCS on new coal-fired power stations without affecting gas-fired generation.

Two levels of EPS are considered: 450 and 600 gCO2/kWh, both of which, would only be applied to new-build plants, with the aim of preventing the construction of coal-fired plant without the installation of emissions abatement.

The lower EPS figure sets a CO2 emission level that is considerably lower than that required for demonstration project funding by the EU or UK Government. However, whichever level is selected, measures will be included to prevent the EPS adversely affecting the demonstration projects. Also, to avoid concerns that the regulatory risk associated with the potential for progressive tightening of EPS levels in the future might affect investment decisions relating to new coal-fired plant outside the demonstration projects, EPS levels shall be set on a plant specific basis and shall remain fixed at this level for the duration of the plant's operational life (this is dubbed 'grandfathering'). This largely removes the regulatory risk associated with the EPS in the development of new coal-fired power stations.

The EPS will be assessed on annual averaged emissions rather than instantaneous emission rates. There will also be exemptions from the EPS where these are required in order to secure energy supply. This will allow the generator some flexibility in the operation of their plant and could lead to decisions to install CCS plants that are large enough to significantly exceed the EPS in order that the plant operator might generate unabated when electricity prices are high (exactly when flexible plant is required) in the knowledge that it can still meet its EPS commitments by capturing more carbon at other times. The proposed methodology for assessing compliance with the EPS might therefore render investment in coal-fired plant fitted with CCS more attractive by making the operation of this type of plant potentially more flexible, and therefore profitable, but also has the potential to see the demonstration of larger CCS plants than might be the case with a less flexible assessment method.

The consultation makes it clear that the present Government considers that, while it may be necessary to reduce EPS levels in the future to those which would require CCS on gas-fired plant, the application of EPS levels in such a range at this time would present unacceptable risks to security of electricity supply in the short to medium term.

Furthermore, the consultation gives assurances that the same plant specific EPS level 'grandfathering' commitments that apply to coal-fired plant will be extended to gas-fired plant. Therefore, although it is not explicitly stated, it appears that there is a policy shift with respect to the need for new gas fired stations currently being approved to be Carbon Capture Ready (CCR), as this requirement would be contradictory with the grandfathering guarantees that initially unabated gas-fired stations would not be required to retrofit CCS for the entirety of their operational life.

GCCSI - achievements in its first year

The Global Carbon Capture and Storage Institute hit the ground running in its first year with a series of comprehensive reports into the state of CCS worldwide and the establishment of a Project Support Program to help demonstration projects overcome key barriers and an online knowledge platform.

By June 2010, the Institute reported in an 'Interim' report that 80 large-scale, integrated projects were being developed around the world and at various stages of development planning.

Institute data also indicated that over US$26 billion has been flagged globally by governments to support the development of CCS projects. Despite this, the application of a set of criteria to determine whether a project can be considered as 'launched' indicates that most projects have significant work ahead to address specific barriers to deployment.

A key goal for the Institute for 2009–10 was to directly engage with large-scale, integrated projects to address the barriers to deployment and leverage key knowledge sharing products for wider dissemination amongst the industry.

Initiated in December 2009, the Project Support Program allocated approximately AU$50 million annually to provide targeted financial and knowledge-based support to Member activities to address key barriers to the delivery of large-scale, integrated projects. The program will facilitate transfer of knowledge amongst Institute Members and the wider CCS community.

During 2009–10 the Institute:

- developed a baseline report on the deployment status of the world's CCS projects;
- developed a model for the 'Ideal Portfolio' of CCS demonstration projects;
- established a Project Support Program to help demonstration projects overcome key barriers;
- established the basis for an online CCS knowledge platform;
- collaborated in the development of CCS recommendations to the Muskoka 2010 G8/G20 Summit;
- secured membership and an advisory capacity to the Major Economies Forum, newly established Carbon Capture Use and Storage Action Group; and
- established a collaborative definition for CCS Ready and recommended

The Institute's website was also updated to support networking and personal interaction, collaboration and knowledge exchange between users and the CCS community.

"At the Institute, we believe that understanding the challenges facing CCS projects and then using this knowledge and expertise to help 'unstick' those projects is fundamental to creating an immediate and lasting contribution to the deployment of this technology," said Nick Otter, DEO, Global CCS Institute, in his introduction to a report on the GCCSI's first year of operation.

"This first year, the Institute has made good progress towards its strategic goals. We established a Strategic Framework for our activities, creating clarity about the purpose of the organisation, what we want to achieve and the steps we should take to reach our goals."

"We put in place the necessary foundations, expertise, policies and governance required to deliver services to our Members. And, most importantly we commenced the delivery of real assistance to our Members through the analysis of the status of projects, direct project support and through understanding the necessary conditions for commercial-scale deployment."

Major goals for 2010–11 are to:

• Develop an authoritative knowledge base across the priority issues facing CCS and disseminate lessons contained within.

• Complete a more detailed analysis of the most mature of the large-scale, commercial, integrated projects.

• Complete the first round of the Project Support Program.

• Establish a process and the capability to engage with project proponents to identify and address specific issues through knowledge sharing across the Institute's Membership base.

• Rapidly increase the use and functionality of the digital knowledge sharing platform.

• Ensure all industry sectors and relevant Governments crucial to the acceleration of CCS are well represented as part of the Institute's Membership base.

• Complete the recruitment of key positions and core skill sets and embed within key global markets.

For more information go to:
www.globalccsinstitute.com

Global CCS Institute Members' Meeting Pittsburgh (13-14 May 2010)

Bellona on Weyburn, Saskatchewan: safe storage of CO2 crucial

Bellona understands that people who have lived in proximity of the Weyburn oil field in Saskatchewan, Canada, where CO2 is injected, have questions about the project. Although extensive research indicates that the injected CO2 has stayed put, there is a need for a thorough investigation when questions about safety are raised. By Anne Karin Saether, Bellona Foundation

According to Canadian newspapers, a couple Jane and Cameron Kerr, claim that contamination from a CO2 capture and storage (CCS) project in Weyburn, Saskatchewan has driven them from their home.

The Weyburn project is operated by Cenovus Energy, which uses CO2 for enhanced oil recovery (EOR) in oilfields. The Kerrs says that between 2004 and 2005 a cat, a goat and a rabbit died at their farm, which is located near an injection site, and they suspect it was caused by higher concentrations of CO2 in the area. As far as Bellona has been able to learn, there have been no incidents since 2005.

Independent research

In a statement yesterday, the Petroleum Technology Research Centre (PTRC) said that baselines for CO2 in the soils and wells were taken in multiple locations starting in July, 2001, prior to any injection, and surveys have been repeated yearly until the fall of 2003 to monitor effects after the injection of CO2 began.

These tests have all indicated that soil gases sampled are in the normal range. According to PTRC, no CO2 originating from the injection unit at the Weyburn field has been observed in any of the studies undertaken by international scientific organizations such as British Geological Survey, BRGM (French Geological Survey), and INGV (Italian Geological Survey).

"We do, however, want to express our concern regarding the situation the Kerr couple is in, and we see a need for a thorough investigation. People should not have a reason to worry about possible seepage of CO2 closes at storage sites," says Erlend Fjøsna, Programme Director of the Bellona's Environmental CCS Team (BEST).

The climate at stake

Bellona sees CO2 capture and storage (CCS) as a crucial part of the fight against climate change. Global CO2 emissions must be cut by up to 85 percent by 2050 to avoid the most dramatic consequences of global warming, and enhanced energy efficiency and more renewable energy production alone is, unfortunately, not enough. Such solutions cannot be deployed fast enough to obtain sufficient emissions reductions, whereas CCS can give large immediate reductions once deployed.

"We support CCS because the climate is at stake, but totally safe storage of CO2 is crucial. Storage sites must be selected carefully, and there must always be a proper monitoring system," says Fjøsna.

He explains that although CO2 is in soft drinks and in the breath, that humans exhale, it can be harmful in high concentrations:

"If CO2 seeps out of a ditch or a hollow in the ground on a windless day, there is a risk that small animals or birds could die. CO2 can come out of the ground naturally, though, and, for instance, in Iceland the geysers contain a lot of CO2."

For more information go to:
www.bellona.org

DOE CCS Roadmap updated

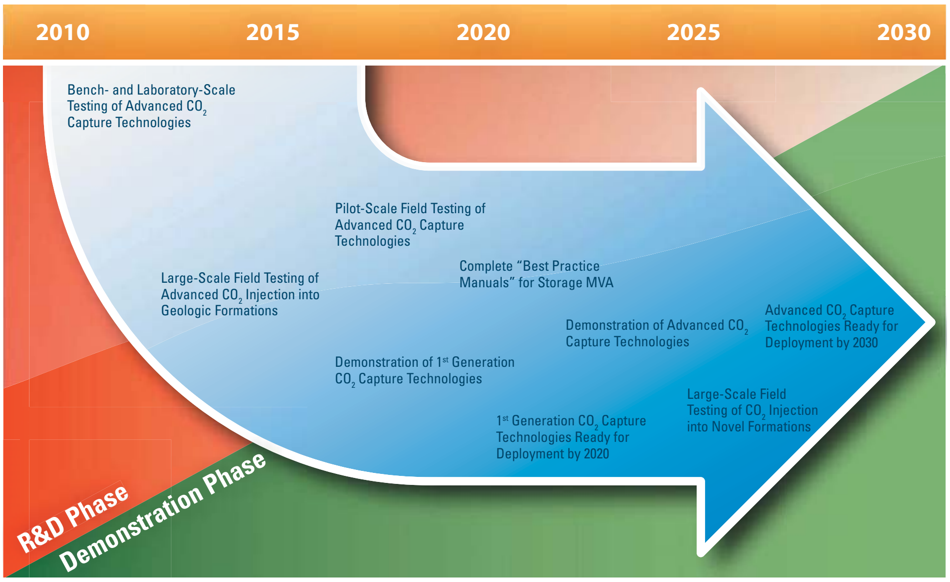
An overview of research, development, and demonstration (RD&D) efforts to supply cost-effective, advanced carbon capture and storage (CCS) technologies for coal-based power systems is the focus of a new roadmap published by the U.S. Department of Energy (DOE).

The U.S. Department of Energy's (DOE) Clean Coal Research Program is focused on the integrated development of carbon capture and storage (CCS) technologies to affordably and efficiently sequester carbon dioxide (CO2) from coal-based power plants. The program is gathering the data, building the knowledge base, and developing the advanced technology platforms needed to prove that CCS can be a viable climate change mitigation strategy, thus ensuring that coal, a secure and affordable energy resource, remains available to power a sustainable economy.

DOE's overarching mission is to advance the national, economic, and energy security of the United States. To that end, the DOE Office of Fossil Energy's (FE) mission is to ensure the availability of ultra-clean (near-zero emissions), abundant, low-cost domestic energy from coal to fuel economic prosperity, strengthen energy security, and enhance environmental quality. The DOE/FE's Clean Coal Research Program is implemented by the National Energy Technology Laboratory (NETL). Program contributions include the research, development, and demonstration (RD&D) of clean coal technologies that are highly efficient, achieve near-zero emissions (including carbon), and are commercially deployable in a competitive energy market.

Through fossil energy-related provisions in the American Recovery and Reinvestment Act of 2009 (Recovery Act) and annual appropriations, the development of CCS is being pursued to meet future energy needs.

Specific programs associated with the application of Recovery Act funding include: expansion of Round 3 of the Clean Coal Power Initiative (CCPI); development of advanced technology for large-scale CCS from industrial sources; characterization of geologic sequestration sites; implementation of geologic sequestration training and research; acceleration of the deployment of advanced coal gasification-based power production technologies linked with CCS; a CCS demonstration using oxy-combustion technology for CO2capture under the FutureGen 2.0 Initiative; and acceleration of CCS technology development through the Carbon Capture and Storage Simulation Initiative.



DOE's CCS Research RD&D Effort Timeline (Source: CCS Roadmap ©DOE)

The DOE Fossil Energy Research Program is developing a variety of major cost-reduction technology innovations that could help make CCS a viable domestic and global option. A focused portfolio of technologies is being pursued along multiple technology paths to mitigate the risks inherent to RD&D efforts.

Further, the program plan encompasses RD&D across a wide scale, integrating advances and lessons learned from fundamental research, technology development, and large-scale demonstration. DOE envisions having an advanced CCS technology portfolio ready by 2020 for large-scale demonstration that provides for the safe, cost-effective carbon management that will meet our Nation's goals for reducing GHG emissions.

A large part of this program is NETL's domestic and international transfer of technologies and processes. NETL sponsors the Regional Carbon Sequestration Partnerships (RCSPs), a government-industry effort to determine the technologies, regulations, and infrastructure changes needed to achieve CO2 management in various regions of the United States and Canada. In addition, the majority of DOE's collaboration with international research organizations, including the Carbon Sequestration Leadership Forum (CSLF), focuses on technologies that can handle the scale of capture required by commercial power plants, by far the largest stationary producers of CO2.

New technological solutions are urgently needed. The United States can no longer afford the luxury of conventional, long-lead times for RD&D to bear results. New approaches must emphasize rapid commercialization of efficient, economic solutions that minimize CO2 emissions. On February 3, 2010, President Obama established an Interagency Task Force on Carbon Capture and Storage that was charged with proposing a plan to overcome the barriers to the widespread, cost-effective deployment of CCS within 10 years. The Task Force issued its final report in August 2010, which acknowledged the importance of DOE/NETL's CCS RD&D efforts.

The success of DOE research and related program activities will enable CCS technologies to overcome a multitude of economic, social, and technical challenges including cost-effective CO2 capture, compression, transport, and storage through successful CCS integration with power generation systems; effective CO2 monitoring and verification; permanence of underground CO2 storage; and public acceptance. The document provides a roadmap for NETL's CCS RD&D effort.

The report can be downloaded at: www.netl.doe.gov

Carbon Capture and Storage in Industrial Applications - UN report

A United Nations Industrial Development Organization technical synthesis report describes the main technology options available to the industry sectors which have the highest potential for CO2 mitigation and provides summary descriptions, highlights case studies and provides cost estimates for research, demonstration and commercial projects being planned or developed.

Currently direct industrial carbon dioxide (CO2) emissions account for one third of total global energy use and for 40% of process CO2 emissions (IEA Energy Technology Perspectives 2010). Industrial energy use and CO2 emissions are projected to further grow in the coming decades. The processes in industry are diverse, and so are the options to reduce emissions, now and in the future.

In industry, there are two situations in which CCS can be demonstrated and applied early. First, as many industrial CO2 emissions are inherent to industrial processes, it is technically and economically more difficult to reduce these emissions in industry than in other sectors. In such cases, CCS - as a mitigation option in industry - becomes one of the only options for large scale emissions reductions.

Second, some industries vent high-purity CO2 into the atmosphere. Such 'pure'-sources of CO2 are relatively cost-effective to capture and could therefore represent early opportunities for CCS to be demonstrated. For deep emission cuts, CCS is a key emissions abatement option in industry, in addition to energy efficiency measures.

However, the vast majority of research and development (R&D) and demonstration funds as well as policy efforts for CCS are aimed at the power sector. Currently, there are few incentives for CCS from industrial CO2 sources, even for the low-cost options. In the short term and in some regions, enhanced oil recovery (EOR) can provide a financial incentive to capturing and injecting CO2, in a project, and therefore act as a "market pull" for developing CO2 capture technology.

Policy for industrial CO2 reduction in industry is more challenging than in the power sector with its domestic focus, because industry more often operates on a global market, facing global competition. The implementation of CCS-policies in one country may cause companies to relocate their operations to countries without such policies. Thus, the industry sector requires international agreements on policies and measures to prevent such carbon leakage and relocation. Industrial CO2 streams are typically smaller than coal power plant CO2 streams. While the smaller scale may raise the cost per tonne of CO2 captured, interesting integrated process designs are under development which can lower this cost.

Sector	Production process	Capture technology
High-purity industrial sources	Natural gas processing (onshore/offshore)	Existing industrial gas separation techniques[3]
	Coal-to-liquids (CtL)	
	Ethylene oxide production	
	Ammonia production	
Iron and steel	Blast furnace (pig iron)	Top gas recycling (TGR) Oxyfuel blast furnace
	Direct reduction of iron (DRI)	Pre combustion (gasification) + PSA[4], VPSA[5] or chemical absorption
	FINEX technologies	PSA[6]
	The HIsarna process	PSA or VPSA
Cement	Kiln/calcination	Post combustion technology using chemical solvents, Oxyfuel technology
Refineries	Hydrogen production	Chemical absorption, PSA
	Hydrogen gasification residues	Pre combustion (gasification) + chemical absorption
	Fluidised catalytic cracking	Post combustion using chemical absorption, or oxyfuel technology
	Process heat	Post combustion using chemical absorption, or oxyfuel technology
Biomass conversion	Synthetic natural gas	Pre combustion (gasification) + chemical absorption
	Ethanol production	Dehydration only
	Hydrogen production from biomass	Pre combustion (gasification) + chemical absorption
	Black liquor processing in pulp and paper manufacturing	Pre combustion (gasification) + chemical absorption

Sectors, sources and technologies presented in the report
3 There are a number of existing gas separation techniques such as membrane separation, chemical absorption using solvents including amine-based solutions monoethanolamine (MEA), methyldiethanolamine (MDEA) and hot potassium carbonate based processes, physical sorbent based process, pressure swing absorption (PSA) and cryogenic separation process.
4 Pressure swing adsorption
5 Vacuum pressure swing adsorption
Source: Carbon Capture and Storage in Industrial Applications: Technology Synthesis Report Working Paper - November 2010

Finally, the technologies required in industry are more diverse than in power generation and therefore need a more diverse demonstration programme. The technical synthesis report captures the main findings drawn from five sectoral assessment reports that were commissioned by expert consultants to the CCS Industrial Sector Roadmap project, namely: high purity CO2 sources, refineries, cement, iron and steel and biomass based; and from the reports from the workshops undertaken as part of the development of the Roadmap.

The report was funded by the Norwegian Ministry of Petroleum and Energy and the Global CCS Institute, and was coordinated by the United Nations Industrial Development Organisation (UNIDO). The International Energy Agency (IEA) supplied most of the data.

The report can be downloaded at: www.unido.org

DNV position paper - is CO2 storage safe?

CO2 geologic storage (CGS) technology is by no means fail-proof or riskfree, but carefully selected and qualified storage sites that are operated according to effective regulatory supervision should be safe according to a DNV position paper.

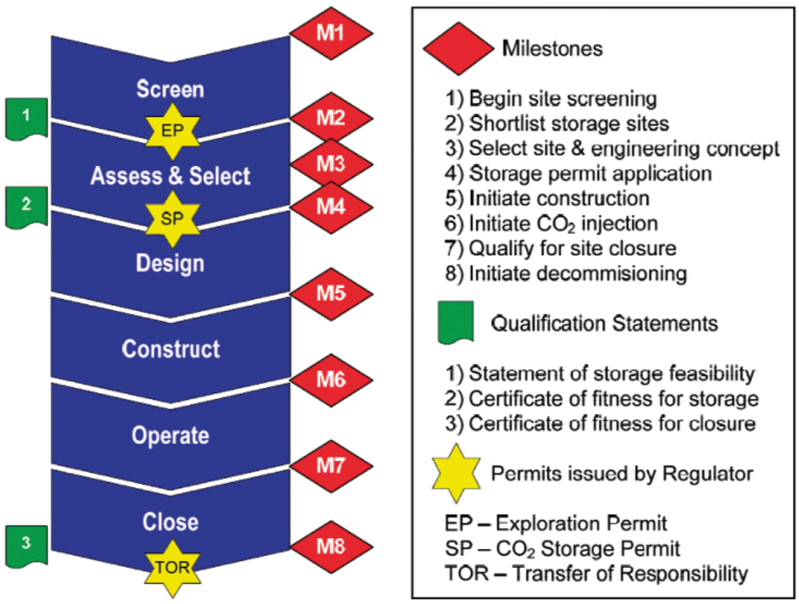
The key will be to apply fit-for-purpose risk management throughout the lifecycle of the storage sites, starting from screening, and continuing through site selection, qualification, injection operations, and, finally, closure, says the report from DNV.

CGS is a mature technology that has been used at industrial scale at several large sites both onshore and offshore. CGS technology can be applied immediately, at a much larger scale, at tens to hundreds of sites globally. The main evidence for this is empirical, collected through relevant analogue subsurface industrial experiences and at large-scale demonstrations of CGS at several sites. This includes almost 100 years of natural gas storage at hundreds of sites in North America and Europe, 35+ years of experience with CO2 enhanced oil recovery (EOR) in North America, 15+ years experience with acid gas (mixtures of H2S and CO2) injection in western Canada, and 14+ years experience at dedicated CGS projects in the North Sea and Algeria.

The current state of CO2 injection technology can best be summarized by the conclusions reached by the Massachusetts Institute of Technology in their Environmental Assessment of Geological Storage of CO2, namely that: "The technologies and practices associated with geological CO2 storage are all in current commercial operation, and have been so for a decade to several decades. No major "breakthrough" technological innovations appear to be required for large scale CO2 transportation and storage."

All the important risks for CGS projects have been identified, and the R&D community and industry have found solutions to most, if not all, of these. Because every storage site will be unique, each site will need to be individually qualified, based on its own specific profile of subsurface and surface properties, and using the best available technology and solutions as they inevitably evolve and improve. Standardized work flows that promote sitespecific qualification will make this task more effective, while avoiding the traps of prescriptive, static, technical solutions. The key features of site qualification will be transparency and complete, auditable records of the permit approval process, such that public confidence can be earned and maintained.

Very similar industrial activities in the EOR industry, injecting CO2 in large quantities (cumulative injection ca. 600 million tons CO2) in the underground to increase oil production, have generated high confidence in key parts of the systems required for CGS in deep saline formations for the purpose of reducing GHG emissions. Indeed, permanent disposal of gases by injecting them into the subsurface has been practiced for over 15 years in Canada, and CO2 permanent storage by injecting large volumes into a deep saline formation has been practiced at Sleipner since 1996.



CGS project lifecycle and associated qualification statements, relevant permits, and project milestones

These projects have shown that although the CGS strategy is neither failure-free nor totally without risk, industry and regulators have the necessary solutions to manage risks effectively. Nonetheless, scale up of this strategy, from the current situation of a few projects to hundreds of projects, remains a challenge.

DNV is actively developing and promoting compact, standardized evaluation tools for the site screening phase and that have the potential to be applied to screening thousands of candidate sites, so that they can be ranked according to a relatively sparse, but indicative, set of site characteristics. Once candidate sites have been selected for more detailed exploration and site surveying, a set of more advanced and detailed evaluation processes will potentially lead to application for a storage permit. Fit-for-purpose regulatory capacity and frameworks are being developed and will be fully operational in the near future. Proper site performance will be verifiable for sites that have carefully designed and installed fit-for-purpose monitoring systems that follow the evolution of the site throughout its lifecycle.

DNV anticipates a growing need for independent verification of monitoring systems and data to maintain public confidence in site integrity. Although final site closure is a challenge that is still 20 years away, the entire community of CGS stakeholders is actively preparing for this phase. Much of the experience from sealing and abandoning wellbores in the oil and gas industry will be directly applicable.

CO2 geologic storage can be made very safe, concludes the report, given that the main safety barrier is a kilometer (or more) of the Earth's crust, and that subsurface geoscience and engineering are applied using the most effective risk management methods, originally developed for a range of industrial activities and carefully adapted to fulfil the special needs of CGS.

The report can be downloaded at: www.dnv.com

Policy, company and regulation news

UN accepts CCS in the Clean Development Mechanism

The decision to include CCS projects under the CDM came in the dawn hours of the closing day of climate talks at the UN Convention on Climate Change (UNFCCC) in Mexico.

The resolution calls for rules around CCS projects to be finalized at the next climate talks in December 2011 and for issues such as permanence, boundaries and safety to be addressed and resolved.

"CCS has a critical role to play – right along with other measures such as energy efficiency and renewable – in reducing the world's emissions to the required level by 2050," said Dale Seymour, Senior Vice President for Strategy at the Global CCS Institute. "The UN confirms this with its decision, which now clears the way for developing countries to finance CCS projects."

"This decision will ultimately see a framework established that could provide for the institutional arrangements of CCS under any future UNFCCC mechanism and/or adopted within national government policy settings," Seymour said.

Some 3,400 CCS projects need to be up and running by 2050, many of them in the developing world, says the GCCSI. Until now the vast majority of projects have been in Europe, North America and Australia.

In Cancun, the Institute hosted a number of events, including around the launch of a paper that addresses concerns previously raised about CCS in the UNFCCC.

"This is a big step forward for CCS and I'd like to think that the Institute has contributed in a way, through the informative events we hosted and substantial meetings with delegates," said Seymour. "In particular I expressed – and express again – the Institute's appreciation to the Mexican delegation for boldly initiating high level bilateral discussions among delegations that clearly helped pave the way for this decision."

Queensland delays ZeroGen project

www.cabinet.qld.gov.au

The ZeroGen project to build a clean coal power station project in central Queensland will not go ahead in its current form.

The ZeroGen project is a joint State-Commonwealth Government and industry led research project into carbon capture technology for coal fired power production.

Premier Anna Bligh confirmed that the State Government has decided not to pursue at this time the proposal to fund an Integrated Gasification Combined Cycle power station incorporating carbon capture and storage.

Under the restructure the state government proposes that ZeroGen will be transitioned into an independent entity, owned and run by industry and dedicated to the accelerated development and deployment of CCS.

Ms Bligh said $50 million of Government money, leveraging a further $100 million from industry and the Commonwealth, will remain in the Clean Coal Fund to assist companies like ZeroGen compete for funding for the development of CCS in Queensland.

"We are not about to walk away from Carbon Capture and Storage technology but we will be changing the focus of our efforts.

"We embarked on this research program because Queensland is one of the world's major coal producing regions.

"It is in the best interests and prosperity of future generations that we develop this clean coal technology and the research we have carried out to date has made us world leaders in this field.

"We had hoped to have a clean coal power station up and running by 2015 but the fact is that the early research has shown us that this is not viable at this time on a commercial scale.

"The Queensland government will work with the coal industry over the next three years to prioritise suitable storage in Queensland that would support the construction of an integrated power plant with CCS.

"Expert advice recommends undertaking further carbon storage site identification in other parts of the State which could become viable in the future," she said.

"This is where an independent, industry-led ZeroGen will now direct its attention.

"Identifying storage locations is the critical first step in the process towards the development of Carbon Capture and Storage capacity in Queensland."

The Premier said that the Queensland Government, together with other funders, remains fully committed to identifying suitable storage and developing power station CO2 capture technologies including Callide Oxyfuel and the Tarong Post Combustion pilot project.

"Earlier this month the Minister for Mines and Energy opened the Tarong Post Combustion Capture Project – a pilot plant designed to capture 1,000 tonnes per annum of CO2 from the power station," she said.

"And the Callide Oxyfuel project has the potential to capture around 25,000 tonnes of CO2 per annum eventually capturing up to 10% of the entire Unit's CO2 production.

"By identifying future areas that are geologically suited to future projects we can ensure that other viable integrated capture and storage projects can be created in the future."

Shell Quest CCS project plan submitted

www.shell.com

Shell Canada has submitted a regulatory application for its Quest Carbon Capture and Storage (CCS) project located in central Alberta.

Shell submitted the application on behalf of the Athabasca Oil Sands Project, a joint venture among Shell Canada Energy (60%) Chevron Canada Limited (20%) and Marathon Oil Canada Corporation (20%).

The Quest project would capture more than one million tonnes of CO2 per year from the Shell Scotford Upgrader, located about 40 kilometres northeast of Edmonton. The CO2 would be transported by an 84-km pipeline to injection wells north of Shell Scotford and permanently stored more than two kilometres underground beneath several layers of impermeable rock.

The regulatory submission includes applications for each component of the project, including the capture, transport and storage of CO2. The Energy Resources Conservation Board (ERCB) is the primary regulatory agency for the project. A cooperative Environmental Assessment was conducted to meet both provincial and federal requirements - with Alberta Environment acting as the lead party.

A final investment decision on the proposed Quest project would not be taken until the regulatory process is complete. A decision to proceed with the project would depend on a number of factors, including but not limited to, the outcome of the regulatory process, economic feasibility and final project costs, and ongoing consultation with key stakeholders, says Shell.

Aker Clean Carbon feasibility study on German power plant

www.akercleancarbon.com

Aker Clean Carbon has won a contract to study full size retrofitting and integration of its carbon capture technology for EnBW's new supercritical 912 MW coal fired power plant in Germany.

The plant is located in Karlsruhe and will produce around 5M tonnes CO2 per annum. It is due on line in 2012.

Aker Clean Carbon will conduct the feasibility study in 2 phases: the first phase includes process design and estimates for the capital investment and operational cost of the CO2 capture unit; phase two includes integration and optimization studies.

Luminant donates $500k to University of Texas

www.luminant.com

Luminant has given a further $500,000 to The University of Texas at Austin's Luminant Carbon Management Program bringing its total program contribution to $2.3 million over five years.

Founded in January 2007, the program offers Ph.D. candidates at the university an opportunity to conduct hands-on research in the area of carbon capture and storage. To date, seven students have graduated from the program and 17 are currently participating.

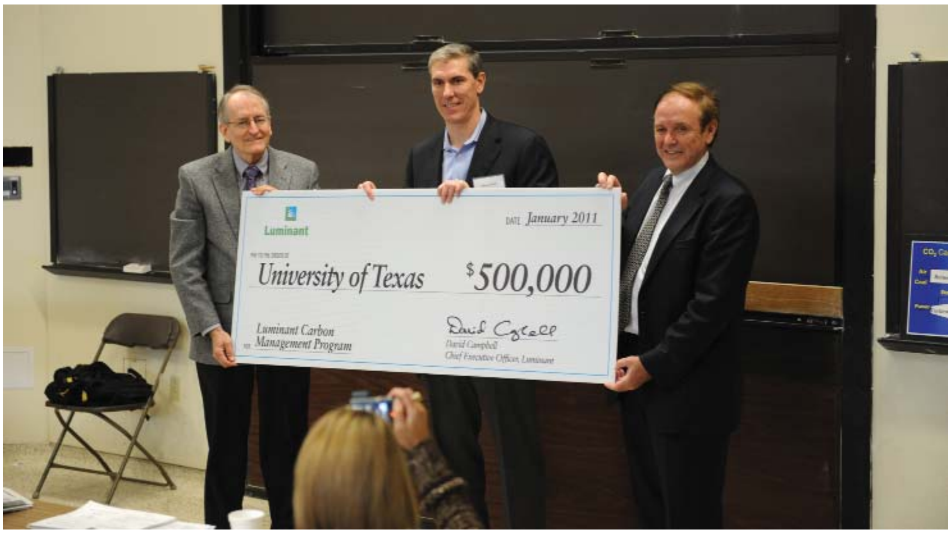
"These results reaffirm our enthusiasm for the program and the long-term impacts we believe it can have on our industry," said Steve Horn, Luminant vice president of engineering and technology. "As Texas' largest power generator, we are committed to funding the research of emerging technology such as this.."

The program is headed by Dr. Gary Rochelle, the Carol and Henry Groppe Professor of chemical engineering.

"The Luminant program has been exceedingly successful," Rochelle said. "Through their research, our students have identified a new carbon capture process and are now working to find a way to make the process less energy intensive, which will have additional positive environmental impacts."

Among the research advancements enabled by Luminant's funding, Rochelle and his team have developed a more stable and less energy-intensive method for removing carbon dioxide from coal-fired flue gas. The method uses aqueous piperazine, an organic compound that acts as a solvent, to absorb carbon dioxide from the gas.

Luminant's dedication to the program has also helped prompt more than 30 other companies to sign on as industrial associates with commitments of $25,000 per year.



Steve Horn, Luminant vice president of engineering, presented a check for $500,000 to chemical engineering Professor Dr. Gary Rochelle and Juan M. Sanchez, vice president for research at The University of Texas at Austin

CSLF releases CCS technology roadmap

www.cslforum.org

A report released by the Carbon Sequestration Leadership Forum (CSLF) indicates significant international progress has been made in the past year on advancing carbon capture and storage (CCS), but that a number of important challenges must be addressed if widespread commercial deployment is to be achieved.

"While significant carbon capture and storage project activity and technological progress is underway globally, continued advancements are needed to gain public acceptance as well as contribute to the creation of a sound regulatory framework for geological CO2 storage," according to the CSLF's 2010 Technology Roadmap. The report notes the "sheer scale of creating major CO2 pipeline transmission systems, some of which may pass through populated areas, will raise financial, legal, institutional, and regulatory issues as well as public concerns."

This latest CSLF report says there are now 32 active or completed CSLF-recognized projects demonstrating worldwide collaboration on CCS and contributing to the CCS knowledge base. It also indicates that significant national investments are occurring globally to advance deployment of CCS technologies.

The Roadmap notes that the "understanding of regional capacity and potential for geological storage has improved with the completion or undertaking of several national and regional storage atlases," and that there is a shift in emphasis toward specific storage issues, such as capacity estimation, well design and integrity. Also, major progress has been made toward a consistent methodology for capacity estimation in deep saline reservoir storage systems, "but this area still remains a key priority."

In the final analysis, continued research, development and deployment "to reduce capture costs and validate safe, long-term storage of CO2 at all levels, from theoretical and laboratory work through pilots and large integrated projects, is vital. In all aspects, effective knowledge sharing and lessons learned will be key elements that will contribute to the accelerated deployment of CCS."

The purpose of the Roadmap is to "provide a pathway toward the commercial development of integrated CO2 capture, transport, and storage technologies."

Texas CCSA returns from China carbon capture trip

www.TxCCSA.org

A delegation including the Texas Carbon Capture and Storage Association (TxCCSA) has returned from a seven-day fact-finding trip to China, in an effort to learn more about carbon capture and storage (CCS) technologies in that country.

The delegation included several prominent lawmakers and industry leaders from Texas, the UK and other regions of the United States.

"China is now the largest producer of CO2 in the world. It is a fascinating country, however, their carbon mitigation and CCS efforts require additional integration and experience," said TxCCSA general counsel Darrick Eugene.

Texas is uniquely positioned as both a national and world leader in CCS technologies. It produces more CO2 than any other U.S. state, which gives it a very broad range of opportunities to test and commercialize carbon capture technologies. It also has more underground geologic storage potential than any other state, including partially-depleted oil reservoirs used for enhanced oil recovery.

CO2-driven enhanced oil recovery (EOR), the process of injecting CO2 into oil wells to recover remaining oil deposits, has been used in the Texas Permian Basin for more than 35 years. Experts believe CO2-driven EOR could yield tens of billions of barrels of oil in Texas.

During the China visit, TxCCSA and other delegates visited facilities that incorporated various components of CCS. However, integrating the components of CCS remained a challenge. Officials for several leading CO2 capture initiatives, when asked what they planned to do with the CO2 once captured, were uncertain.

Texas has been a leader paving the way for CCS and other clean coal technologies. Several companies, including TxCCSA member Tenaska, have facilities planned in Texas that would fully integrate CCS.

“China is known for bold decisions, therefore the lack of focus regarding CCS was surprising to many of us,” said Eugene. “Texas has several projects in development that would incorporate all facets of CCS while competing in an open electric marketplace. TxCCSA believes commercial application under true market forces is crucial to the widespread adoption of these cleaner technologies.”

In 2009, TxCCSA worked with lawmakers to pass legislation that would legally clarify how CO2 storage will proceed. TxCCSA also worked to pass a sweeping list of tax and other financial incentives for early adopters of clean coal technology.

This session, TxCCSA plans to again work with lawmakers to improve the marketplace for CCS adoption in Texas. The legislative package includes technical changes to SB 13871 which established the regulatory framework for geologic storage in Texas, as well as efforts to address long-term stewardship.

UK Committee releases fourth carbon budget

www.theccc.org.uk

The report sets out the UK Committee on Climate Change's advice on the fourth carbon budget, covering the period 2023-27.

The UK Government will propose draft legislation for the fourth budget in Spring 2011. The report welcomes the current proposal to support four CCS power generation projects (in the Coalition Agreement, reconfirmed in the 2010 Spending Review), which, "would result in a critical mass for potential roll-out from the early 2020s. It is important that a funding mechanism for the four projects is finalised and that these are tendered in 2011 to facilitate early deployment. Given the extent of decarbonisation required by 2030, and the possibility that future gas prices may be lower than seemed likely at the time of our 2008 report, CCS for gas as well as coal generation will be a crucial set of technologies. The Government’s recent announcement that gas CCS will be included in the demonstration projects is therefore welcome."

The Carbon Capture and Storage Association (CCSA) welcomed the Committee on Climate Change’s report setting out its advice on the fourth carbon budget.

Commenting on the publication of the Committee’s recommendations, Dr. Jeff Chapman, Chief Executive of the CCSA, said:

“The Committee’s report sets out an ambitious carbon reduction target for 2030 and up to 2050 which is achievable but only with CCS.

“We agree with the committee that we cannot meet the country’s 2050 and interim climate budgets without urgent and radical decarbonisation of industry and power generation. The report makes it clear that this cannot be realistically or cost-effectively achieved on the proposed timescale without an infrastructure that balances fossil-fuel sources of energy with renewables, and that CCS is integral to this equation.

GCCSI partners with Scotland on CCS regulations toolkit

www.globalccsinstitute.com

The Global CCS Institute has commissioned Scotland to produce a toolkit on ensuring CCS best practice regulations and permitting processes, providing a valuable blueprint for nations seeking to roll out the technology.

The Institute will promote the toolkit around the world. In Europe, it has the support of the CCS Demonstration Project Network, through which the European Union will lead the world in sharing the knowledge emerging from full scale CCS projects in Scotland and other European countries.

The toolkit will be designed by the Scottish CCS Centre in Edinburgh, supported by the Scottish Government and the Scottish European Green Energy Centre. It builds on a "dry-run" regulatory simulation of a hypothetical CCS project run in Scotland in August, which brought together regulatory agencies, project developers, public interest groups and others including the Institute.

Replacing end-of-life power stations with CCS coal-fired plants

www.informaworld.com

A recent study has evaluated the economic and environmental merits of different designs of coal-fired power plants, all with carbon capture and storage (CCS), to replace an old power station in Germany. An integrated gasification combined cycle (IGCC) plant with pre-combustion CO2 capture was found to offer the best profit for plant operators and significantly lower the life cycle emissions of CO2.

Several of Europe’s power stations are reaching the end of their useful lives and plant operators face difficult decisions about how to replace them. The intention is to move towards non-carbon and renewable sources of energy, but coal is currently one of the most abundant and cheap forms of fuel. Building new coal-fired power plants with carbon capture and storage (CCS) units would allow the continued use of coal in the near-term whilst substantially reducing CO2 emissions to the atmosphere from power generation. This has been proposed as an interim solution until other forms of energy become more economically and technologically feasible, although estimates as to when CCS will become commercially viable vary from 2015 to 2030.

This study assessed three different types of coal-fired power stations power plant, all with CCS, for their environmental impact and profitability. The designs have been proposed as replacements for the existing coal-fired power station in Kiel, Germany. The power plants were: an IGCC plant with pre-combustion carbon capture, a pulverised coal (PC) plant with post-combustion carbon capture and a pulverised coal plant with oxyfuel combustion carbon capture.

The profitability of alternative coal-fired power plants with CCS was assessed using three scenarios of possible future CO2 permit prices, fuel prices and power revenues to plant owners. Results of the profit analysis suggest an IGCC plant with pre-combustion capture would be the best option in terms of economic returns for plant owners. An IGCC plant with CCS requires the least amount of fuel to operate the capture unit and is therefore more efficient than the other two types of plant. Oxyfuel technology is the most costly option for carbon capture.

In addition, the study investigated retrofitting CCS to an existing coal power station, either an IGCC plant or a PC plant. In both cases, fitting a CCS unit after the power plant has been built is less profitable than a plant with a CCS unit installed initially.

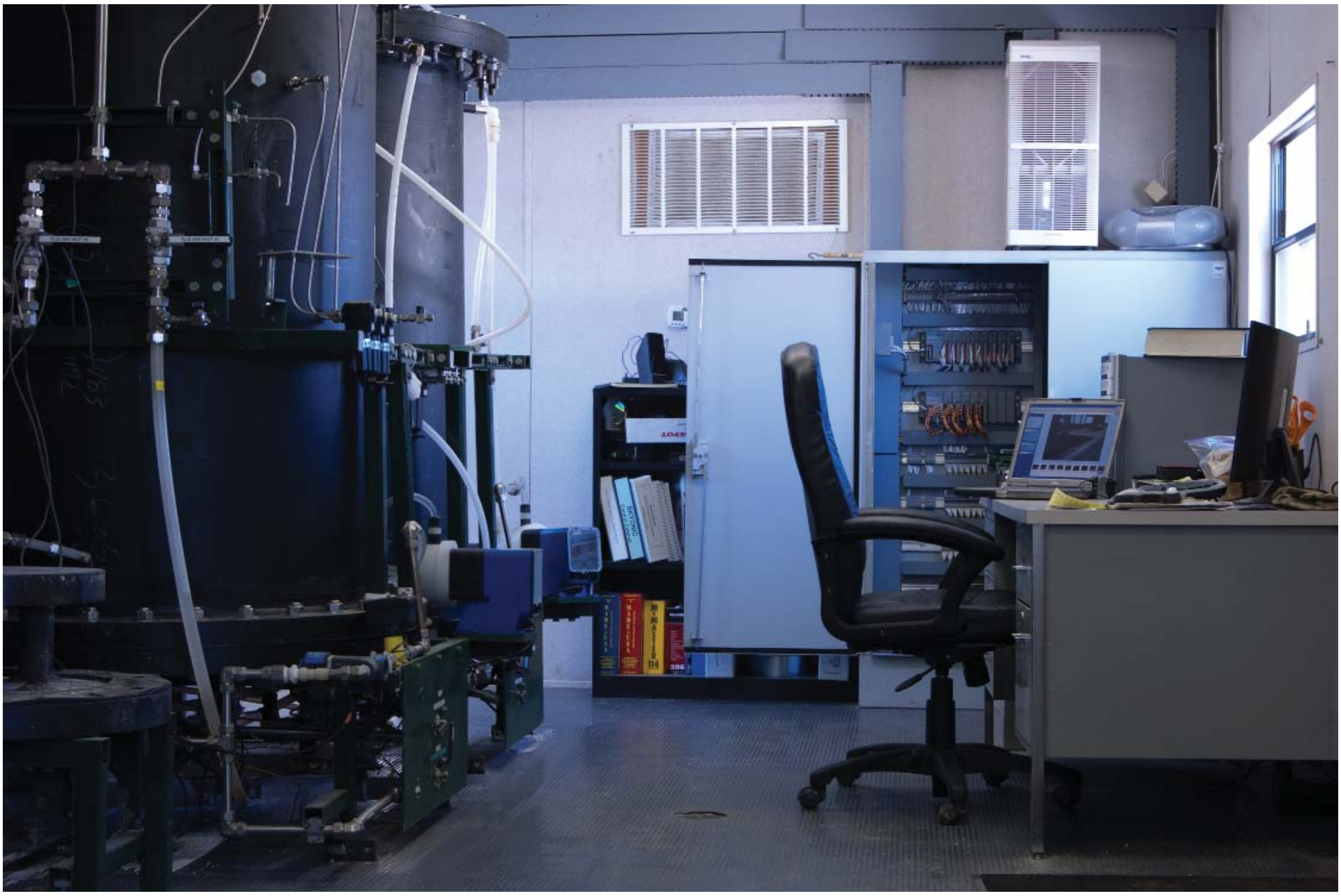
A life cycle analysis was used to compare the environmental impact of the different power plants. Although CCS considerably reduces CO2 emissions from all plants, the reduction is not as great as estimated by other studies, which suggest reductions of up to 99 per cent. These figures typically refer to emissions only from the plant and do not take into account the increased energy demand of using CCS. For instance, life cycle emissions from a PC plant with CCS are only reduced by 67 per cent compared with a coal-fired plant without CCS, according to this study.

Source: Lindner, S., Peterson, S., Windhorst, W. (2010) An economic and environmental assessment of carbon capture and storage (CCS) power plants: a case study for the City of Kiel. Journal of Environmental Planning and Management. 53: 1069-1088.

Capturing the profitability of carbon

Skyonic has developed a process called SkyMine® to make profitable and useful by-products out of waste CO2.

By By Joe Jones, CEO and founder of Skyonic



Equipment from the SkyMine® demonstration laboratory on site at Capitol Aggregates in San Antonio, TX. Photo by John Davidson for Skyonic

Over the past 40 years, scientists, organizations and governments have become concerned and, in most cases, convinced that man-made carbon dioxide (CO2) is affecting the global climate system. Current technologies for carbon dioxide reduction are characterized as absorption and geologic injection methods.

These methods are cost-intensive and require carbon to be injected underground, which is an unproven solution that has unknown, potentially disastrous long-term consequences. For example, CO2 has the potential to acidify waters, potentially causing leaching and mobilization of naturally-occurring metals or other contaminants such as arsenic, lead, and organic compounds that could endanger drinking water.

Five years ago Skyonic invented a radical new approach to solving the problem of excess industrial CO2 emissions. Instead of injecting CO2 underground, we found a way to capture the CO2 before it is emitted into the air and transform it into marketable byproducts.

Today, Skyonic is the first company to secure a U.S. patent for a carbon capture mineralization process that provides tremendous opportunity to commercial organizations worldwide. Based on pending environmental mandates created to off-set global warming, industrial organizations are struggling with the exuberant costs associated with stripping their emissions of toxic pollutants and CO2. Skyonic has created a technology process, called SkyMine®, that enables industrial manufacturers to reduce emissions while at the same time providing them with an additional revenue stream.

Mineralization Process

Skyonic's SkyMine process captures and mineralizes CO2 emitted from industrial flue gas stacks into sodium bicarbonate and other marketable chemicals, such as hydrochloric acid, hydrogen chloride, chlorine and hydrogen. It also scrubs 99 percent of SOx, NO2, mercury, and other heavy metals from exhaust emitted from the industrial plants. Because SkyMine captures CO2 as carbonate compounds, the environmental concerns associated with CO2 pipelines and groundwater contamination are completely avoided.

The process removes CO2, acid gases, such as SOx and NO2, and heavy metals from coal combustion or other flue gas streams in a safe, efficient and profitable manner. A major differentiator of the process is that the SkyMine process captures CO2 as a stable solid: sodium bicarbonate, often used as common household baking soda. The process inputs low cost materials such as flue gas, salt, and water, and in turn, produces high-value outputs. Hydrogen and chlorine are valuable commodity chemicals used in a number of ways, such as in the fuel industry and the manufacturing of other compounds.

The SkyMine process is divided into three major operations: gas handling, absorption, and electrochemical production. In the gas handling phase, the hot flue gas is cooled to room temperature. Also during this process, heat and water are harvested and heavy metals like mercury are removed. The harvested heat is used to undertake the cost of chemical production. The harvested water is then reused. After passing through activated carbon filters to remove heavy metals, it becomes a process feed.

In absorption, the cooled flue gas containing carbon dioxide and acid gases is scrubbed in a spray tower in a reaction with sodium hydroxide. The CO_2 reacts to form baking soda and the acid gases react to form sulfate and nitrate salts. Because of the low concentration of acid gases, the bicarbonate has been shown to be of unusually high purity, guaranteeing simplistic disposal. The cleaned flue gas is returned to the exhaust stack.

In electrochemical production, the sodium hydroxide that will be used in the absorption process, the hydrogen and the chlorine, are produced using a feed of salt, water, and electricity.

Economic Value

The costs associated with a SkyMine plant include salt, water, electricity and freight, which are all affordable elements. Salt is abundant in nature and, as such, is relatively inexpensive when compared to the outputs produced. In addition, much, if not all of the SkyMine water requirements can be harvested from the flue gas. Other operating expenses from SkyMine, such as headcount costs, are relatively minimal as compared to the revenue streams which can be generated. The process also operates at energy-efficient conditions, further adding to its profitability and environmentally-friendly stance.

There are several advantages to using the SkyMine process for an industrial plant. First, heat from the gas handling steps is used to warm the process chemicals to defray costs. Second, chemical production can occur during off-peak periods when electricity is readily available and at a lower cost. Finally, the caustic produced is low concentration and used immediately. This eliminates the need for an energy intensive evaporation step, thus also saving on costs.

In addition to the cost savings within the process itself, Skyonic has the only carbon capture mineralization technology on the market that profitably captures CO_2 from industrial flue-gas stacks and converts the pollutants into marketable byproducts. A plant using this process can generate revenue from a number of different sources through the sale of chemical byproducts such as hydrogen, chlorine and sodium bicarbonate. Many chemical revenue scenarios are possible, depending on choices driven by market conditions, site location and capital investment desired.

Another option for the chemicals produced is converting the chlorine to hydrochloric acid (HCl). It is estimated that a SkyMine plant could produce 431,000 MT of HCl, which could be resold for use in things such as enhanced oil recovery.

The hydrogen revenue from a SkyMine plant also has some attractive alternatives associated with it. Hydrogen could be sold to market and displace natural gas used for hydrogen production. If this displaced natural gas is used to generate peak electricity, additional compelling revenue opportunities could be realized and the basis plant would consume zero power.

A SkyMine plant will also generate a revenue stream from SOx, NOx and CO_2 credits upon certification. Assuming a value of $750 for SOx credits, $1,900 for NOx credits, and $22.00 for CO_2 credits, the credits' revenue stream from a SkyMine would equal $9.4 million per year.

Another differentiator of the SkyMine process is its ability to be easily retrofitted to the existing structure of the plant. Skyonic builds the SkyMine® facility next door to a plant and pipes the emissions from the smokestack into it. This eliminates the need for costly and time consuming remodeling within the plant.

Commercializing the Process

Skyonic has been testing its technology on small laboratory-scale plants for several

years now. In 2010, Skyonic was awarded two grants from the U.S. Department of Energy (DOE) to scale up their operations and support the build out of the first commercial-scale carbon capture mineralization project to date. Skyonic's first build is taking place at Capitol Aggregates Ldt., a large cement plant in Texas. The first grant was awarded in the amount of $3 million given to support the planning phase. The company was also awarded a second grant in the amount of $25 million, the DOE's largest grant given to an innovative carbon capture project, to support the build. The plant is designed to capture 75,000 metric-tons a year of carbon dioxide from flue gas emitted by Capitol Aggregates and should reach this goal by 2012.

It is clear that there exists a need for carbon capture in an easily retrofittable, safe and profitable manner. Skyonic's SkyMine system is an answer to these challenges.

More information

Joe Jones, President and CEO of Skyonic, earned a BS in Chemical Engineering from the University of Texas and spent the first 25 years of his career in the semiconductor manufacturing industry, working at Texas Industries, Cypress Semiconductors, and founding an independent outsource semiconductor company (BridgePoint Technical Manufacturing).

Joe left his position as CEO of BridgePoint when his belief in the need for clean, sustainable energy led him to begin development of the SkyMine technology and found Skyonic Corporation in 2005.

info@skyonic.com

Capture news

CO2 capture from coal plant begins in Australia

www.csiro.au

The A$5 million PCC demonstration project is a partnership between CSIRO and Tarong Energy Corporation Limited.

The pilot plant is designed to capture approximately 1000 tonnes of CO2 per annum. It will evaluate the effectiveness of CO2 capture using amine-based solvents and inform the development of efficient and economical PCC technology at commercial scale.

Tarong Energy Chair Graham Carpenter said the Corporation is proud to be involved in hosting Queensland's first PCC plant.

'The opening of the plant marks a significant milestone as it is the first time in the Tarong Power Station's 26-year history that carbon has been successfully captured onsite,' Mr Carpenter said.

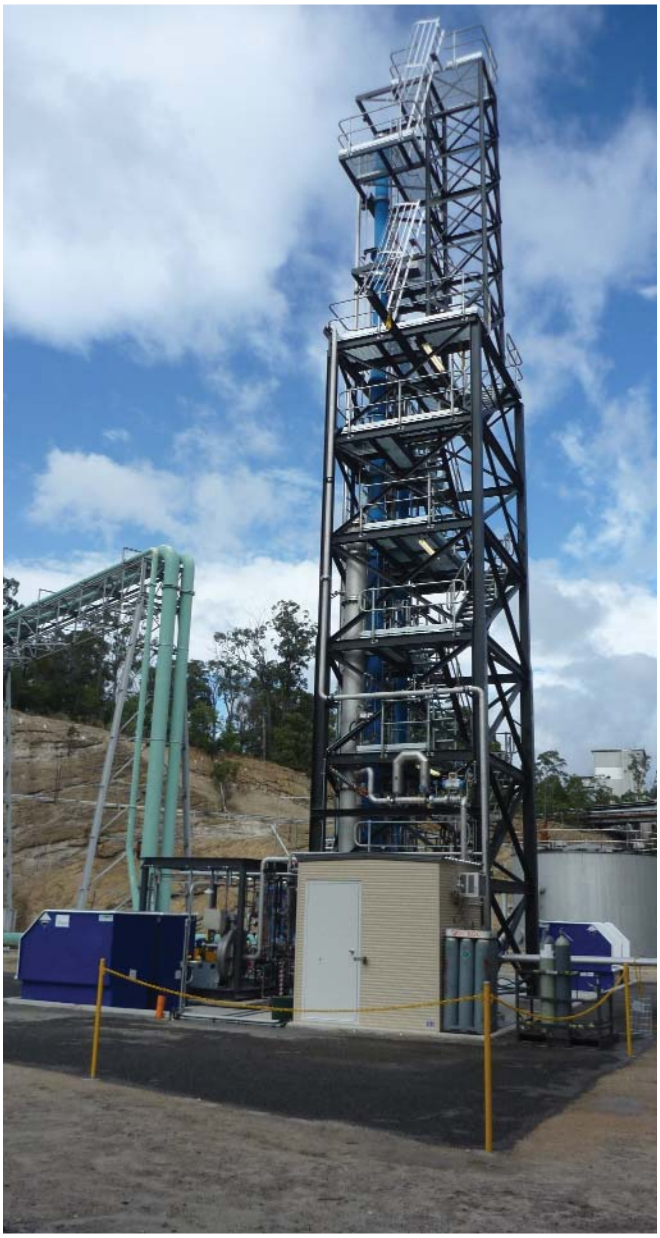
'The Corporation is acutely aware of its environmental responsibilities and we have introduced a number of initiatives to reduce our impact on the environment over the past few years.

'If the trial is successful and carbon storage sites are identified, this PCC technology has the potential to lead to a reduction in greenhouse gas emissions from not only Tarong Power Station, but also from other coal-fired generators throughout Queensland and Australia.

'Working with CSIRO – Australia's leading scientific research agency – has provided the team at Tarong Power Station with a fantastic opportunity to work with cutting-edge technology.”

The pilot plant was officially launched by Queensland’s Minister for Natural Resources, Mines and Energy, Stephen Robertson MP. The project received funding from the Australian Government as part of the Asia-Pacific Partnership on Clean Development and Climate program, which includes two other PCC pilot plants operating in Victoria and China.

The announcement of the first CO2 capture in Queensland coincides with Australia’s inaugural National Carbon Capture and Storage Week – an event that provides a focus for carbon capture and storage as an essential part of global efforts to reduce greenhouse gas emissions.



The PCC pilot plant at Tarong Power Station is designed to capture approximately 1000 tonnes of CO2 per year (Image: CSIRO)

Indian state fertilizer company licenses Mitsubishi CO2 capture

www.mhi.co.jp

Mitsubishi Heavy Industries, Ltd. (MHI) has signed a license agreement for carbon dioxide recovery technology with National Fertilizers Limited (NFL), a state fertilizer company in India.

NFL will use the technology to increase urea production at its existing Vijaipur Plant in Guna District, Madhya Pradesh State. The recovery units can capture 450 metric tons of CO2 per day, one of the world's largest capacities. The CO2 recovery plant is scheduled for completion in June 2012.

The technology to be licensed by MHI separates and recovers CO2, using the company's proprietary KS-1 solvent, from flue gas emitted during the urea fertilizer production process, which uses natural gas as fuel. The captured CO2, of 99% purity, will be provided as feedstock for urea synthesis from ammonia. The KS-1 solvent was jointly developed by MHI and Kansai Electric Power Company, Inc. (Kansai EP).

The CO2 recovery plant to adopt MHI's CO2 recovery technology using the KS-1 solvent - officially known as the "KM CDR Process" (Kansai-Mitsubishi Carbon Dioxide Recovery Process) - will be constructed at NFL’s Vijaipur Plant, which already consists of two trains of ammonia-urea plants. The technology can recover approximately 90% of the CO2 in flue gas, and as such the process contributes significantly to environmental preservation and energy saving. The CO2 recovery plant will be constructed by Tecnimont ICB Pvt. Ltd., an Indian engineering firm.

NFL, established in 1974, is India's one of-largest urea fertilizer producer.

According to Mitsubishi, the KM CDR Process requires considerably lower energy consumption compared with other technology processes. To date MHI has delivered the plant or licensed the technology to a total of nine fertilizer production plants around the world. The company believes that the high reputation stemming from this track record contributed largely to NFL’s selection of the technology.

The latest event represents the third licensing of the technology to an Indian fertilizer company, following earlier agreements with Indian Farmers Fertilizer Cooperative Limited (IFFCO) and Nagarjuna Fertilizers and Chemicals Limited (NFCL). In terms of number of plants, licensing to NFL represents the fourth Indian plant: two plants have been licensed to IFFCO.

In addition to urea production, CO2 recovery technology can be employed in chemical applications such as production of methanol and dimethyl ether (DME).

Going forward, MHI intends to promote its large-scale CO2 recovery facilities for both chemical plants and CCS/EOR applications.

Siemens announces CO2 capture test results

www.siemens.com

Siemens Energy has successfully completed the first test phase with its CO2 capture process in a pilot facility at the Staudinger power plant operated by E.ON.

Process efficiency, the long-term chemical stability of the scrubbing agent and emissions were investigated in the pilot facility under real power plant conditions. After over 3,000 operating hours since commissioning of the facility in September 2009, it has been demonstrated that the post-combustion capture process developed by Siemens (PostCap) attains a CO2 capture efficiency of over 90 percent with practically zero solvent emissions. The energy consumption is significantly lower than comparable conventional processes, says the company.

The absorber and desorber columns at the Staudinger pilot plant in Germany. Source: Siemens/E.ON

The test results confirm the expectations of the Siemens engineers - the high level of stability of the solvent and the extremely low losses will have a positive impact on the operating costs of CO2 capture facilities. Since the scrubbing agent, an aqueous amino acid salt solution, is non-volatile, there are practically no solvent emissions at the outlet of the capture facility.

By contrast with conventional CO2 capture processes, such as those using amines, the Siemens PostCap process does not require any complex downstream scrubbing of the flue gas after CO2 capture. In addition to CO2, the solvent also removes further contaminants contained in the flue gas. These contaminants additionally absorbed by the solvent and any by-products produced will in the future be removed from the liquid solution using an proprietary separation process.

“For us a major requirement made on our process is to produce no new emissions during CO2 capture and to provide simple handling for power plant operators. From the very outset we’ve therefore been using aqueous solutions of amino acid salts as the scrubbing agent, which does not represent a hazard for humans or the environment,” said Nicolas Vortmeyer, CEO for New Technologies Fossil Power Generation at Siemens Energy.

“Setting the course at an early stage is now paying off. We’ve confirmed with the first operating results at our pilot facility that our CO2 capture process is not only highly efficient but also meets the most stringent requirements on environmental compatibility without additional downstream scrubbing. We will continue pilot plant operation in order to gain further expertise.”

The pilot project at Staudinger power plant is sponsored by E.ON and the German Federal Ministry of Economics and Technology within the framework of the COORETEC Initiative. This initiative is part of the federal government’s 5th Energy Research Program entitled "Innovation and New Energy Technologies" and promotes research into and the development of low-CO2-emissions power plant technologies.

The experience accumulated with the pilot facility in the Staudinger power plant provides the basis for an anticipated larger-scale deployment of the PostCap process which is proposed to be performed at the Big Bend coal-fired plant operated by Tampa Electric under an award to Siemens Energy, Inc. by the United States Department of Energy to further advance this state-of-the-art carbon capture process for coal-fired power plants.

ExxonMobil expands its LaBarge CO2 capture facility

www.exxonmobile.com

ExxonMobil has completed a USD $86m expansion of the world's largest carbon dioxide capture plant, in LaBarge, Wyoming.

The expansion includes the installation of compressors to capture 50% more carbon dioxide for potential use in enhanced oil recovery and other industrial uses, the company said.

The carbon dioxide for this project is captured from the natural gas streams produced from fields in Wyoming. The gas streams contain significant amounts of carbon dioxide and other components that are removed at the LaBarge processing plant.

Following this expansion the plant has the capacity to capture approximately 365m cubic feet per day of carbon dioxide from the gas streams - equivalent to the amount emitted by more than 1.5m cars.

According to ExxonMobil the captured carbon dioxide is sold to companies for enhanced oil recovery, helping to extend the productive lives of mature oil fields.

B&W awarded boiler contract at SaskPower CCS demo

www.babcock.com

The Babcock & Wilcox Company (B&W) has been awarded a $107 million contract from SaskPower to engineer, manufacture, deliver and construct critical components for SaskPower's Boundary Dam Unit 3 in Estevan, Saskatchewan.

The boiler retrofit for Boundary Dam Unit 3 is an integral part of the plant's life extension and conversion to allow for the capture of carbon dioxide through SaskPower's Integrated Carbon Capture and Storage Demonstration Project. While a final decision on the carbon capture system component has been deferred until new federal emission control regulations are completed, B&W Canada will engineer and supply all heat transfer surfaces and a new combustion system with low-NOx technology.

The project is expected to be completed in August 2013.

Third U.S. carbon storage atlas published

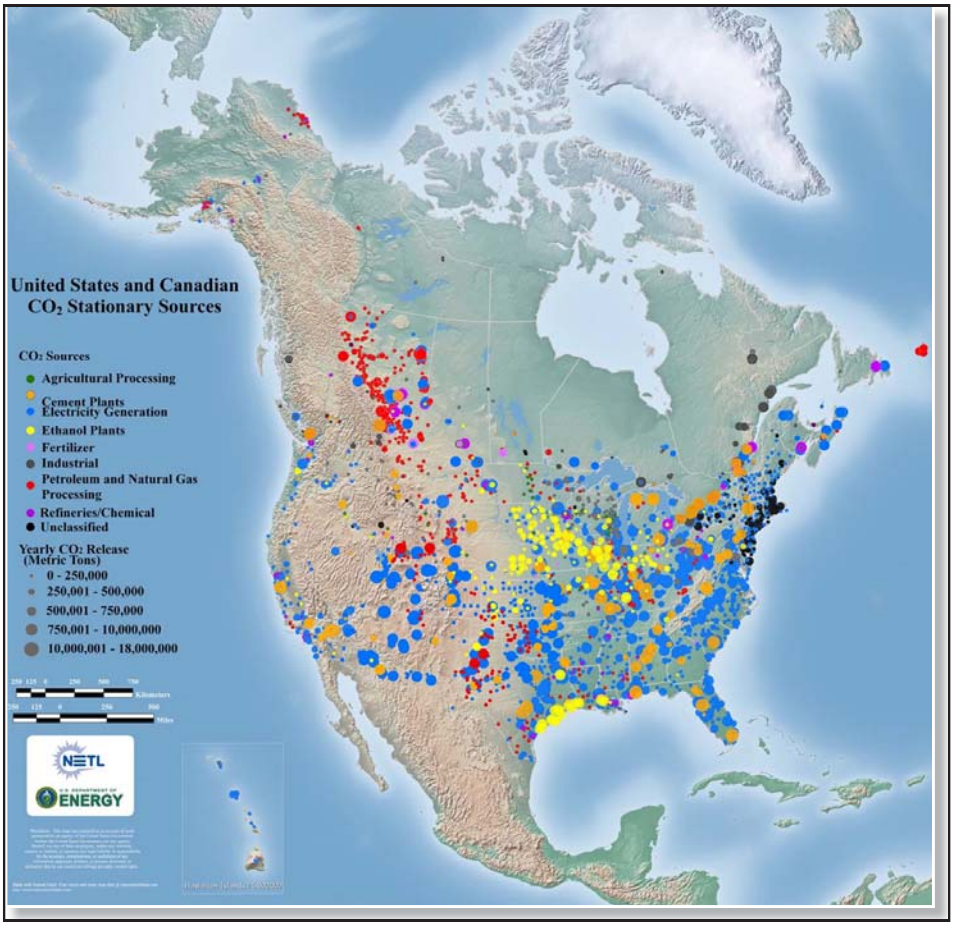
There could be as much as 5,700 years of carbon dioxide storage potential available in geologic formations in the United States and portions of Canada, according to the latest edition of the U.S. Department of Energy's (DOE) Carbon Sequestration Atlas (Atlas III).

The updated preliminary estimate, based on current emission rates, documents 1,800 billion to more than 20,000 billion metric tons of CO2 storage potential in saline formations, oil and gas reservoirs, and unmineable coal areas. This suggests the availability of approximately 500 to 5,700 years of CO2 storage for the U.S. and covered Canadian areas, according to the third edition of the Atlas.

The primary purpose of Atlas III is to update U.S./Canadian CO2 storage potential and provide updated information on the activities of DOE's seven Regional Carbon Sequestration Partnerships (RCSPs), comprised of more than 400 organizations, 43 states, and four Canadian provinces. Atlas III also outlines DOE's Carbon Sequestration Program and international carbon capture and storage (CCS) collaborations, as well as worldwide CCS projects, and CCS regulatory issues.

In addition, it presents updated information on the location of CO2 stationary source emissions, as well as the locations and geologic storage potential of various formations and it provides details about the commercialization opportunities for CCS technologies from each RCSP. The CO2 geologic storage resource calculation methodology of Atlas III was refined to better reflect uncertainties in geologic formation properties, says the DOE.

There are two editions of the new Atlas available: An interactive version located at the NATCARB website, and a print version available for viewing and downloading at the NETL website.



This map displays CO2 stationary source data which were obtained from the RCSPs and other external sources and compiled by NATCARB. Each colored dot represents a different type of CO2 stationary source with the dot size representing the relative magnitude of the CO2 emissions (see map legend). (Source: NETL Carbon Atlas III)

The atlas can be downloaded at:
www.netl.doe.gov

Transport and storage news

EPA finalises CO2 storage rules

www.epa.gov

The U.S. Environmental Protection Agency (EPA) has finalized two rules related to the capture and sequestration of carbon dioxide.

The new rules aim to protect drinking water and to track the amount of carbon dioxide that is sequestered from facilities that carry out geologic sequestration.

"Together, these actions are consistent with the recommendations made by President Obama's interagency task force on this topic and help create a consistent national framework to ensure the safe and effective deployment of technologies that will help position the United States as a leader in the global clean energy race," said the EPA.

In August 2010, President Obama's Interagency Task Force on Carbon Capture and Storage, co-chaired by the EPA, delivered a series of recommendations to the president on overcoming the barriers to the widespread, cost-effective deployment of CCS within 10 years.

Drinking Water Protection:

EPA finalized a rule that sets requirements for geologic sequestration of carbon dioxide, including the development of a new class of injection well called Class VI, established under EPA's Underground Injection Control (UIC) Program. The rule requirements are designed to ensure that wells used for geologic sequestration of carbon dioxide are appropriately sited, constructed, tested, monitored, and closed. The UIC Program was established under the authority of the Safe Drinking Water Act.

Greenhouse Gas Reporting:

EPA also finalized a rule on the greenhouse gas reporting requirements for facilities that carry out geologic sequestration. Information gathered under the Greenhouse Gas Reporting Program will enable EPA to track the amount of carbon dioxide sequestered by these facilities. The program was established in 2009 under authority of the Clean Air Act and requires reporting of greenhouse gases from various source categories in the United States.

DOE manual on CO2 storage site selection

www.netl.doe.gov

The most promising methods for assessing potential carbon dioxide geologic storage sites is the focus of the latest in a series of U.S. Department of Energy (DOE) CCS "best practices" manuals.

Developed by the Office of Fossil Energy's (FE) National Energy Technology Laboratory (NETL), the manual – Site Screening, Site Selection and Initial Characterization for Storage of CO2 in Deep Geologic Formations – is a resource for future project developers and CO2 producers and transporters. It can also be used to apprise government agencies of the best practices for exploring potential CO2 geologic storage sites and to inform the general public about the rigorous analyses conducted for potential storage sites.

The newest manual, the fourth in a series, focuses on the exploration phase of the site characterization process, and communicates rigorous analyses and guidelines for paring down potential sub-regions into qualified sites for geologic storage. Three described stages—site screening, site selection and initial characterization—include specific elements to be analyzed.

The manual does not promote one specific methodology for determining storage resources; instead, it provides a framework for reporting resources calculated using methods developed by DOE, the Carbon Sequestration Leadership Forum, the United States Geological Survey, and others.

The process diagrams and guidelines described in the manual are integrated into a proposed CO2 geologic storage classification system. The system integrates processes and guidelines developed from the regional partnership's activities, such as regional characterization, small and large-scale injection projects, and regional storage resource assessments.

The proposed classification system builds on the existing Petroleum Resources Management System (PRMS), sponsored by the Society of Petroleum Engineers, America Association of Petroleum Geologists, World Petroleum Council, and Society of Petroleum Evaluation Engineers. The PRMS has standardized the definitions of reserves and resources throughout the petroleum industry.

Development of the geologic storage system proposed in the new manual will be instrumental in developing consistent industry-standard terminology and guidelines for communicating storage resources and storage capacity estimates, including project risk, to stakeholders.

DOE sponsored study on CO2 storage monitoring

fossil.energy.gov

A Duke University study, published in the October 26, 2010 edition of Environmental Science & Technology, confirms earlier research showing that proper site selection and monitoring is essential for helping anticipate and mitigate possible risks.

It also provided information that can be used for advanced detection of CO2 in the unlikely event of a leak.

The Duke report, "Potential Impacts of Leakage from Deep CO2 Geosequestration on Overlying Freshwater Aquifers," presented the results of a year-long study investigating the impacts of CO2 injection into different geologic formations and the possible dissolution of metals from specific rocks that naturally contain high concentration of these metals.

The researchers incubated core samples from a variety of freshwater aquifers with CO2 for more than 300 days, and found increased acidity and metals concentrations in water surrounding the samples. They concluded that "the relative severity of the impact of leaks on overlying drinking water aquifers should be considered in the selection of CO2 sequestration sites." This confirms earlier research conducted by FE's National Energy Technology Laboratory (NETL), several other DOE national laboratories, the U.S. Geological Survey, and others indicating that CCS sites must be carefully selected and monitored.

The Duke researchers also identified three elements—manganese, iron, and calcium—which they suggest should be monitored, along with pH, as geochemical markers of CO2 leaks.

The Duke research project is one of many being sponsored by DOE to investigate the impact of CO2 injection into geologic formations, including the dissolution of metals from rock. This has been recognized for many years as a potential risk in CCS projects and it continues to be a focus of research. The research provides fundamental data that are used to improve risk assessment models and the design of CCS projects and monitoring programs. The risk to drinking water supplies can be mitigated by proper site characterization, having an impervious caprock, and proper construction materials, and by maintaining proper operating conditions as required by the EPA's Underground Injection Control Program.

Although CCS is an emerging field, it benefits from the experience of oil and gas producers who have more than 40 years of experience injecting CO2 into deep geologic formations to increase the flow of oil and natural gas. This provides a sound base for DOE's scientific investigations and the development of risk assessment and mitigation strategies.

Status of CCS project database

The status of 80 large-scale integrated projects data courtesy of the Global CCS Institute

For the full list, with the latest data, please come back to the pdf version online in the coming weeks at www.carboncapturejournal.com

Project Name	Project Description	Project Stage	Project Status
Shenhua CTL Phase 2 (1Mtpa)	This project intends to capture around 1 million tonnes of CO2 from a coal to liquids facility. It is the second phase of the smaller scale Ordos Shenhua DCL plant CCS Project which plans to start capturing 100,000 tonnes of CO2 yearly by the end of 2010.	Identify	Planned
Coolimba Power Project	Aviva Corporation Ltd proposes the construction of a "CCS-ready", coal-fired base-load power station using circulating fluidized bed (CFB) technology. Suitable storage sites are being sought.	Identify	Planned
Vattenfall Jänschwalde	Planned to demonstrate oxyfuel and post-combustion capture, Jänschwalde consists of boilers and a 500 MWe generator, each fired with lignite from an open cast mine close by. Storage options in the area are under investigation.	Identify	Planned
Immingham CCS Project	This project proposes to use IGCC and pre-combustion carbon capture technology at an oil refinery. The CO2 captured will we transported offshore to the Southern North Sea for geological sequestration.	Identify	Planned
Chemical Plant, Yulin	This project developed by Dow Chemical proposes to build a coal-to-liquids plant. Various storage options are under evaluation.	Identify	Planned
FutureGen 2.0	FutureGen is an initiative to demonstrate state-of-the-art CCT and CCS systems on a new build 275 MW IGCC power plant with a goal of near-zero emissions.	Identify	Planned
Eemshaven RWE	RWE and Gasunie aim to capture and store 0.2 to 1.2 million tonnes of CO2 per year in this project, which is scheduled to become operational in 2015.	Evaluate	Active
Wandoan Power IGCC CCS Project	This project based on General Electric's IGCC and capture technologies will capture up to 2.5mtpa of CO2 from a 400 MW power plant. The carbon transport and storage components are pursued in alliance with Xstrata Coal.	Evaluate	Planned
CEMEX - CO2 Capture in Cement Plant	CEMEX proposes to demonstrate a dry sorbent CO2 capture and compression technology at one of its cement plants in the United States, capturing around 1 million tonnes of CO2 each year.	Evaluate	Active
The Northern California CO2 Reduction Project	This project proposes to transport by pipeline approximately 1 million tonnes per year of CO2 streams from a range of capture facilities located in the Bay Area, California, for injection into a saline formation.	Evaluate	Active
Leucadia Energy Capture Project - Mississippi	Leucadia Energy LLC and Mississippi Gasification LLC propose to capture around 4 million tonnes per year of CO2 from a petcoke gasification plant in Moss Point, Mississippi. The CO2 will be used for enhanced oil recovery.	Evaluate	Active
Battelle Memorial Institute, Boise Inc and Fluor Corporation	The Battelle Memorial Institute is partnering with Boise White Paper and Fluor Corp to demonstrate CO2 capture from the combustion of black liquor at a paper mill. Around 700,000 tonnes per year will be captured and stored in deep flood basalt formations.	Evaluate	Active
Good Spring IGCC	Future Power PA plans to build a 270 MW IGCC plant in Pennsylvania in partnership with China's Thermal Power Research Institute. Around 1 million tonnes of CO2 per annum will be captured at the plant.	Evaluate	Active
Victorian CarbonNet Project	The Victorian Government is developing this CO2 transport and storage hub project in the state of Victoria. The project aims to collect between 4 and 10 million tonnes per year of CO2 from various capture facilities.	Evaluate	Planned
The Collie South West Geosequestration Hub Project	This project proposes to develop a CO2 storage hub collecting CO2 captured from various facilities in Western Australia. The project aims to store between 2.5 and 7.5 million tonnes per annum of CO2 in saline formations.	Evaluate	Planned
Rotterdam CCS Network	This project aims at developing a business case for a large-scale CO2 transport hub based in Rotterdam. Nine capture facilities have been validated, as well as the transport infrastructure. The independent storage assessment is under way.	Evaluate	Planned
Korea-CCS2	This project proposes to capture 1.5 to 2.5 million tonnes per year of CO2 from an oxyfuel or IGCC power plant. The CO2 would be shipped for injection into a saline formation.	Evaluate	Planned
Spectra Fort Nelson CCS Project	CO2 sourced at the Fort Nelson natural gas-processing plant will be injected into a nearby saline formation at a depth of approximately 2200 metres. Injection rates will ramp up to 1.2 to 2 million tonnes of CO2 per annum.	Evaluate	Planned
Antelope Valley Station	This project by Basin Electric will use HTC Purenergy capture technology at a coal-fired electricity plant. Up to 1 million tonnes per year of CO2 will be transported through an existing 330 km pipeline and injected for enhanced oil recovery.	Evaluate	Planned
Mongstad	StatoilHydro and the Norwegian government entered into an implementation agreement to develop carbon capture solutions at the Mongstad natural gas energy plant, with a view to capture and store up to 1 million tonnes per year of CO2.	Evaluate	Planned

Capture Facilily	Capture Type	Transport Type	Storage Type	ProjectURL	Location
Coal to liquids plant	Pre-Combustion	30-100 km unspecified transport	Geological (saline formations)	http://www.shenhuagroup.com.cn/english/cpyfw_5.html	Inner Mongolia, China
2x200 MW or 3x150 MW coal fired CFB power plant	Post-Combustion	20-80 km pipeline	Geological (Depleted Oil and Gas Reservoirs)	www.coolimbapower.com.au	Western Australia, Australia
500 MW lignite fired power plant	Oxyfuel combustion and Post-Combustion	150 km pipeline	Geological (Saline Formations)	http://www.vattenfall.com/www/co2_en/co2_en/879177tbd/879231demon/879320demon/index.jsp	Brandenburg, Germany
800-1200 MW IGCC power plant at oil refinery	Pre-Combustion	300 km pipeline	Geological	http://www.conocophillips.com/EN/susdev/environment/climatechange/carboncapture/Pages/index.aspx	Lincolnshire, England, United Kingdom
Coal to liquids plant	Pre-Combustion	Pipeline	Various storage options being considered	http://news.dow.com/corporate/2007/20070514a.htm	Shanxi Province, China
275 MW IGCC power plant	Oxyfuel Combustion	Pipeline	Geological (TBD)	http://www.futuregenalliance.org/	Illinois, United States
814 MW gross coal fired power plant (biomass in future)	Post-Combustion	Not Specified	Geological (Depleted Oil and Gas Reservoirs)	http://www.co2-cato.nl/cato-2/locations/regions/northern-netherlands/rwe-eemshaven	Groningen, Netherlands
400 MW net IGCC power plant	Pre-Combustion	200 km pipeline	Beneficial reuse or Geoligical	http://www.wandoanpower.com.au	Queensland, Australia
Cement plant	Post-Combustion	Pipeline	Not specified	http://www.cemex.com/su/Su_ow_cc.aspx	TBD, United States
Range of CO2 capture facilities	Various	Pipeline	Geological (Saline Formations)	http://www.westcarb.org/norcal_co2reduction_project.html	California, United States
Petcoke to SNG plant	Pre-Combustion	110 mile pipeline	Beneficial Reuse (EOR)	http://www.denbury.com/index.php?id=16&searched=mississippi+gasification&advsearch=oneword&highlight=ajaxSearch_highlight+ajaxSearch_highlight1+ajaxSearch_highlight2	Mississippi, United States
Paper mill	Post-Combustion	Not specified	Geological (basalt formations)	http://www.battelle.org/index.aspx	Washington, United States
270 MW IGCC power plant	Pre-Combustion	Pipeline	Beneficial reuse (EOR) and Geological (saline formations)	http://futurefuelsllc.com/projects/north-america/pa/	Pennsylvania, United States
Range of CO2 capture facilities	Pre-Combustion and Post-Combustion	Pipeline	Geological (saline formations)	http://www.invest.vic.gov.au/081209VictorianCarbonNetmakesshortlistforAustralianfirst	Victoria, Australia
Range of CO2 capture facilities	Pre-Combustion and Post-Combustion	Pipeline	Geological (Saline Formations)	http://www.dmp.wa.gov.au/9525.aspx	Western Australia, Australia
Range of CO2 capture facilities	Not Specified	25-150 km shipping or common carrier pipeline	Geological (Depleted Oil and Gas Reservoirs)	http://www.rotterdamclimateinitiative.nl/documents/Documenten/RCI-CCS-ExecSumm.pdf	Rotterdam, Netherlands
Oxyfuel or IGCC	Other	800 km by ship	Geological (Saline Formations)	http://www.cesisp.unige.it/iea-ge/files/Korea%20-%20Jae-Keun%20LEE.pdf	Koseong Province or Taean Province, Korea, Republic Of
Natural gas processing plant	Gas Processing	15 km pipeline	Geological (Saline Formations)	http://www.netl.doe.gov/technologies/carbon_seq/core_rd/RegionalPartnership/PCOR-DP.html	British Columbia, Canada
120 MW slipstream from 450 MW unit PF coal power plant	Post-Combustion	330 km pipeline	Beneficial Reuse (EOR)	http://www.basinelectric.com/Gasification/index.html	tes
Natural gas fired power plant 280 MW electric 350 MW heat	Post-Combustion	Pipeline	Geological (Saline Formations)	http://www.statoil.com/en/OurOperations/TerminalsRefining/ProdFacilitiesMongstad/Pages/EnergiverkMongstad.aspx	Hordaland, Norway