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Front cover: Statoil's Sleipner CO2 injection project continues to provide significant results, safely storing CO2 below the North Sea. Sleipner has recently joined the European CCS Demonstration Network, and has contributed a wealth of information which will help accelerate the deployment of other projects (Image: Kjetil Alsvik - Statoil ASA)

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Global Status of CCS - 2013 update

The Global CCS Institute has identified 65 large-scale integrated projects (LSIPs) in 2013 compared to the 75 reported last year. Although four additional projects have become operational since 2012, Institute CEO Brad Page said momentum was still too slow if CCS was to play its full part in tackling climate change at lowest cost.

Releasing The Global Status of CCS: 2013 report in Seoul, South Korea, Global CCS Institute CEO Brad Page called for a renewed focus on the significance of CCS in the portfolio of low carbon technologies required to deal with climate change.

Since the Institute's 2012 report, the number of large-scale integrated CCS projects around the world has reduced from 75 to 65; five have been cancelled, one downscaled and seven put on hold; and three new projects identified – one each in Brazil, China and Saudi Arabia.

Globally, 12 large-scale integrated carbon capture and storage projects are preventing 25 million tonnes a year (Mtpa) of greenhouse gases from reaching the atmosphere. A further eight under construction are expected to increase the total to 38 Mtpa by 2016.

Notwithstanding recent strong progress, with four additional projects becoming operational since 2012 – an increase of 50 per cent in one year – Mr Page said momentum was too slow if CCS was to play its full part in tackling climate change at lowest cost.

"Seventy per cent of CCS proponents agree that policy uncertainty is a major risk to their project. Indeed, ongoing uncertainty about the timing, nature, extent and durability of emissions reduction policies is limiting investment in CCS and stalling its development and deployment. This must be addressed."

Mr Page said this was evidenced by slow project progression, almost no new projects outside China, and a strong development bias toward projects with additional revenue opportunities, like enhanced oil recovery.

"Of concern is that no new projects were identified in Europe, nor are any under construction," he said. "Accordingly, what we need globally are technology–neutral policies that provide sufficient incentives for projects to develop robust long–term business cases and attract the private funding needed to create market conditions conducive to broadbased CCS deployment.

Reviewing the Institute's report, Myles Allen – Oxford University Professor and a Lead Author of the recently released Intergovernmental Panel on Climate Change (IPCC) Working Group 1 Assessment Report – went further, stating that CCS was the pivotal technology for addressing the problem of climate change.

"Fossil fuels are useful, plentiful and affordable, so of course we will continue to use them," Professor Allen said. "To exploit this resource to the full, without further damaging the planet, we need CCS.

"We will eventually need large–scale CCS – no two ways about it. And it would be far safer, and cheaper, to deploy this technology steadily as we approach the limit than to deploy it in a panic in 30 years' time."

Recommendations for decision makers

To effectively mitigate climate change and provide energy security, there is an urgent need to progress carbon capture and storage (CCS) demonstration projects around the world. Successful demonstration will build con.dence by showing the technology in action and, through innovation combined with advances in capture technology, bring down costs.

It is vital that CCS is included in a portfolio of low-carbon technologies to tackle climate change at least cost.

We must therefore:

• implement sustained policy support that includes long-term commitments to climate change mitigation and strong market-based mechanisms that ensure CCS is not disadvantaged

• boost short-term support for the implementation of demonstration projects. This will require targeted .nancial support measures that enable .rst mover projects to progress faster through development planning into construction and provide necessary support during operations

• implement measures to deal with the remaining critical regulatory uncertainties, such as long-term liabilities. This will involve learning from the efforts of jurisdictions within Australia, Canada, Europe and the US, where signi.cant legal and regulatory issues have been, and continue to be, resolved

• continue strong funding support for CCS research and development activities and encourage collaborative approaches to knowledge sharing across the CCS community

• create a positive pathway for CCS demonstration by advancing plans for storage site selection

• encourage the ef.cient design and development of transportation infrastructure through shared hub opportunities to become "trunk lines" for several carbon dioxide capture projects.

Projects

More projects are entering operation and construction and China's importance is growing

• Twenty large-scale projects are in operation or construction, four more than in 2012 and eight more than in 2010. Eight projects are in construction: a significant milestone is that the first two power projects - both in North America - are scheduled for operation in 2014. Nearly all the remaining projects in construction are expected to be operational by the end of 2015.

• Four projects have commenced operation in 2013 - Air Products Steam Methane Reformer Enhanced Oil Recovery (EOR) Project, Coffeyville Gasification Plant, Lost Cabin Gas Plant, all in the United States (US) and Petrobras Lula Oil Field CCS Project in Brazil.

• The next tranche of dedicated geological storage projects under construction will significantly increase saline formation storage (from 1.5 to 7 Mtpa) and provide additional demonstrations of large-scale injection and storage of CO2 in different geologic settings.

• There are signals that the steady progress of large-scale CCS projects into construction will continue. Five projects may be in a position to make a final investment decision in the coming year. Four of

these projects are in the power sector (of which two, in Europe, use deep saline or depleted oil and gas field storage) and one in iron and steel.

• China now has 12 projects spread across all stages of development planning compared to five in 2010, ranking second to the US (20 projects). China is well positioned to influence the future success of CCS. The inclusion of CCS in China's 12th Five Year Plan reflects a strong commitment to develop and deploy the technology.

Significant gaps remain and progress on CCS must be accelerated

Notwithstanding the steady progress in CCS projects entering operation and construction, momentum is too slow to support the widespread commercial deployment needed to underpin climate change risk mitigation scenarios. A very substantial increase in new projects entering construction is required.

There is a notable absence of advanced projects in industrial applications, with only two iron and steel projects in development planning and none in cement. Considerable work is still needed to encourage capture demonstrations and CCS technology developments in these and other industries.

While significant progress is being made to advance CO2 storage programs in many developing countries, overall levels of CCS activity are at early stages. To achieve global emission targets, 70 per cent of the cumulative mass of captured CO2 by 2050 will need to occur in non-OECD countries (IEA 2012a).

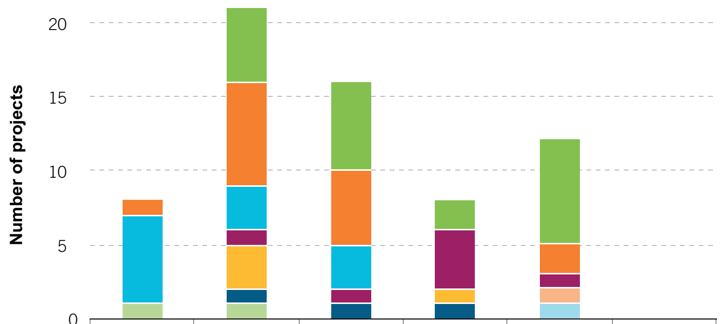
Policy and regulatory framework enhancements are critical

The international climate change policy dialogue consistently acknowledges the important future mitigation role of CCS. Solid progress continues within the United Nations Framework Convention on Climate Change (UNFCCC), and in agendas of the Clean Energy Ministerial (CEM), Carbon Sequestration Leadership Forum (CSLF), and International Organization for Standardization (ISO).

Paradoxically, progress in the international dialogue on CCS, and the criticality of CCS in climate change mitigation continually identified in energy roadmaps, have not been translated into policy settings that have delivered a sustainable pipeline of CCS projects in individual countries.

Policy and regulatory actions to accelerate the momentum of CCS projects must address the following issues:

• Strong, sustainable emissions reduction policies to support longer term deployment Project proponents strongly highlight



	Identify	Evaluate	Define	Execute	Operate	Total
United States	0	5	6	2	7	**20**
Europe	1	7	5	0	2	**15**
China	6	3	3	0	0	**12**
Canada	0	1	1	4	1	**7**
Australia	0	3	0	1	0	**4**
Middle East	0	1	1	1	0	**3**
Other Asia	1	1	0	0	0	**2**
South America	0	0	0	0	1	**1**
Africa	0	0	0	0	1	**1**
Total	**8**	**21**	**16**	**8**	**12**	**65**

Large Scale Integrated Projects by project lifecycle and region/country (Source: ©Global CCS Institute "The Global Status of CCS: 2013")

that there is too much policy uncertainty to support a business case for large-scale CCS projects. CCS projects have large capital costs and long development times. Investors require long-term predictability if they are to invest in CCS.

Thoughtfully developed emission reduction policies that encourage CCS and other low-carbon technologies are urgently needed and necessary for longer term deployment. Continued uncertainty about the timing, nature, extent and durability of such policies is stalling the development of CCS.

• Strengthened incentive mechanisms to support the immediate demonstration effort Most public funding programs for large-scale CCS projects have been exhausted or have not delivered funds commensurate with former commitments. Since 2009, funding support for CCS has fallen by more than US$7 billion from earlier commitments, reflecting either changing government priorities or a reliance on carbon price support that has subsequently collapsed. Moreover, this figure excludes funding received by projects that were subsequently suspended or cancelled and is no longer available.

While some countries are considering approaches to reinvigorate funding programs, no firm initiatives have been announced. In the short-term, financial support measures must be introduced to enable robust projects to progress faster through the development pipeline and enter construction. This is especially the case in Europe, where no large-scale CCS demonstration projects have progressed into construction since the Snøhvit CO2 Injection project in the early 2000s. A broad, successful demonstration program is vital to improve community understanding of CCS as an environmentally friendly technology and reinforce the important role of CCS in reducing global CO2 emissions.

It is important that the value and benefits of CCS are continually asserted and that CCS is not disadvantaged in relation to other low-carbon technologies in policy considerations and government support. First mover projects incur higher risks and upfront costs than later projects; appropriate recognition of this should be taken into consideration in the framing of financial and policy support for first movers.

Direct financial support through grants, preferential loans, investment tax credits, and public/private partnerships can help project development. Other incentive mechanisms such as feed-in tariffs, performance-based subsidies, contract for difference and purchase agreements can provide direct support for operations. The combination of support mechanisms used may vary globally, depending on jurisdictional factors.

• Regulation uncertainties still need to be addressed

A core group of jurisdictions - Australia, Canada, Europe and the US - are early movers that have progressed the development and implementation of law and regulation for CCS. These jurisdictions have remained at the forefront in recent years. There has also been welcome increased activity from second generation regulators in coun-

tries with high levels of CCS interest but less well developed policy frameworks (for example, Malaysia and South Africa).

Despite these developments, however, several legal and regulatory issues persist. Almost all jurisdictions must address issues arising from post-closure stewardship (transfer of responsibilities, liabilities) in a way that accommodates the risk profiles of governments and .rst mover project developers. This must begin immediately to remove a key impediment to the progression of CCS.

Technological development

Successful CCS demonstrations in the power sector and additional industrial applications are essential to gain valuable design, construction and operational experience. The knowledge or learning from demonstrating CCS technology in new applications at different sites and different settings is critical for reducing costs and strengthening investor and stakeholder con.dence.

Current CCS demonstration projects are vital for these learning curve achievements.

Just like any other industry, a vibrant R&D effort is important for CCS. R&D efforts across CCS (and especially capture) technologies, higher ef.ciency power generation cycles and industrial processes are important to accelerate the longer term deployment of CCS technology.

In power generation, for example, the capture element of CCS accounts for more than 90 per cent of the cost of the entire CCS chain. Significant progress is being made with several promising capture technologies, but the development and maturation of these and other capture (and related) technologies must be accelerated. The technologies cover a broad spectrum of options. For example, novel approaches and techniques have been identi.ed in the use of solvents, membranes and sorbents that can improve the ef.ciency of CO2 capture and reduce costs.

Cost effective capture R&D is achievable through globally coordinated efforts. It is promising that capture centres around the globe have formed networks to coordinate pilot-scale testing and development of new capture technologies, as evidenced by groups such as TCM Mongstad in Norway and the National Carbon Capture Center in the US.

It is important to connect this pipeline of new technology development with the learning obtained from demonstration projects using current generation technologies. This continuous development pipeline assures a smooth transition of new capture (and related) technologies into the market place.

Lessons from the current generation of capture technologies (as applied to new applications) will be realised in the 2020 time frame. When this occurs, we must be ready to transition from current to next generation capture systems, higher ef.ciency power generation cycles and industrial processes to accelerate CCS deployment on a global basis.

Infrastructure development

Storage exploration needs urgent attention. The estimated lead time for a greenfield storage assessment can be 10 or more years. This is a much longer time frame than is generally required for the engineering and construction of a large-scale capture facility. The characteristics of a particular storage site may have important influences on the design of the CO2 capture and transportation elements.

These co-dependencies mean that the exploration and appraisal needed for storage assurance must be scheduled in advance of major CO2 source and transport assessment expenditure. This may involve the investigation of several storage targets to mitigate the exploration risk.

Many countries have undertaken storage screening and identified the opportunity for adequate storage within their jurisdictions. While national screening is important, there is an increasing need to focus on maturing demonstration project storage sites and investing the tens to hundreds of millions of dollars to prove up storage sites that can store large amounts of CO2.

There is currently no incentive for industry to undertake costly exploration programs and governments have generally not stepped in to fill the void (with some exceptions, like the Regional Carbon Sequestration Partnerships in the US).

To lessen the risk of CCS demonstration and deployment being slowed by uncertainty over available storage, there is an urgent need for policies and funded programs that encourage the exploration and appraisal of significant CO2 storage capacity.

Linked transportation and storage solutions can reduce costs and timelines

For CCS to meet the longer term climate challenge of restricting global warming to less than 2°C, the estimated magnitude of the CO2 transportation infrastructure that will need to be built in the coming 30-40 years is 100 times larger than currently operating CO2 pipeline networks.

The development of new large capacity CO2 "trunk lines" that connect one or more large-scale CO2 capture projects with identified storage formations could lower barriers to entry for other CCS projects and lead to the establishment of integrated CCS networks. An example of such is the Alberta Carbon Trunk Line (ACTL). The initial supply of CO2 (nearly 2 Mtpa) will come from North West Upgrading Inc. and Agrium Inc., but at full capacity the trunk line will be able to transport up to 14.6 Mtpa of CO2 from various industrial sources.

Recommendations and future outlook

CCS is at something of a crossroads. For those immersed in a highly challenging environment with often slow-moving funding and policy commitments, it would be very easy to put the commercial deployment of CCS in the "too difficult" basket. However, for those with an eye to the very real challenges of creating a sustainable low-carbon energy future, the commercial deployment of CCS is non-negotiable.

The value proposition for CCS does exist, but it is complex and challenging to communicate to an uninformed audience. To better position CCS in the minds of the public and policymakers, the encouraging work various CCS networks are starting to undertake to improve the definition and communication of the CCS value proposition in different regions must be continued and supported.

Since 2012, many projects and networks have taken the initiative to improve public engagement on CCS. It is clear from the comprehensive responses to the Institute's 2013 survey that public engagement best practices are filtering through to emerging projects, although there is a need for more tangible examples of crucial activities like social site characterisation.

With an estimated 70 per cent of CCS emissions reductions needing to come from non-OECD nations by 2050 (IEA, ETP 2012), the importance of developing capacity and improving the accessibility of early CCS demonstration learning in these regions will be a key goal.

Finally, support for, and collaboration on, CCS by influential stakeholder groups like the ENGO Network are important for garnering public support and improving public understanding. This kind of support helps to position CCS in its rightful place as a key emissions reduction technology with a critical role to play in a low-carbon future. More of these collaborative relationships must be fostered to raise the public understanding and credibility of CCS.

More information

Download the complete Status Update at:
www.globalccsinstitute.com

CCS policy developments in Asia

Eros Artuso looks at the development of policy frameworks for implementing CCS in Asia, and focusses on three countries, China, Indonesia and South Korea, for more detailed case studies.

By Eros Artuso, Associate Director, AS Management & Consulting

There are increasing concerns with regards to the role of greenhouse gases when it comes to accelerating climate change. Although technology improvements and policy developments in the field of renewables as well as energy efficiency are growing fast, fossil fuels will still play a key role as part of the world energy supply mix for decades.

There is a need to identify ways to use the available fossil energy sources in a way to minimize the impact on climate change. Global fossil fuel resources, accounts for up to 21,000 gigatonnes of carbon equivalent (Gtce), and most of it comes from coal, with gas as runner up and oil in third place.

If we also take into account the fastest ever demand for electric power coming from emerging economies, this number is even more disturbing. The current fossil fuel usage rate - about 16 Gtce per annum - and the large availability of coal due to its large geographical distribution, in combination with low extraction and utilization costs, causes coal to be seen by many countries as the most efficient and low-cost means to ensure the availability and security of their energy supply. Consequently, major infrastructure investments continue to be made to ensure the steady production, transport and utilization of fossil fuels worldwide.

This article will provide an overview of some of the key aspects of the current policy developments in emerging countries with a special focus on Asia. A few countries have been selected and analyzed based on the relevance of their recent regulatory attempts to establish a CCS policy framework based on the experience from more advanced ones currently in place in some western countries. There will be also a section dedicated to the current efforts to integrate CCS technology as part of one of the Kyoto Protocol's mechanisms to tackle climate change, the Clean Development Mechanism (CDM).

The growing energy demand from the Asian emerging economies

Asian countries as many other developing countries are experiencing an increasing demand for power that is met by the development of new, higher efficiency modern coal fired plants (although they will not start to be decommissioned for years). These countries see the use of their large indigenous coal supplies as a means to underpin economic growth with competitive power generation that can fulfill countries' demand and reduce the dependency on major western developed exporters (e.g. Australia).

If we take into account that those individuals living in the poorest countries will actually be the most affected by the impacts of climate change and against that backdrop, the introduction of CCS, both for new plants but also retrofit facilities, which can be coupled with CO2 utilisation such as enhanced oil recovery (EOR), offers a means to maintain economic sustainability while ensuring effective carbon mitigation.

In April 2011, the Carbon Capture Use and Storage Action Group (CCUS AG) prepared a report with several recommendations, including among them "to identify and advance appropriate funding mechanisms to support the demonstration of large scale CCS projects in developing economies" (better known as Recommendation 2).

Following the CEM meeting the Global CCS Institute (GCCSI) agreed to coordinate with the World Bank (WB), the Asian Development Bank (ADB) and the World Resources Institute (WRI) in an assessment of the CCUS AG's Recommendation 2. This work was undertaken in consultation with other international agencies such as the IEA and governments.

CCS demonstration and deployment can only occur at sufficient scale if a much broader set of countries become engaged and prepare the policy frameworks for this to happen. In order to achieve this need, financial mechanisms shall be developed or deployed to support activities designed to help smaller but rapidly developing countries, such as those in Asia, address in more general terms the way in which they use fossil fuel resources to generate power.

In order to accelerate the development, demonstration and deployment of CCS technologies in developing countries, international efforts need to be focused on those countries that have large carbon footprints, such as China, Indonesia and South Korea, that have already been engaged on CCS and indicated a willingness to initiate demonstration projects.

Unlike some western jurisdictions where there are already established frameworks for cross-national/state cooperation, Asia is sensitive to international cooperation. Global efforts to reduce atmospheric CO2 levels depend on the successful implementation of CCS in all major countries because these countries are becoming the major players in global CO2 emissions.

Case studies: China, Indonesia and South Korea

All these countries are vulnerable to adverse effects from climate change and all are major fossil fuel users and suppliers, with domestic economies that are primarily dependent on coal. Their involvement to date and chosen means to pursue CCS though are different, both in terms of technology considerations and the institutional approaches to determining its suitability for demonstration and deployment.

In each case, the national authorities have established policies to counter climate change and have undertaken various CCS capacity building activities, most of which have been supported with bi-lateral and multi-lateral agreements (e.g. EU, US, etc).

For all three countries the lack of progress is a combination of several factors, such as the high capital cost of CCS demonstration and deployment or the energy penalty associated with the operation of CCS plant.

China CCS: China has been recently engaging at international level on climate change issues, reflecting an increasing realisation of the need to establish a sustainable energy policy. However, their large economic growth is also linked to an increasing coal use and demand.

China's vision for 2020 includes reducing carbon intensity by 40-45% from 2005 levels and meeting 15% of its total 2020 energy demand with non-fossil fuel. Despite that, in order for China to reduce its aggregate CO2 emissions, it requires the introduction of CCS in the period from 2030 to 2050. CCS has therefore been recognised as a key technology for achieving such targets.

Indonesia CCS: The Indonesian economy is recognized as the third most vulnerable to climate change and the government has raised its concerns about impacts on the developing world.

The government has issued the National Action Plan Addressing Climate Change, which sets out Indonesia's intention to reduce greenhouse gas emissions from the energy

sector, land use, land use change and forestry while also identifying CCS as a key means to reduce CO_2 emissions. This included a non-binding commitment to reduce CO_2 emissions in the range 26%-41% by 2020.

With regard to CCS, this is a policy objective in the National Energy Plan, with a high-level blueprint for its deployment. There have been and still are ongoing a number of investigative studies undertaken involving various national stakeholders, with some form of international cooperation, but some sort of external assistance is required in order to ignite action.

South Korea CCS: South Korea has developed a national CCS master action plan to promote CCS deployment. The Master Plan, prepared by the WRI and the Tsinghua University in collaboration with the government, industry and academic institutions, calls for the development of regulations and establishing national networks for technology demonstration by 2014.

This is even more relevant in the perspective that Korea will formally start GHG emission trading scheme from Jan. 1, 2015 in terms of how the two programs or initiatives will work together. Since 2000, the Korean government had spent about USD 89 million in funding for CCS R&D to support several independent projects to develop CO_2 capture technologies. In April 2010, the Basic Law on Low-Carbon Green Growth went into force, which would provide a broad framework for sustainability policies in Korea.

The new legislation will provide a foundation to reduce national emissions by 30% against BAU by 2020, through government intervention to regulate national emissions such as an Emission Trading Scheme and low carbon technology development national plan including as CCS.

In July 2010 the presidential committee on green growth together with five ministries has announced the national CCS master action plan – also known as the “Korea CCS 2020 Action Plan”.

There are a few categories of action such as innovative CCS technology development and large-scale integrated demonstrations, following the example from Europe, including infrastructure for CO_2 transportation; the selection of potential storage sites and CO_2 utilization. Korea is aiming to develop world class CCS technology and commercialize the technology by 2020 through the implementation of Korea CCS 2020 action plan.

According to the Korean Carbon Capture and Sequestration R&C center, the research team has developed commercially feasible membrane technology for CCS in October 2013 which is the most significant technology development in the last decade.

CDM and CCS

The establishment and refinement of the arrangements for CCS in the Clean Development Mechanism (CDM) will also help create the institutional arrangements necessary for CCS as a mitigation option and enhance industry and public confidence in CCS.

During the United Nations Framework Convention on Climate Change (UNFCCC) conference held in Doha, Qatar, from 26 November to 8 December 2012, two outstanding CCS issues under the CDM negotiations were dealt with at the 8th session of the Conference of the Parties serving as the Meeting of the Parties to the Kyoto Protocol (CMP 8). The two issues were first outlined at the Meeting of the Parties in 2011, after which the Subsidiary Body for Scientific and Technological Advice (SBSTA) was tasked to:

- explore the eligibility of CCS projects that involve the transport of CO_2 from one country to another or which involve geological storage sites that are located in more than one country;
- establish a global reserve of certified emission reduction units for CCS projects (in addition to the agreed temporary reserve of five per cent).

As a large number of CDM projects - more than 50% worldwide - have actually been developed in Asia and taking into account that there is already a well established legal and institutional framework in place dealing with renewables and energy efficiency projects under the Kyoto Protocol, there is a clear potential to finance and deploy CCS pilot projects under such a scheme.

Conclusions

It is essential that CCS will be included in a portfolio of low-carbon technology as a means to mitigate climate change for developing countries. First in line are the emerging Asian countries that have seen a massive increase in energy demand in the last decade due to their booming economies getting more and more competitive with the western world.

It makes sense for such economies dominated by fossil fuel–based emissions to start laying the groundwork for CCS as from now as some of the essential enabling (regulatory) and pre-investment activities – by being country specific - can take years to realize.

Whereas policy makers might fail or delay their decision, the business sector should play a key role on this: in fact, in the last few years, several financial organisations have started to put conditions into contracts for new power plants. It is essential to start these activities early so that a country can benefit from CCS in the years ahead.

More information

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Can industrial CO2 use contribute to climate change mitigation?

Carbon capture and reuse has the potential to have significant energy, economic and environmental benefits. But the technology needs to be brought up to commercial scale and markets developed for the end products.

By Paul Zakkour, Director, Carbon Counts, London, UK and Member, CCS Working Group of the CDM Executive Board

Over the last decade or so, interest in the use of carbon capture and geological storage (CCS) as a climate change mitigation option has largely overshadowed the potential for using CO2 in industrial and commercial applications.

The general perception is that CO2 use as an industrial feedstock has limited applicability, whilst concerns regarding the permanence of such emission reductions and the fundamentally low activation state of the molecule – meaning large amounts of energy and/or catalysts are needed to synthesize products from CO2 – has resulted in CO2 utilisation (CCU) being widely ignored in discussions regarding climate change mitigation. The one exception to this has been the use of CO2 to mobilise hydrocarbon fractions in mature oilfields, know as CO2-enhanced oil recovery (CO2-EOR), for which interest has been sustained, albeit with deployment still limited to only a few parts of the world. More recently, however, the idea of utilising CO2 in industrial processes has been making something of a comeback.

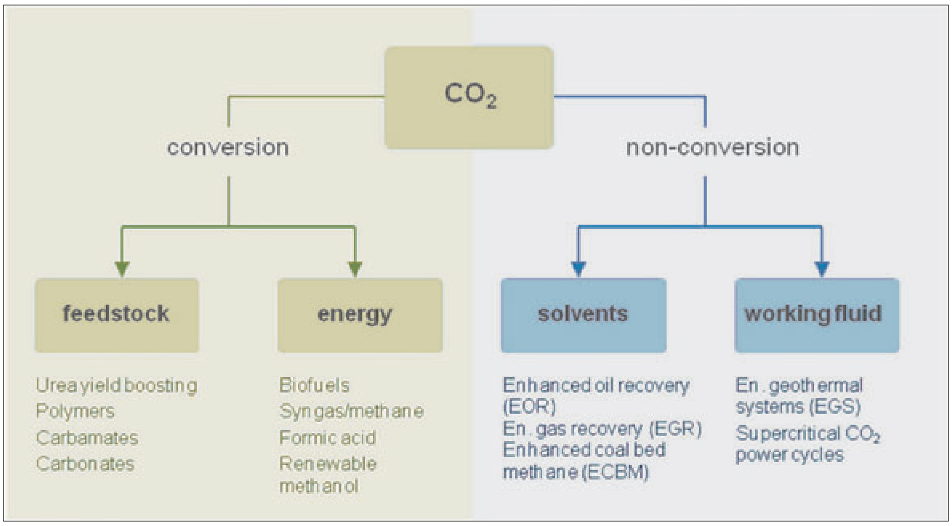

Figure 1 - Summary of CCU application typology Source: Ecofys/Carbon Counts[1]

What's driving the interest?

A variety of factors are renewing interest: firstly, widespread demonstration of CO2 capture with geological storage hasn't really met the expectations of a few years ago, especially in Europe; second, many developing countries without firm commitments to reduce emissions are less attracted to paying to put CO2 into the ground, but are interested in potential applications where captured CO2 can be put to work; third, from a commercial perspective, using CO2 offers a means to offset capture costs and enhance productivity, whilst its use as a substitute for other sources of carbon could significantly reduce the cost of materials production. Moreover, utilising CO2 can help to create a closed-loop recycling system for carbon at a facility-level, supporting wider sustainability goals.

What are the potential applications for CCU?

Using CO2 in a variety of commercial and industrial applications is nothing new. Presently, CO2 is used for things such as food preservation, dry cleaning, decaffeinating coffee and the manufacture of inorganic fertilisers. In addition, use of captured CO2 for EOR - essentially an extension of the geological storage climate mitigation pathway – has been practised for almost 40 years in the United States.

Aside from these, other more novel means to utilise captured CO2 in industry include processes where CO2 is used for conversion into new products, or in non-conversion applications where it acts as working fluid (Figure 1). Such applications include:

Using CO2 to make low carbon liquid fuels, such as methanol made using renewable electricity, where CO2 forms an essential source of carbon, or use of CO2 to enhance algae growth, which can be used to make 3rd generation biofuels and other advanced products including cosmetics and nutra- and pharmaceuticals;

Using CO2 to make polymers, where it acts as an alternative source of carbon to oil or natural gas. Products under trial using CO2 include polyurethane foams, which can be used to make mattresses, and polycarbonates, which can be used to make a variety of consumer and industrial products;

Its use as a working fluid – such as in CO2-EOR – and in power cycles in boilers and for enhanced geothermal technologies; and,

Using CO2 in concrete curing for precast concrete applications and to stabilise toxic waste such as "red mud", a by-product of bauxite mining.

What's the current status of the different technology pathways?

These different applications are presently at differing stages of technical and commercial maturity. While some of the incremental technologies could be readily established in existing mature markets (e.g. using more CO2 to boost urea production), others remain at the theoretical and R&D phase and need further efforts to reach commercial status.

Pre-commercial CCU technologies face a wide range of obstacles to commercialisation, including successful demonstration of the technology itself i.e. overcoming R&D challenges, and also external factors, such as competition from alternative services and goods, public acceptance. A key technical challenge facing several promising CCU applications is overcoming the large energy re-

quirements in the conversion of CO2 to other products, particularly those involving catalytic processes.

In some circumstances, certain technologies are already well established but will only be viable only under certain conditions, requiring a niche set of circumstances for this to be applied on a large and replicable scale (as exists for CO2-EOR in parts of the United States).

Notwithstanding the technical challenges for CCU development, a brief look around the world suggests that interest is growing in many places.

Who is involved in developing CCU technologies? Where is it happening?

Interest in CCU technology development is being driven at a number of levels across a wide range of global settings. Key actors include various academic R&D programmes, international companies such as Bayer, BASF and Dow Chemicals, and, increasingly, a number of VC-backed start-up companies. In the case of the latter, the US contains a wide variety of start-ups actively looking at the CO2-to-fuels, often backed by large federal R&D and funding programmes.

Several US programmes are also developing new uses for CO2 in chemicals production, including a US Department of Energy-funded CCU programme under which the Massachusetts Institute of Technology (MIT) in partnership with Siemens has been developing CO2 utilization technologies for the production of polymers.

Europe is also increasingly active in seeking uses for CO2 within the chemicals sector, most noticeably Germany with its large, advanced, chemical engineering industry but also within other pockets in UK, France and Italy. Supported by a range of funding programmes, various R&D efforts are ongoing across Europe exploring processes for using CO2 across different energy applications, from algae-based biofuels to hydrogen fuel cell technologies.

Further afield, a growing body of RD&D activity is emerging in India, China and other parts of the Far East, and also in the Middle East - where pilot projects using CO2 for algae cultivation and in cement production have recently been launched. Further, the potential use of CO2-EOR to increase oil and gas production remains a key interest to many governments, such countries in the Middle East, Egypt, China, South East Asia (e.g. Thailand, Indonesia), and India.

However, whilst interest in CCU technologies is growing fast in many parts of the world, expansion is from a small base, limited to lab- and, at best, pilot-scales, and restricted to certain niche circumstances. The primary challenges regarding the fundamental economics and the capacity of such technologies to contribute to long-term emission reductions remain key hurdles to progress.

CCU category	CCU technology	Research	Demonstration	Economically feasible under certain conditions	Mature market
CO_2 to fuels	Hydrogen (renewable methanol)		Main activities	Some activities	
	Hydrogen (formic acid)	Main activities	Some activities		
	Algae (to biofuels)	Main activities	Main activities		
	Photocatalytic processes	Main activities			
	Nanomaterial catalysts	Main activities			
Enhanced commodity production	Power cycles (using $scCO_2$)	Main activities			
	Enhanced production (urea; methanol)				Main activities
Enhanced hydrocarbon recovery	Miscible/immiscible floods (CO_2-EOR)			Some activities	Main activities
	Miscible/immiscible floods (CO_2-EGR)		Main activities		
	Sorption-based displacement (ECBM)		Main activities		
CO_2 mineralisation	Cement production	Some activities	Main activities		
	CO_2 concrete curing		Some activities	Main activities	
	Bauxite residue carbonation (red mud)			Main activities	
	Carbonate mineralisation (other)	Main activities	Main activities		
Chemicals production	Sodium carbonate				Main activities
	Polymers	Main activities	Some activities		
	Other chemicals (e.g. acetic acid)	Main activities			
	Algae (for chemicals)		Main activities	Some activities	

Legend
Main activities
Some activities

'Research' means that while the basic science is understood, the technology is conceptually feasible and some testing at the laboratory or bench scale has been carried out, it has not yet been demonstrated in a pilot plant. 'Demonstration' means that the technology has been, or is being, built and operated at the scale of a pilot plant, but that further development is required before the technology is ready for use in a commercial/full scale system. 'Economically feasible under certain conditions' means that the technology is well understood and is applied in selected commercial applications, although it has not been proven in all conditions. 'Mature market' means that the technology is in commercial operation with multiple replications, or could be easily modified to accommodate new applications involving non-captive CO_2.

Table 1 - Technical maturity of various CCU technologies
Source: Ecofys/Carbon Counts[1]
Note: status description based on similar approaches used by the Intergovernmental Panel on Climate Change (IPCC)[2]

Economic challenges for CCU

At present, most CCU technologies face high capital and operating costs. Although some applications are already being deployed on a limited commercial basis in different settings worldwide, others will need a major step-change in cost reductions to compete with existing products. For example, it's likely that the costs associated with algae cultivation will need to fall by factor of between 5 to 10 for it to become cost-effective and competitive with other emerging low carbon energy sources.[1]

Different CCU technologies face various specific challenges, but as with all emerging technologies the real key to reducing costs is about scaling-up. As seen in numerous cases from the development of solar photovoltaic (PV) cells to flue gas desulphurisation (FGD) units, step-change technology cost reductions are only achieved with the scaling-up of production and technology dissemination.

Further, most CCU technologies share the same barriers as those faced by CCS. These include the high up-front investment and ongoing project costs, unproven technology at scale and across the full value chain, and additional energy requirements – the so-called "energy penalty". However, whereas CCS is undertaken purely for reasons of emissions reduction, most CCU applications will be competing in existing markets.

Reducing costs is important, but competition will therefore also play a role – in both established markets such as chemicals, but also emerging ones such as low carbon transport fuels. Here, the barriers to commercialisation can vary from market inertia (i.e. the challenges of displacing technically and economically proven products) to the need for large-scale infrastructure changes to be made (e.g. for widespread use of CO2-EOR or formic acid-to-hydrogen energy).

Where costs cannot be reduced to levels comparable with incumbent products and services, then CCU technologies will clearly need to demonstrate additional benefits

which can create added value or avoid costs (e.g. of CO2 emissions), or be otherwise supported (e.g. through other climate policy incentives). This latter point poses a further hurdle for CCU technologies to address and overcome.

Can CCU contribute to climate policy goals?

The diverse range of CCU technologies all share in common the ability to retain carbon within a cycle at least over the short-term, thereby avoiding release of CO2 to the atmosphere. However, different technologies deliver emissions reductions that can be either permanent or semi-permanent, and/or direct or indirect (Figure 2).

Some technologies fix carbon into products such as polymers and mineralised form such as construction materials, whilst others, such CO2-EOR involve geologically storing CO2, essentially locking CO2 up for variable lengths of time. Alternatively, others that involve alternative forms of liquid fuels only temporarily store CO2, but also reduce emissions through substitution and displacement effects on conventional petroleum derived products.

In addition, where alternative processes employing CCU technologies use less energy intensive conversion processes – or value chains – than conventional methods, secondary emission reductions can also be achieved through e.g. reduced electricity or fossil fuel consumption. Furthermore, using CO2 as a working fluid in some applications can increase their energy use efficiency.

Although there is still a lack of reliable evidence demonstrating the total and net greenhouse gas benefits from CCU applications, there is a clear case recognised by policy-makers that several CCU technologies can potentially play a part in reducing CO2 emissions to the atmosphere. In addition, CCU is widely viewed as offering a suite of technologies that can provide financial support for wider CCS deployment through the creation of additional revenues to partially offset the costs of establishing a full CCS chain.

The prospect of developing value-added applications for captured CO2 has been a key element in garnering interest in CCS over recent years, as demonstrated in the transition in 2009 of the Major Economies Forum initiative on CCS to the Clean Energy Ministerial action group on CCUS – the "U" representing the addition of CO2 utilization to the scope of the group's remit.

Incorporating CCU within existing climate and CCS regulations presents challenges, however. Many of these relate to how

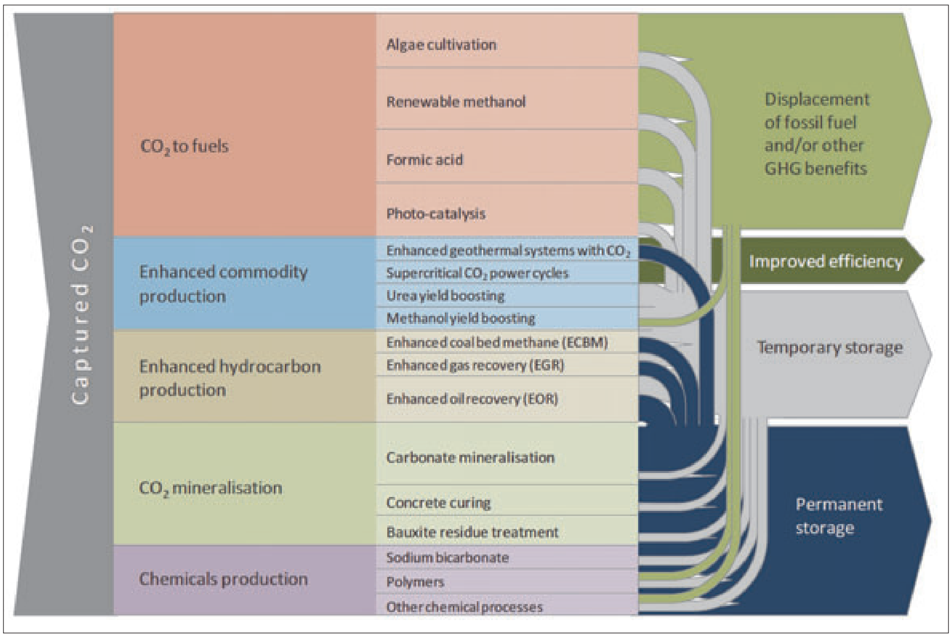

Figure 2 - Illustrative emission reduction pathways for CCU technologies
Source: Ecofys/Carbon Counts[1]
Note: Because of the complexities involved and the lack of robust and comparable data currently available, the scale of abatement shown is purely illustrative

their potential abatement benefits can be adequately recognised and accounted for. One such example is the treatment of CCU in the EU emission trading scheme, where monitoring (or "MRV") rules for Phase III of the scheme do not allow for utilised CO2 to be counted as a non-emission, except in the case of geological storage (including CO2-EOR).

Allowing CCU technologies to be included within the scheme will require the development of specific MRV rules, which could be challenging given the temporary or non-permanent nature of some reductions, and the substitution effects which will not be readily visible through standard monitoring approaches. For the latter, life-cycle based accounting approaches covering production, consumption and end-use will be needed to reveal the true emission reduction benefits that may be achieved.

But given the growing interest, there is an emerging need for policy-makers to start addressing these questions within climate and low carbon policy frameworks, although the MRV-related challenges are considerable however, and will likely require bespoke approaches for specific applications. In addition to allowing a carbon price signal for CCU technologies, other approaches that can promote the potential benefits to consumers could be used to help provide a commercial incentive for CCU development. For example, eco-labelling could offer a means to enhance the visibility of CCU derived products, using established schemes such as the EC Ecolabel and Blau Engel.

What next for CCU?

There is growing interest in the role of CCU technology worldwide, driven by various factors of which climate policy is just one. A Clean Energy Ministerial CCUS Action Group now reports annually to leading energy ministers, and several countries are actively looking at how to incorporate the "U" into their CCS policy frameworks.
In Europe, the Joint Research Centre (JRC) of the European Commission is currently funding a study to assess the potential role of emerging CCU technologies in greater detail. This project, building upon recent CCU studies for the Commission, should help to inform policy choices and focus R&D funds under the EU's flagship R&D programme, Horizon 2020, starting in 2014.

There is clearly enthusiasm in Brussels and elsewhere to support CCU for a number of reasons, including climate policy, support for CCS, and industrial innovation. As such, the coming years look likely to be an inter-

!. Hendriks, C., Noothout, P., Zakkour, P.D. and Cook, G. (2013) Implications of the Reuse of Captured CO2 for European Climate Action Policies. Final Report to the European Commission, DG Climate Action. February 2013, Brussels. Publication forthcoming.

2. Metz, B, Davidson, O., de Coninck, H. C., Loos, M., and Meyer, L. A. (eds.), 2005. IPCC Special Report on Carbon Dioxide Capture and Storage. Prepared by Working Group III of the Intergovernmental Panel on Climate Change Cambridge and New York: Cambridge University Press.

esting period for CCU related research and policy developments.Mitigation of a global environmental issue, climate change, is an extremely complex challenge that requires a broad based strategy to ensure a long-term sustainable solution. A key method practiced today is utilization of carbon dioxide (CO2) through Carbon Capture and Reuse (CCR).

Here the CO2 emitted from industrial sources is captured and processed into valuable products resulting in recycling of CO2. These methods have the potential to have significant energy, economic and environmental benefits and form an important leg of the carbon capture technology.

However, before the benefits can be realized, this technology needs to be brought to commercial scale and large volume markets for the end products containing CO2 need to be developed.

More information

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Manufacturing innovative materials for CO2 capture and reuse

Novomer is rapidly scaling its novel technology to produce high performance polycarbonate polymers using CO2 as an inexpensive chemical feedstock.

By Harshal Sawant, Business Development Associate, Novomer Inc.

In an effort to advance Carbon Capture and Reuse (CCR), Novomer has developed a novel catalyst technology which enables CO2 to react with petrochemical epoxides to create a family of polymers that contain up to 50 percent by weight CO2.

Novomer polyols are designed to replace conventional petroleum-based polyether, polyester, and polycarbonate polyols. Novomer's ability to reduce petroleum usage by at least 50 percent – while also converting CO2 from pollution into valuable materials – has the potential to transform the polyurethane industry on a large scale.

This method also yields a product with an extremely low carbon footprint. In addition, since waste CO2 is significantly lower in cost than conventional petroleum-based raw materials, Novomer polyol manufacturing costs will be favorable when compared to conventional polyols (at similar scale production). The initial market for Novomer products accounts for over 7 million tons of production per year, growing at 5.5% annually.

Figure 1 - Novomer's Polypropylene Carbonate (PPC) Polyol and its various applications

The application to carbon sequestration

In 2009, industrial sector energy consumption accounted for slightly more than one-quarter of the total U.S. carbon dioxide (CO2) emissions of 5,405 million metric tons, according to data from DOE's Energy Information Administration. It is therefore anticipated that large volumes of CO2 will be available as fossil fuel-based power plants and other CO2-emitting industries are equipped with CO2 emissions control technologies to comply with regulatory requirements.

Novomer's technology of converting CO2 into useful materials can help reduce CO2 emissions from industrial plants, especially in areas where long-term geologic storage of CO2 is not practical. In contrast to Carbon Capture and Sequestration (CCS), this conversion of emissions to Novomer products can be achieved without the benefit of government subsidies as the materials can be sold at a profit given their high performance and low cost structure.

Analyzing only one of Novomer's many potential applications, 1.33 million tons of C02 would be utilized globally per year to produce rigid and flexible Polyurethane foams containing 25% of their polyol. This is roughly equivalent to the annual amount of CO2 emissions generated by 275,000 cars.

Products and unique properties

The core catalyst which enables this technology is a proprietary cobalt-based compound first developed at Cornell University by Professor Geoffrey Coates and further optimized by Novomer. The resulting CO2-containing polymers can be tailored for applications with

a broad range of material characteristics depending on the size of the polymer chain, epoxides used, and functionality.

Due to its unique high density polycarbonate backbone, perfect OH functionality, and precise Molecular Weight control, the incorporation of Novomer's PPC polyols into existing polyurethane formulations results in flexible, rigid, and microcellular packaging foams with higher tensile strength, tear strength, load bearing capacity; adhesives and surface coatings with improved adhesion, cohesive strength, and weatherabilty properties such as UV and water-resistance; and elastomers with greater tensile and flexural strength.

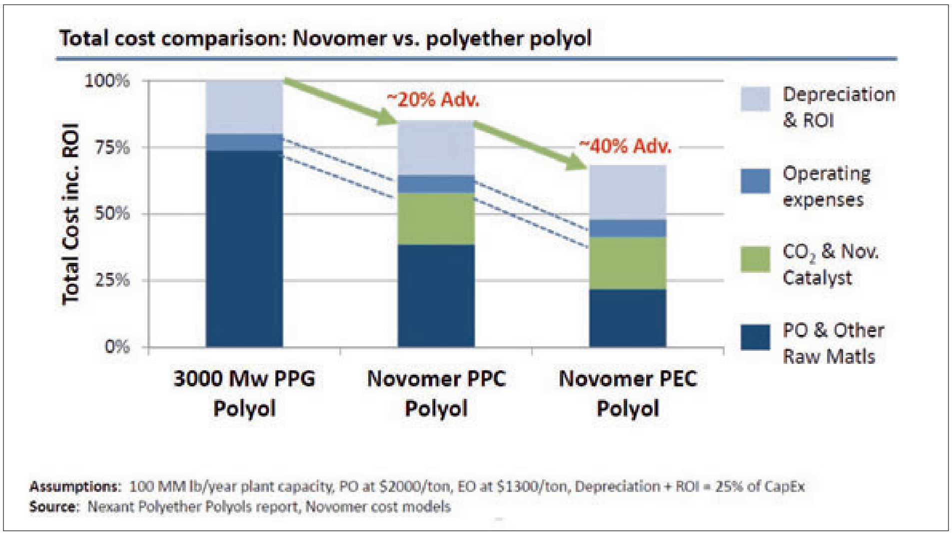

Figure 2 - Total cost comparison. CapEx and OpEx costs are similar so raw material advantage hits bottom line

Current status of Novomer's technology and future efforts

To demonstrate the robustness of the catalyst and manufacturing process, and the ability to move from lab to commercial scale, Novomer successfully ran the world's first large-scale production campaign of a 1,000 molecular weight polypropylene carbonate (PPC) polyol. The PPC polyol was scaled up and produced with Albemarle at their Orangeburg, SC manufacturing facility using existing Albemarle equipment with only minor modifications.

The multi-batch production run generated over seven tons of in-spec finished polyol, which will be used to accelerate product qualification. The capital requirements and operational costs to produce these new polyols closely mirror conventional petroleum based polyol production costs. The combination of mild reaction conditions and displaced petroleum feedstock greatly improves the energy efficiency, embedded energy, and Green House Gas (GHG) footprint of Novomer's materials versus competitive materials.

This production run was the culmination of a $25 million, three year project funded in part by an award from the U.S. Department of Energy - Office of Fossil Energy. Converting captured CO2 emissions from industrial sources into useful products is an important component of the Office of Fossil Energy's Carbon Capture and Storage program, which is managed by the National Energy Technology Laboratory and funded by the American Recovery and Reinvestment Act.

In addition to the US Department of Energy's significant financial recognition of Novomer's technology, a number of leading institutions have recognized its potential with various awards such as MIT Technology Review's 50 Most Innovative Companies, 2011 ICIS Award for Innovation with Best Environmental Benefit, Informex USA Sustainability Award, and the best paper award at the CPI Global Polyurethanes Conferences in 2012 and 2013.

Novomer's polyols are currently ready for commercialization. Novomer is actively developing applications for their polyol by working closely with more than 100 companies in various segments of the polyurethanes industry. Novomer's future production plans involve building a 5,000 ton/year fully integrated demonstration scale plant.

This increased capacity is needed to serve customers and to refine the techno-economic model and eliminate the risk of moving to full commercial scale plant (50K tons/year capacity). Novomer is currently in discussion with several potential toll manufactures who already have the equipment in place to produce its products.

Future application of this kind of technology in the wider context of carbon mitigation.

Currently geologic storage of CO2 is the primary method used for CCS, involving methods such as CO2 sequestration and Enhanced Oil Recovery (EOR), which have been commercially proven and are viable. In addition to polyurethane applications, Novomer is also exploring the potential for its CO2 polymer technology to enhance the yield of CO2 EOR technology through the creation of specialized surfactants or additives.

Like Novomer polyols, these surfactants would be partially composed of CO2 and are designed to make the use of CO2 EOR more efficient. While this work shows promise, it is still in the early phases of development.

The use of CO2 as a feedstock is a growing area of research and commercial activity. Other new technologies being investigated by other emerging companies include the utilization of CO2 as a feedstock for the production of chemicals and fuels. Novomer, however, is one such company well down the path of commercializing an innovative technology to convert carbon pollution from a climate threat to an economic resource. This represents one step towards a thriving and clean energy economy.

More information

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Integrating carbon capture into precast concrete production

CarbonCure has developed a carbon capture process that is fast and easy to integrate with existing cement plants. Using CO2 as a feedstock can improve concrete properties as well as permanently storing CO2.

By S. Monkman, Vice President Technology Development, CarbonCure Technologies, Halifax, Canada

Approximately 5% of global CO2 emissions are related to cement production. The cement and concrete industry is pursuing a number of initiatives to reduce CO2 emissions but a significant CO2 mitigation will still be desired.

Novel solutions are sought. The reaction of carbon dioxide with hydrating cement is known to produce stable carbonate reaction products. These reactions can serve to effectively bind CO2 in the cement matrix while offering material benefits. Studies suggest that a carbon dioxide treatment of fresh concrete can improve concrete properties such as strength, resistance to chloride permeability, and freeze-thaw damage while permanently sequestering CO2.

Efforts are underway to develop a commercial process to manufacture concrete products using fresh concrete carbonation. Demonstration data suggests that carbon dioxide can be integrated into precast concrete production with resultant strength benefits in excess of 20%. A producer can use the increased strength to reduced cement usage and thereby lead to economic savings and reductions in embodied CO2.

Figure 1 - An example of the kind of concrete products that can be manufactured using the CarbonCure process

Background

Carbon dioxide emissions are a significant issue for the cement and concrete industry. It is estimated that 5% of the world's annual CO2 emissions are attributable to cement production. The process of producing cement produces carbon dioxide from two sources.

Raw materials, including limestone, are heated to drive off chemically combined CO2 and leave reactive CaO phases. Significant emissions further come from the carbon dioxide associated with the fuel required to operate the cement kiln.

The production of 1 tonne of clinker requires 1.13 tonnes of raw materials and results in an emission of around 0.865 tonnes of CO2 wherein about 0.5 tonnes is associated with the calcination and the remainder with the energy consumption. The resulting cement clinker will then typically be blended with additional materials (i.e. blast furnace slag, fly ash, silica fume) to create a blended cement.

If the substitution rate of the clinker reaches 25% then the specific emissions intensity can be driven down from 865 kg/tonne for the clinker to 650 kg/tonne for blended cement.

The cement industry recognizes a few approaches to reduce the emissions intensity of the cement as it is produced and later used in concrete. The thermal and electrical efficiency of cement production can be improved by deploying the best available technology in new cement plants and retrofits.

Alternative and less carbon-intensive fuels can be used as the energy source. The rate of substitution in blended cements can be maximized. Finally, carbon capture and storage (CCS) can capture cement industry CO2 emissions before they are released and store them permanently.

It is clear, however, that practical limits on the impacts of these measures mean that it will be difficult to achieve the industry goal to reduce emissions 50% below 2006 levels by 2050 that was outlined in the Global Cement Technology roadmap released by the International Energy Agency and the WBCSD.

The history of emissions intensity reductions relating to concrete has seen significant improvements through greater kiln and process efficiency, the use of blast furnace slag and fly ash as supplementary cementitious materials, and, more recently, the increased use of limestone fines in blended cements.

Further reductions will come from a variety of approaches though none promise to be sufficient on their own to amount to the desired difference. Innovative approaches are sought.

One potential measure is to investigate the beneficial reaction of carbon dioxide and freshly hydrating cement. If an industrial process could successfully use carbon dioxide as a feedstock in the production of concrete building products there would be widely distributed carbon utilization that would effectively 'close the loop' for the carbon

dioxide emitted during the cement production.

Figure 2 - The mobile pilot trailer in place at one of the trial sites

Carbon Capture by cement

The mechanism of the carbonation-curing of cement was systematically studied in the 1970s at the University of Illinois. The main calcium silicate phases in cement (3CaO-SiO2 and 2CaO-SiO2) were shown to react in the presence of water to form both calcium carbonate and a lower calcium form of calcium silicate hydrate gel. In contrast, the conventional hydration products are mainly calcium hydroxide and calcium silicate hydrate gel.

The carbonation reaction is spontaneous and exothermic and the calcium carbonate is thermodynamically stable thereby offering permanent carbon dioxide storage.

The reaction of carbon dioxide with a mature concrete microstructure can be associated with durability issues such as shrinkage, reduced pore solution pH and carbonation induced corrosion. Notably, the carbonation curing process applies CO2 to fresh concrete rather than to mature concrete.

Researchers have identified beneficial outcomes such as: improved strength, reduced absorption, improved resistance to chloride permeability, and improved freeze-thaw performance. Additionally, permanent CO2 storage in the concrete allows producers to create more sustainable building products with improved performance.

Concrete masonry production

The commercial production of precast concrete block occurs by forming dry mix concrete in a moulding machine and then curing the formed blocks. In a typical plant, various ingredients are conveyed to a mixer to make concrete. The ingredients may be, for example, fine aggregate, coarse aggregate, fly ash, cement, chemical admixtures, and water.

The mixed concrete is transferred to a hopper located over a moulding machine. In each production cycle, an appropriate volume of concrete passes from the hopper to the moulding machine. The concrete is formed and compacted (shaken and compressed) in the moulding machine into a plurality of blocks, typically four or more. A complete production cycle is typically complete in 6 to 12 seconds.

The blocks move from the moulding machine on a tray, which is thereby conveyed to a curing area. Normally, the blocks are subject to accelerated curing through the application of steam or heat. The cured blocks are removed from the curing area and sent to further processing stations for packaging and transport to the end user. CarbonCure Technologies has pursued the beneficial utilization of carbon dioxide in the manufacture of precast concrete products.

The first generation concrete carbonation technology developed by CarbonCure was directed towards standard concrete blocks.

Integration of carbon capture

The CarbonCure™ Masonry System provides controlled doses of gaseous carbon dioxide into the mixer feeding into a masonry production machine. The concrete and carbon dioxide are intermixed while the mixing cycle proceeds. The brief gas delivery time allows the carbon dioxide to be simply integrated into a conventional process whereby benefits of carbonation of fresh concrete can be realized in an industrially scalable manner.

The mixer serves as a nominally contained reaction vessel. The immediate impacts of carbon dioxide on fresh concrete can typically be addressed with simple steps such as slight increases in the amount of mix water. The carbonated concrete is discharged from the mixer and thereafter used within the conventional masonry production process.

The technology is supplied as a retrofit to existing production equipment and systems. A liquid CO2 supply on site communes with the gas delivery system to provide a room temperature supply of carbon dioxide gas. The injection is synchronized with the mixing cycle and is proportioned appropriately for a given mix design. The gas is commercial grade CO2 that has been captured from point-source supplies.

Alternative carbonation approaches for fresh concrete potentially offer higher carbon dioxide absorption through the use of specialized and displacive plant infrastructure (i.e. pressure chambers) and greatly extended carbonation times. These tradeoffs are unattractive for concrete producers that prefer to use their existing equipment and adhere to their established production cycles.

The CarbonCure system has minimal impact on the conventional production processes and producers can apply their existing knowledge of concrete production to optimally run the integrated carbon capture process.

Ultimately, the CarbonCure Masonry System is a platform technology that can be readily integrated with other strategies (e.g. supplementary cementitious materials, alternative manufactured aggregates) to reduce the carbon footprint of concrete.

Industrial Pilot

The technology has been developed through a series of trials at Shaw Brick (Nova Scotia), Basalite Concrete Products (California), Atlas Block (Ontario) and Northfield (Illinois) in 2011 to 2013. An August 2013 trial found that uptake efficiencies (carbon dioxide captured as a fraction of the carbon dioxide delivered during the injection) exceeded 80%. The carbonated blocks were found to develop strength that was 15% to 19% higher than the control strength at 7, 28 and 56

days. The carbonated blocks had a density equivalent to the control block and water absorption 18% lower.

A proprietary admixture has been developed for use in the carbonated concrete that allows the treatment to further improve the concrete properties. Carbonated blocks made using the admixture were 25 to 46% better in the 7 to 56 day range, the water absorption was 33% lower and the density was 1.6% higher. The absorbed carbon dioxide was estimated to reach 78 lbs of CO2 permanently captured within a 1000 ft2 masonry wall.

Producers can accept the potential strength benefits or develop a reoptimized mix design for use with the carbonation process that matches the conventional strength but does so using a lower cement content. In the latter case, the absorbed carbon dioxide and avoided emissions associated with the cement reduction would work together to effectively to lower the embodied carbon of the concrete blocks.

Future

CarbonCure Technologies is pursuing technological developments to improve the carbon dioxide absorption and to expand the concrete product types the system can address. Experimental procedural modifications have established that the amount of carbon dioxide that can absorbed by the concrete can be double or tripled without deviating from the industrial production rates.

The carbonation approach has also been used in trials with precast and ready mix concrete. Early results offer promise that equivalent materials performance can be assured if not strength benefits realized. Work is underway to expand the technology into the wet mix concrete space by first pursuing a broad durability study.

Over the course of the next five years, our technology roadmap will yield a proven turn-key engineered solution for the Canadian and global concrete industry that addresses their urgent demand for green technologies without negatively impacting their material performance or profitability. The ultimate goal is to integrate CarbonCure technologies with complementary materials and technologies to produce carbon-negative concrete at full-scale without compromising profitability or material quality.

More information

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Guangdong Province, China - getting ready for CCUS development

A three-year project , funded by the UK Government and the Global CCS Institute, has yielded promising results for CCUS deployment in Guangdong.

Guangdong is among the wealthiest and most populous provinces in China, supported by an expansive manufacturing sector and home to a wide-ranging set of multinational and Chinese Corporations. Under the 12th Five–Year Plan, Guangdong was one of seven cities and provinces designated to pilot emissions trading schemes (ETS) ahead of a national ETS to be implemented by 2016.

While carbon capture utilisation and storage (CCUS) research and demonstration projects have been undertaken in the northern parts of China from as early as 2005, the Guangdong CCS Ready (GCCSR) project is the first substantial CCUS activity in Southeast China. Guangdong has a high dependence on imported energy (about 95 per cent) and, compared with some other provinces, its industrial structure is considered 'light'. CCUS was therefore not a priority in this region and, prior to the GCCSR project, local knowledge of CCUS and its potential use was limited. Since the GCCSR project, however, CCUS has been included in the Provincial Low–Carbon Development Plan.

These results are published in the GCCSR Project Final Report, which comprises the following six parts:

- Analysis of carbon dioxide (CO2) emissions in Guangdong Province, China
- Assessment of CO2 storage potential for Guangdong Province, China
- CO2 mitigation potential and cost analysis of CCS in the power sector in Guangdong Province, China
- Techno-economic and commercial opportunities for CCS-ready plants in Guangdong Province, China
- CCUS capacity building and public awareness in Guangdong Province, China
- CCUS development roadmap study for Guangdong Province, China

The key report findings are summarised as follows:

- CCUS is necessary to achieve deep cuts in CO2 emissions in Guangdong Province, China
- CO2 storage in the province will mainly be offshore
- there are great cost benefits in making new thermal power plants CCUS-ready
- an early opportunity exists for a large–scale (one million tonnes of CO2 per annum) CCUS demonstration project in Guangdong, involving CO2 captured from hydrogen production for potential storage in an offshore near-depleted oil field.

The project also proposes a CCUS development roadmap for the province to 2030 and, more generally, it has increased CCUS capacity and public awareness in the region and nationally.

Following the success of the GCCSR project, further funding from the UK Government is supporting a new project focusing on the business aspects of CCUS. This project commenced in July 2013 and is called "Implementing CCUS from UK to China: A comparative analysis with a focus on Guangdong Province" (ICCUS). Other activities in the region include development of the Guangdong International CCUS Industry and Academic Collaboration Centre and the signing of the UK–China Low–Carbon Collaboration Joint Statement on 29 October 2013.

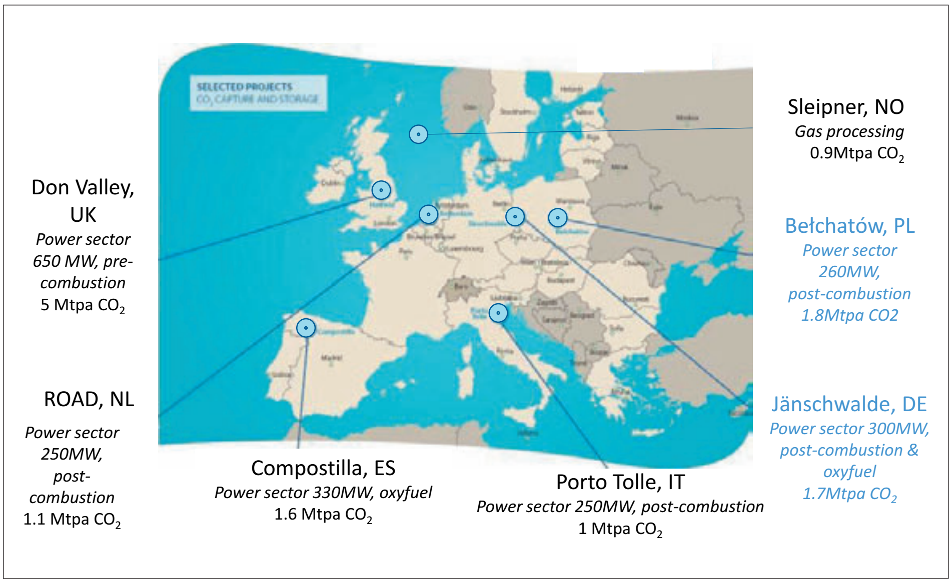
There are clear signals that Guangdong Province recognises the importance of CCUS and that the increasing level of activity we are now seeing is set to continue.

More information

This article was written by Di Zhou, Professor at the South China Sea Institute of Oceanology, Chinese Academy of Sciences. Currently she is leading the research project “Feasibility of CCS Readiness in Guangdong Province”.
It originally appeared as a blog post on the Global CCS Institute website:
www.globalccsinstitute.com

The European CCS Demonstration Project Network - progress update

The report outlines the progress, lessons learnt and details of the European CCS Demonstration Project Network.



European CCS Demonstration Project Network

Founded in 2009, the European Carbon capture and storage (CCS) Demonstration Project Network (Network) is a unique community of leading large-scale CCS projects dedicated to sharing knowledge and aiding the development of this clean, low-carbon technology.

During 2012 the Network comprised the six leading European large scale CCS projects, either operating or in development, which all aim to demonstrate the commercial deployment of the technology, address any issues that arise, and pave the way for the wide-spread use globally of this clean way of generating electricity and industrial production. In 2012 the Network's projects were: Belchatów (Poland - cancelled in early 2013), Compostilla (Spain), Don Valley (UK), Porto Tolle (Italy), ROAD (The Netherlands), and Sleipner (Norway).

The report highlights that the projects are making progress towards deployment, but not as quickly as originally anticipated. While some are facing delays in obtaining permits, most of the projects under development face major challenges in attempting to reach a final investment decision (allowing the projects to be constructed and become operational) due to the lack of appropriate funding and incentives that will allow this key low-carbon technology to be demonstrated at scale in Europe.

While there are no technical obstacles or risks associated with deployment, CCS has not been previously deployed at scale in the power sector. Projects in the US, Canada, Australia and China are being actively developed - and while initially holding the lead in project and technological development, European projects are slowing in their progression. Not actively developing CCS will be a risk for Europe and its long-term competitiveness in a carbon-constrained future.

The Network itself has gone through a number of changes during 2012. An operational project has joined the Network (Sleipner) which turned out to have a wealth of information for the other projects, helping accelerate their deployment. One project left the Network because it has been put on hold (Jänschwalde) followed by the cancellation of a second project (Belchatów) in early 2013. There was also a change in Secretariat of the Network, which now comprises of The Global CCS Institute, IFPEN, TNO and SINTEF.

The Network is composed of two post-combustion power projects (ROAD, Porto Tolle), a gas processing project (Sleipner), one oxy-fuel power project (Compostilla), and one integrated gasification combined cycle (IGCC) power project (Don Valley). Sleipner is the only project currently in operation. All will capture over 1 million tonnes of CO2 per annum each, at a capture rate of over 90%. The capture component incurs the largest capital and operational costs. SOx and NOx (impurities of sulphur and nitrogen) are quoted by the projects as the most common expected impurities in the slip stream gas.

All of the Network's projects will use pipelines to transport the CO2 they capture. Four projects (Don Valley, Porto Tolle, ROAD and Sleipner) use, or intend to use, offshore pipelines. Collectively pipeline inlet pressure will be between 129 and 180bar, and inlet temperature will be between 30 and 80 °C.

For storage, a range of storage sites are being used or have been investigated, ranging from onshore saline formations, to offshore depleted gas reservoirs and the use of CO2 EOR operations. Operational and projected bottom-hole pressures for Compostilla, Don Valley and Sleipner range from 80 to 248 bara, and injection rates vary between 30-70 kg/second.

The Projects consider that public engagement is one of the key management enabling activities to support the deployment of capture, transport and storage infrastructure. As a general conclusion the proponents believed that direct engagement is the most effective form of interaction, and that consistent messaging is very important.

In terms of permitting and regulatory development, the ROAD project's storage permit has been successfully reviewed by the European Commission, which has given its first opinion of a permit submitted under the CCS Directive (a second opinion will be given prior to injection) in February 2012. The Don Valley project has obtained its storage appraisal licence for the target saline storage site in the southern North Sea. This is the first such licence awarded in the UK and pursuant to this intrusive appraisal drilling has been successfully undertaken in summer 2013.

The Belchatów and Compostilla project still require further finalisation and implementation of the transports and storage regulatory regimes by their respective authorities. The Porto Tolle project needs to re-submit the Environmental Impact Assessment for their base plant.

	Bełchatów (Cancelled in 2013)	Compostilla	Don Valley	Jänschwalde (Cancelled in 2012)	Porto Tolle	ROAD	Sleipner *
Production plant type	Power plant	Power plant	Power plant	Power plant	Power plant	Power plant	Natural gas processing
Installed production capacity	260 MWe	300 MWe	650 MWe	300 MWe	250 MWe	260 MWe	N/A
Fuel Type (for power production)	Lignite	Coal	Coal	Lignite	Coal / biomass	Coal / biomass	N/A
Clean electricity production (CCS component), annualised - MWh/year		1,416,600	6,900,000	1,285,900		1,293,000	N/A
Net efficiency (lower heating value) of the power plant without CCS at full load	41.76%	41.10%		36%	44.00%	46.30%	N/A
Net efficiency (lower heating value) of the power plant with CCS (full load value) *Based on various degrees of slip streams (i.e. numbers are not commensurate)*	39.70%	35.4%		36%	38.20%	43.90%	N/A
Capture Type	Post combustion, amine	Oxy-fuel	IGCC	Oxy-fuel and post combustion	Post combustion	Post combustion	Amine
% Increase in Fuel Consumption		8.50%		0% (compared to existing unit - 7-8% compared to new unit)		5.30%	N/A
Transport	140km pipe	147km pipe	175km pipe	52km pipe	100km pipe	26km pipe	1km pipe
Storage	Onshore saline formation	Onshore saline formation	Offshore saline formation	Onshore saline formation/ gas field	Offshore saline formation	Offshore gas field	Offshore saline formation
Planned CO_2 stored Mt/year	1.8	1.6	5	1.7	1	1.1	0.9 (14 to date)*

*CCS project quick reference table. *Project in operation.*

Conclusions

The European CCS Demonstration Project Network has a unique portfolio of projects, covering all of the principal capture technologies in the power sector, a range of transport options, and a variety of on and off shore storage sites. As a body, it has shown a commitment to knowledge sharing, discussing a wide range of topics that are central for the wide deployment of this low-carbon technology.

During 2012 a large number of expert knowledge sharing workshops were held - often with other large scale projects both within Europe and internationally, and a number of research projects - covering a wide range of topics. These workshops included discussions covering CO2 monitoring techniques, public engagement activities, regulatory and permitting developments, and storage characterisation.

Collectively the Network has stored 1 million tonnes of carbon dioxide during 2012. The projects within the Network working toward operational status continue to be developed, despite adverse delays due to permits and the unfavourable conditions for making final investment decisions.

During 2012 the Network was comprised of 3 post-combustion power projects, a gas processing project, one oxy-fuel power project, and one IGCC power project. Sleipner is the only project currently in operation. Each and every project will capture over 1 million tonnes of CO2 per annum, at a capture rate of over 90%. The energy demand for capturing CO2 for the power sector incurs the largest cost. SOx and NOx are quoted by the projects as the most common expected impurities in the slip stream gas.

Four projects (Don Valley, Porto Tolle, ROAD and Sleipner) use, or intend to use offshore pipelines. Collectively pipeline inlet pressure will be between 129 and 180bar, and inlet temperature will be between 30 and 80 °C.

For storage, a range of storage sites are being used or have been investigated, ranging from onshore saline formations, to offshore depleted gas reservoirs and EOR operations. Projected bottomhole pressures for Compostilla, Don Valley and Sleipner range from 80 to 248 bara, and injection rates varying between 30-70kg/second.

Public engagement is one of the key management activities for the projects, with the proponents concluding that direct engagement is the most effective form of interaction and that consistent messaging is very important.

In terms of permitting and regulatory development, the ROAD project's storage permit has been successfully reviewed by the European Commission, which has given its first opinion of a permit submitted under the CCS Directive (a second opinion will be given prior to injection). The Belchatów and Compostilla project still require further finalisation and implementation of the transports and storage regulatory regimes by their respective authorities. The Porto Tolle project needs to re-submit the Environmental Impact Assessment for their base plant.

The overall deployment of projects has been largely delayed for two reasons. There is currently too much policy uncertainty within Europe as a whole. CCS has large capital costs and development times - often more than 10 years for early movers - with investors requiring long-term certainty that they can invest in CCS. Regional and national climate and energy policies must provide long-term clarity on the way forward. Short, medium and long term incentive mechanisms should be introduced that are consistent with policy positions. While the UK and Norway have taken active and practical steps in this direction, other countries need to follow suit.

Two of the Network's projects will not be proceeding - Jänschwalde and Belchatów. Both were well developed and very credible projects, situated within two countries that have a great reliance on fossil fuel generated electricity and industries - ideally placed to benefit from the environmental benefits; economic benefits; and energy security benefits that CCS provides. Both have been cancelled largely due to a lack of investment and policy commitment and certainty.

Current deployment and incentive mechanisms are insufficient. Short-term measures need to be introduced that enable first mover projects to enter operation, supported by appropriate market mechanisms that drive large scale deployment. The ETS is a mechanism unsuited to supporting the deployment of new technologies such as CCS, and with the deterioration of ETS prices there are few signals to the market that encourage investment. First movers face significant risks and costs. Unlike many forms of renewables, which are commercially viable, there has been a lack of similar or appropriate incentives and support from Member States for this low-carbon technology.

More information

www.ccsnetwork.eu

Policy, projects and regulation news

Norway strengthens capture research at TCM

www.tcmda.com

Despite the cancelling of a full-scale test at Mongstad, CO2 capture research has received additional funding.

The Norwegian Government has strengthened its support for CO2 Technology Centre Mongstad by providing it with an additional NOK 400 million ($67.7m) for carbon capture technology testing over the next four years.

The full scale project at Mongstad has been cancelled, however, at the same time, the Government renewed its commitment to 'continue and strengthen' TCM, the world's largest and most advanced carbon capture testing centre.

Frank Ellingsen, Managing Director, TCM, said:

"We are pleased to see the renewed commitment from Norway to CCS. Climate risk is now firmly on the agenda of energy investors. With shareholder and compliance pressure pushing energy companies to decarbonise, CCS will reach an inevitable tipping point. TCM plays a vital role in reducing the technical, environmental and financial risk of CCS to accelerate that moment."

To date, major technology brands have already registered their interest for testing using TCM's amine plant, including Aker Solutions (which is continuing its use of the plant), plus Hitachi, Mitsubishi and Siemens.

In addition to the fully operational Amine and Chilled Ammonia Process plants at TCM, 14 leading technology vendors are queuing up to use available space for testing their technologies, which could be used for the construction of one or several smaller test units.

Over the last year TCM has enabled a series of major advancements in reducing the cost and the technical, environmental and financial risks of implementing CO2 capture technology. The key achievements from the Amine and Chilled Ammonia plant include gaining operational experience from more than 7,000 hours of testing with more than 90% of uptime.

In terms of reducing technical risk of carbon capture, TCM highlighted the following achievements:

- Developing documented and transferable experiences on the operation, start-up, shut down, emergency shut downs etc., which is available to the CCS community
- Developed and verified simulation tools for the total facility based on NH3 and MEA, to be used in the planning, operation and evaluation of day to day activities at TCM
- Established an available analytical laboratory tool box
- Operated with zero injuries and environmental impacts
- Developed a toolbox for process monitoring including emissions
- Extensive research into possible effect of amines. More than 55 external studies have been performed
- Established a test centre network with national and international institutes and research organisations.

CO2 capture research is continuing at Technology Center Mongstad, with additional financial support from the Norwegian Government

As well as the NOK 400 million commitment to TCM, Norway's allocation for CCS R&D through the research programme, Climit, will also be increased by NOK 100 million over two years. The Government will also promote CCS capacity building and deployment internationally. The Norwegian Government has committed to ensure the financial and other conditions necessary to result in at least one realization of full-scale CCS project in Norway by 2020.

Mongstad project stopped by Norwegian Government

www.statoil.com

The Norwegian government has announced that the full-scale carbon capture project at Mongstad will be terminated.

Statoil, one of the leading suppliers on the project, said it is now commencing work in order to ensure a smooth project conclusion.

"The work carried out on carbon capture and storage (CCS) at Mongstad has been extensive and demanding. But it has also provided us with some important lessons and given us new knowledge of capture technology. We have also had the opportunity to develop a toolbox for measuring and analysing emissions. Even though the full-scale project will now be concluded, it is important for Statoil that all we have learnt will be of benefit to the industry in its continuing work on CCS," said Eldar Sætre, executive vice president for Marketing, Processing & Renewable Energy at Statoil.

Statoil signed in 2006 an implementation agreement with the Norwegian Ministry of Petroleum and Energy and, in accordance with this, submitted a master plan for full-scale carbon capture at Mongstad (2009). Together with Gassnova, Shell and Sasol, the company completed the Technology Centre at Mongstad (TCM) for carbon capture technology in 2012.

"CCS is one of the most important technologies in the efforts being made to reduce carbon emissions from industry and from power production. The experience gained at Mongstad indicates that it is necessary to intensify the work being done to develop the technology and reduce the cost involved in so doing. In Statoil we will press on with our technology development efforts in this area," added Sætre.

Alstom continuing carbon capture tests at Mongstad

www.tcmda.com

Alstom will continue testing its Chilled Ammonia process at CO2 Technology Centre Mongstad (TCM) for another year.

Alstom has been testing its technology over the past year at the Norwegian facility and is one of two key technology partners in the project developed by state-owned CCS enterprise Gassnova, as well as oil giants Shell, Statoil and Sasol.

The 'Chilled Ammonia Process' (CAP) method, offers environmentally-friendly carbon capture, says Alstom. The Ammonia Process based CO2 Capture unit at TCM uses industrial flue gases from both a nearby Combined Heat and Power plant (CHP) and Statoil's Mongstad refinery. With real flue gases to work with, the team has been able to test the CAP principles under 'live' conditions, collect valuable data, and improve the process.

The tests will now continue until autumn 2014.

ETI seeks proposals for carbon capture from gas-fired plants

www.eti.co.uk

The ETI is seeking organisations to take part in a project to accelerate the development of advanced carbon capture technologies for gas-fired power stations.

The UK Energy Technologies Institute project is seeking the best possible technologies that are sufficiently developed to move directly into the detailed design, construction and testing of a multi megawatt pilot/demonstration plant.

ETI launched a project last year (led by Inventys Thermal Technologies, in collaboration with Howden Group and Doosan Power Systems) to develop their advanced carbon capture technology for gas-fired power stations. After the initial phase of the work, the aim is to carry out the detailed design, construction and testing of a UK-based 5MW carbon capture demonstration plant capable of capturing up to 95% of carbon dioxide emissions.

The ETI's role is to bring together engineering projects that accelerate the development of affordable, secure and sustainable technologies that help the UK address its long term emissions reductions targets as well as delivering nearer term benefits.

The purpose of the Request for Proposals (RfP) is to ensure that the best technology is selected through a process of open competition. Applicants will need to demonstrate that their technology has the potential to make a substantial reduction in capital and operating costs in the capture plant, and will be ready to catch the wave of CCS implementation in gas-fired power in the UK that is expected to occur during the 2020s and early 2030s.

The ETI will undertake detailed assessment of any proposal selected following the RfP response to confirm the projected benefits and readiness to undertake a project, in parallel with the results from the initial phase of the Inventys-led project, which is due for completion by the end of the year. The ETI will then decide whether it will invest up to £20m over three years in the detailed design, assembly and testing of a UK demonstrator plant.

Andrew Green, the ETI Programme Manager for CCS, said: "With CCS having the potential to play a key role in a future affordable, secure, low carbon UK energy system, it is important for there to be research into and investment now in a range of technologies to help build the economic viability and help extend the role of CCS in any future UK energy system design.

"We expect that by 2020, there will be 30GW of gas-fired power capacity, some of which will require retrofit or upgrade to include CCS by 2030 if we are to meet UK CO2 reduction targets. Newly developed technology which reduces costs and accelerates deployment by 2030 is therefore critical."

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

The deadline for the notification of an intention to submit a proposal for the project is 31 October. The closing date for final submissions is 28 November.

Ferrybridge gets Spirax Sarco heat exchanger

www.spiraxsarco.com

Spirax Sarco has provided a steam-driven heat exchange package for the Ferrybridge capture demonstration.

The Ferrybridge project demonstrates the "capture" part of the process at a larger scale than previous pilot schemes, using an amine-based solvent to absorb up to 100 tonnes of carbon dioxide per day. The Spirax Sarco steam system will be used to reboil and regenerate the carbon dioxide saturated solvent for reuse by stripping the carbon dioxide out under carefully controlled high-temperature conditions.

The temperature and pressure in the clean-up column, or stripper, has to be controlled precisely. If the temperature is too high, the amine solvent breaks down. If it's too low, the pressure in the column drops, which means it subsequently takes more energy to compress the carbon dioxide ready for transport and storage.

Steam is the ideal heating medium, because it helps provide very precise temperature control. And according to project partner Doosan Power Systems, Spirax Sarco was the right choice to provide the steam system, because the company's all-round steam expertise and project management capability meant that Spirax Sarco could deliver a skid mounted package and free Doosan's team to work on other areas of this complex process design.

"Spirax Sarco has an excellent reputation in dealing with steam and condensate management," says Scott Hume, Process Engineer at Doosan. "They supplied everything as a package, from the steam interface back to the condensate return line, including the heat exchanger. That simplified the scope of work for our team and it really helped."

Spirax Sarco supplied everything needed to make the steam system run smoothly, including safety valves, pressure reducing valves, steam traps, heat exchanger, condensate receiving vessel and condensate return system.

The team was working under tight time constraints, but got the entire package designed, checked and built within 12 weeks.

Ferrybridge power station is operated by SSE plc, which has worked with partners Doosan Power Systems and Vattenfall R&D to build the carbon capture pilot plant.

China and United Kingdom announce collaboration on CCUS

www.ukccsrc.ac.uk

Scientists and engineers from China and the United Kingdom have formed an initiative that will pave the way for the research, development and demonstration of innovative carbon capture, utilisation and storage (CCUS) technologies.

The UK Carbon Capture and Storage Research Centre (UKCCSRC), Scottish Carbon Capture and Storage (SCCS), Guangdong Low-carbon Technology and Industry Research Centre (GDLRC) and the Clean Fossil Energy Development Institute (CFEDI) signed the ten-year Memorandum of Understanding (MoU) today at Lancaster House, in London, witnessed by Governor Zhu Xiaodan of Guangdong Province, People's Republic of China, and Minister Greg Barker of the UK's Department of Energy and Climate Change (DECC).

The agreement will lead to the establishment of an international CCUS network, which will promote joint research and devel-

opment, provide advice for local and regional governments and develop ways to exchange knowledge. The partners plan to move rapidly towards demonstration of CCUS technologies in China, potentially within three to five years.

Minister Barker and Governor Xiaodan also concurrently signed a joint statement pledging a collaboration on low carbon development, including CCS technology, between the UK and China.

"The UK has well-established research and development capacity in CCS, and by linking up with China we can further advance and promote the commercialisation of this important climate change mitigation technology," said UKCCSRC Director, Professor Jon Gibbins.

"Preparation for CCS is now in China's Five Year Plan, so Guangdong is preparing to surpass all European efforts with one leap. This strategic and timely agreement will unite researchers from Scotland, the UK and China in the shared ambition of making swift and practical progress on CCS technologies. Guangdong is a leading province for industrial innovation in China. This MoU enables UK researchers and Chinese industry to exchange staff and expertise, so that decisions can be made in mid 2014 to commence construction," said Professor Stuart Haszeldine, SCCS Director, and Professor of Carbon Capture and Storage at the University of Edinburgh

The MoU builds on more than five years of joint CCUS activities between Guangdong and the UK, supported by the UK's Foreign & Commonwealth Office, DECC and Research Councils UK. The MoU signatories have agreed to advise and support the Guangdong International CCUS Industry and Academic Collaboration Promotion Network (GDICCUS), which will promote CCUS research collaboration and technology industrialisation in the Guangdong Province of China.

UK pledges £35m funding for China and Indonesia to develop CCS

www.gov.uk

The UK's Secretary of State for Energy and Climate Change Edward Davey has announced £35 million funding to support CCS development in Asia with a focus on China and Indonesia.

The funding is being used to support the Carbon Capture and Storage Fund (CCSF) under the Clean Energy Financing Partnership Facility (CEFPF) administered by the Asian Development Bank (ADB). The ADB is working with the UK's Department of Energy & Climate Change, the Global CCS Institute and partners within the Chinese Government to identify opportunities to accelerate the development and deployment of CCS.

The funding will also support the GreenGen project in Tianjin City of China, which will receive over $10m from the ADB CCSF. The project was launched in 2005 by China's five largest power companies, two largest coal companies and one investment group, aiming to complete a 400 megawatt power plant before 2020 with over 80% of the CO_2 separated and stored. To increase UK collaboration, and in partnership with the ADB, three CCS centres will be set up, two of which will be in China and one in Indonesia.

The UK Government has also been working with Chinese partners in Guangdong to create a CCS roadmap for the province. This joint work has identified storage capacity in deep geological formations offshore in South China Sea as well as a low-cost full-chain Carbon Capture, Use and Storage pilot. Further work is now ongoing to transfer technical experience from UK industries to Guangdong, including establishing a UK-Guangdong CCS Centre that would build research capability, policy capacity and manufacturing excellence in the province.

B&W begins FEED work for FutureGen 2.0

www.babcock.com

Babcock & Wilcox has signed an agreement with the FutureGen Industrial Alliance to perform full front-end engineering and design (FEED) work on the FutureGen 2.0 CCS project.

The agreement marks the start of the second phase of the three-phase U.S. Department of Energy (DOE)-funded project. The DOE has authorized up to $49 million to fund B&W's Phase 2 engineering and design activities. Construction of the plant would follow in Phase 3, with an anticipated start in June 2014.

B&W Power Generation Group (PGG) will design and supply a boiler island and oxy-coal combustion system, gas quality control system and provide the balance of plant engineering for the first-of-its-kind, near-zero emissions coal-fired plant.

The project's goal is to capture more than 90 percent of the carbon dioxide (CO_2) generated during the combustion process, reducing the plant's CO_2 footprint by more than 1 million tons annually.

"This agreement is an important next step in our progress toward making near-zero-emissions power generation from coal a reality," said B&W PGG President and Chief Operating Officer J. Randall Data.

"We look forward to continuing our relationship with the FutureGen Industrial Alliance, the DOE and the project team in demonstrating the value of carbon-capture technology."

The oxy-coal combustion process - developed by B&W PGG and Air Liquide - uses oxygen mixed with recycled flue gas to replace the normal combustion air in a coal-fired boiler. As coal is burned, the resulting flue gas consists primarily of CO_2, which is well-suited for compression and storage.

The CO_2 captured from the FutureGen 2.0 plant will be transported and stored underground at a nearby storage facility.

California carbon reduction strategy

www.nrdc.org

The only technology that can provide large-scale emissions reductions in EU energy-intensive industries – such as steel, cement, refineries and chemicals – is CO_2 Capture and Storage, says the report.

A report from Tetra Tech and the National Resources Defence Council (NRDC), 'Carbon Reduction Opportunities in the California Petroleum Industry', looks at significant, concrete steps that the California oil industry can adopt today to curb its carbon emissions.

It identified five approaches to reducing carbon pollution directly from the petroleum supply chain:

- Renewable steam generation: using solar power to generate steam for enhanced oil recovery, rather than combusting fossil fuels for that purpose.
- Steam generation with carbon capture and sequestration (CCS): capturing and storing the flue gas emissions from once-through steam generators used in enhanced oil recovery.
- Refinery energy efficiency: enabling refineries to use less energy in their operations.
- Refinery CCS: capturing and storing carbon emissions resulting from the energy-intensive hydrogen processes needed for refining crude oil.
- Renewable refinery feedstocks: displacing part of the refinery's crude oil with renewable-based oils and waste oils.

The report shows that modest adoption of the five carbon reduction technologies identified above could reduce emissions by nearly 3 million to 6.6 million metric tons annually in 2020. Additional opportunities - such as renewable electricity and hydrogen use at refineries, use of other cleaner technologies at oil production operations, and efficiency improvements at crude oil production facilities - could help reduce emissions even further.

Oxy-firing viable for CO2 capture from refineries

A field demonstration project led by the CO2 Capture Project (CCP) has confirmed the viability of the technology for capturing CO2 from oil refineries.

Oxy-firing has been confirmed by CCP as a viable technology from a technical and economic standpoint for capturing CO2 from the main emitting component of refinery operations, the Fluid Catalytic Cracking (FCC) unit. This comes as a result of the completion of CCP's first capture field demonstration, which took place at a Petrobras research facility in Paraná state, Brazil.

The successful test has brought closer a more cost-effective technology capable of capturing up to 95% of FCC CO2 emissions, potentially equating to some 20-30% of emissions from a typical refinery. The project tested start-up and shut-down procedures and different operational conditions and process configurations – allowing the CCP partners to gain reliable data for scale-up.

The refinery is a challenging environment for capturing CO2, with many different operations producing emissions, said the CCP. The FCC unit converts heavy, lower-value hydrocarbon feedstock into lighter, more valuable products and is often the largest single source of CO2 emissions. Traditionally, air is used to regenerate the catalyst, by burning the coke deposited on the surface. In the oxy-combustion mode, air is replaced by pure oxygen, which is diluted with recycled CO2 to maintain thermal balance and catalyst fluidization.

Nigel Jenvey, CCP Chairman said: "This is a significant moment for CCP and the advancement of CCS. Our first demonstration project has successfully met its objectives and proved that oxy-firing is a viable way of reducing CO2 emissions from oil refineries. This project has shown the real value of collaboration by those within the oil and gas industry in order to discover insights and develop technologies that can help cut our own emissions footprint."

The main results from the demonstration are:

• Technical viability was proved with different feed qualities (VGO, ATR) and in two extreme operating conditions (Same Heat Balance, Same Inert Volumetric Flow Rate), with the same or higher product yields

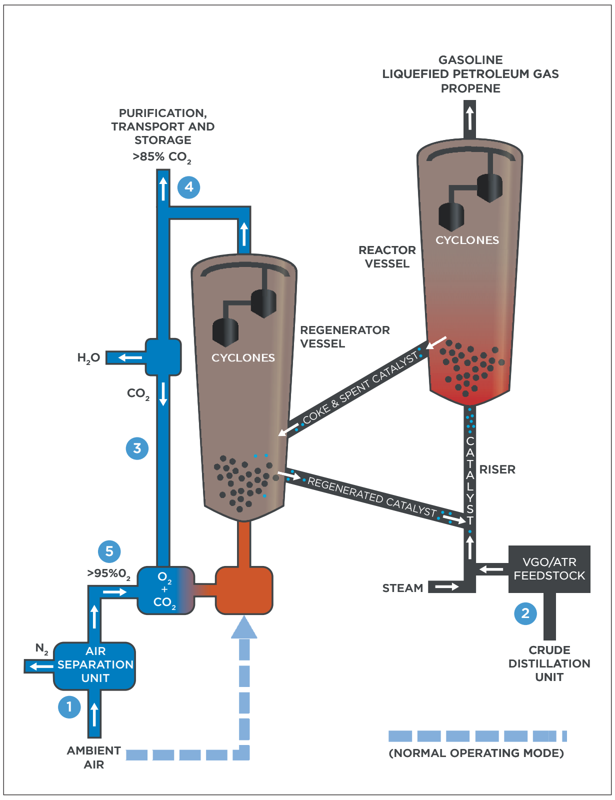
• The purity of captured CO2 reached the target 93-95% under oxy-firing conditions

• Smooth and fast switch between air and oxy-firing through effective monitoring of excess CO2 in the flue gas

• A significant gain in operational flexibility was achieved, meaning the cost of CO2 capture can be somewhat mitigated. This flexibility allows either higher carbon throughput (10% higher flowrate with same conversion) or the processing of lower cost heavier feedstock with the same results

• Catalyst entrainment rates compared to combustion in air varied from lower (Same Heat Balance) to higher (Same Inert Volumetric Flow Rate). An interim condition – Same Solid Entrainment – was also tested delivering the same entrainment as in air operation

• Increase in oxygen partial pressure did not lead to increased catalyst deactivation, thus indicating there will be no need to increase catalyst make-up in full-scale operating conditions. However greater catalyst replacement rate may be needed where higher entrainment rates lead to higher cyclone loading and catalyst loss (most notably when the CO2 recycling rate is above that of the Same Solid Entrainment condition)



Simplified representation of oxy-firing in an FCC unit. Numbers correspond to results achieved (see box below)

• Potential corrosion issues were identified early in the testing due to the presence of NOx and SOx impurities in the flue gas. These are fully understood and are manageable through proper design.

www.co2captureproject.org

Results achieved

1. Effective monitoring of excess oxygen in the flue gas resulted in a smooth and fast switch between air and oxy-firing
2. The difference in physical properties between nitrogen and CO2 enabled flexibility of the plant through two methods – allowing either a higher hydrocarbon throughput (e.g. 10% higher flow-rate with the same conversion) or processing heavier feedstock (i.e. lower cost feeds keeping the same product yield). This flexibility of the plant would help mitigate the cost of CO2 capture
3. Potential corrosion issues were revealed in the recycle system due to the presence of NO2 and SO2 impurities in the flue gas. These issues were fully understood and are manageable through proper design
4. CO2 concentrations reached 93-95% in the tests. Further purification is needed and a dedicated test program may be required for optimization
5. 99.7% O2 concentrations were achieved at the Petrobras research facility through fine tuning the technology and operating mode

Capture and utilisation news

Modular membrane-based CO2 removal system demonstrated

www.mtrinc.com

A National Energy Technology Laboratory supported project has tested a membrane CO2 separation system.

Membrane Technology and Research Inc. (MTR) tested a CO2 separation and capture system designed and developed using its MTR Polaris membrane on a coal gasification slipstream run at the U.S. National Carbon Capture Center.

The Polaris™ membrane system uses a CO2-selective polymeric membrane (microporous films which act as semi-permanent barriers to separate two different mediums) material and module to capture CO2 from a plant's flue gas.The membrane system includesone membrane skid (containing two membrane stages: a sulfur removal unit and a dryer), one heater skid, one compressor skid, and one refrigeration skid (with a condenser to recover liquid CO2).

MTR operated the membrane demonstration system continuously during a run that ended April 21, 2013, processing 500 pounds of syngas per hour. The system successfully produced liquid CO2 at 30 bar continuously for about 500 hours.The captured CO2 stream contained 98% CO2, the balance being light gases such as nitrogen, carbon monoxide, and hydrogen.

Korean researchers develop graphene CO2 separation membrane

www.kcrc.re.kr

A research team at Hanyang University in Seoul, South Korea, has developed an innovative graphene-based membrane material for capturing CO2.

The project, which has secured funding from Korea CCS R&D Center (KCRC) established by the Ministry of Science, ICT and future Planning (MSIP), has demonstrated that some layered graphene and graphene oxide membranes can be engineered to exhibit the desired characteristics for gas separation. The Hanyang University's research team has successfully developed a new graphene based-membrane material with high CO2 selectivity.

"We are pleased with the results of this new membrane material and thank the MSIP and KCRC for their support," said Dr. Ho Bum Park, a professor in the Hanyang University, who leads the study. "Graphene is a distinct two-dimensional material that offers a wide range of opportunities for membrane applications because of ultimate thinness, flexibility, chemical stability, and mechanical strength."

"We focused our research on overcoming the limit of currently available membrane materials by carbon nano-material, i.e. graphene. Especially, technologies relevant to graphene manufacturing allowed us to reach our goal successfully."

Dr. Sang Do Park, a director in the KCRC, said: "While many scientists and engineers have joined the first-class research in this area, there are still gaps in the most technical aspects of CO2 capture membrane technology. The results of his ongoing research clearly show the possibility of manufacturing high-tech membranes with around 5 nm thickness. Furthermore, his membrane demonstrates approximately 1000 times better performance than the commercially available membrane used in separation of the gas targeted in the gaseous mixture. From this study, we are now expecting that this innovative graphene-based membrane can open a new era of Carbon Capture & Sequestration(CCS) technology."

The work has been published in Science (Online) issued in Oct.4.

ION Engineering project receives $15M from DOE

www.ion-engineering.com

The Department of Energy's Office of Fossil Energy will provide $15 million to support a CO2 capture one megawatt equivalent pilot project at Nebraska Public Power District's Gerald Gentleman Station.

ION and partners will contribute another $4 million in matching funds bringing the total to $19 million for the 45-month project. In addition to NPPD, partners include the University of North Dakota Energy & Environmental Research Center (EERC) and the University of Alabama Department of Chemical and Biological Engineering.

Previously, ION has received $5M from DOE-FE to develop its advanced solvent process. During the past year, working in collaboration with the EERC and using their coal- and natural gas-fired Combustion Test Facility, ION says it has demonstrated that its technology is capable of achieving greater CO2 capture rates using less power plant energy relative to other solvent systems currently in development.

"The results obtained at the EERC demonstrate that ION's advanced solvent has the potential to significantly reduce capital costs, operating costs and the parasitic load on an operating power plant that implements ION's technology. When combined with CO2 utilization opportunities such as Enhanced Oil Recovery (EOR), we can imagine a time when the incremental cost of carbon free fossil fuel electricity generation may be much less than previously considered," said ION Engineering CEO, Dr. Alfred "Buz" Brown. "By providing an affordable path to carbon free coal- and natural gas-generated power, we can have a significant impact on reducing carbon emissions worldwide."

"NPPD is interested in the project because our coal burning generating resources bring significant value to our customers," said NPPD Vice President and Chief Operating Officer, Tom Kent. "We also want technologies that can capture CO2 in a cost-effective manner. Testing such technologies should be done on a larger scale to collect 'real world' data. We are pleased to be a participant in this project and hope to learn if the potential exists to capture carbon and advance the technologies in this area for the power industry."

Eco Power Solutions achieves 90% CO2 capture

www.ecopowersolutions.com

The company said its patented CO2 capture technology achieved the result in testing at its Kentucky Technology Center.

The tests were conducted using its MP-AQCS (Multi-Pollutant Air Quality Control System) Reactor Module which captures other pollutants as well as CO2, although the CO2 Capture Module can be fitted independently also.

The process is patented by Eco Power Solutions and is capable of capturing up to 90% of CO2 emissions from coal, natural gas and other fossil fuel based plants. ?The projected cost is $20-$30 per ton of CO2 captured depending on the application.

Shell Cansolv and Technip join for CO2 capture services

www.cansolv.com
www.technip.com

The two companies will offer full chain engineering, procurement and construction (EPC) services for post-combustion CO2 capture to the power generation industry.

Technip is a world leader in project management, engineering and construction for the energy industry. and the cooperation will expand Shell Cansolv's international reach by giving the company a platform to offer its CO2 capture technology in increased scope as well as to new markets.

Earlier in 2013 Cansolv captured the first tonne of carbon dioxide at itsjoint demonstration plant at Aberthaw Power Station in the UK. The project with RWE npower is the world's first integrated sulphur dioxide (SO2)/CO2 capture plant.

Advanced Emissions Solutions progresses on carbon capture research

www.advancedemissionssolutions.com

The company has been awarded two R&D contracts by the DOE to reduce carbon capture costs and investigate a new sorbent technology.

Advanced Emissions Solutions is working on a $20.5 million DOE program supporting the development of its regenerable solid-sorbent based carbon capture technology. Construction of a 1MW Pilot Plant has been completed and it has been transported by barge to the Southern Company Alabama Power Plant Miller where it is being installed for testing in 2014.

In addition, the company was recently awarded two new DOE programs with a total combined value of $1.6 million. One program will be focused on reducing operating costs of a carbon capture plant based on its technology by managing energy demands and recovering heat from other processes. The second program is focused on evaluating a sorbent made with aerogels, a material that has significantly different thermal properties than other sorbents. Both programs are designed to enhance the energy efficiency of the carbon capture process.

HTC technology selected for CO2 capture plant

www.htcCO2systems.com

HTC CO2 Systems Corp. has been selected to build the CO2 capture unit at Husky Energy's Pikes Peak South heavy oil facility in Saskatchewan, Canada.

HTC's LCDesign™ CO2 capture unit is designed to process 50% of the flue gas from a 50 million BTU per hour natural gas fired, once through steam generator ("OTSG") boiler located at the Pikes Peak South facility, near Lashburn. The CO2 will be used to increase heavy oil production through enhanced oil recovery techniques. The LCDesign system incorporates CO2 capture technology that reduces energy usage, lowers environmental emissions/effluents, and improves the quality of CO2 product captured, says HTC.

The project will also incorporate HTC's proprietary and patented SRS Solvent Reclaimer System™. The SRS System has been designed to remove the impurities from mixed and formulated solvents used to capture CO2 and in turn reduces solvent replacement requirements, lowers energy costs, minimizes plant maintenance and reduces waste disposal.

Jeff Allison, Senior Vice President of HTC commented, "OTSG's are the work horse and backbone of heavy oil enhanced production through cyclic/incremental steam or Steam Assisted Gravity Drainage ("SAGD") production processes. These steam boilers are also utilized for producing steam for the in-situ production of oil sands bitumen.

Capturing CO2 for commercial application and emissions reduction purposes on the many hundreds of OTSG boilers currently operating in Western Canada represents a significant future business opportunity. HTC is anxious to showcase how our commercially viable, cost effect solution for capturing CO2 and increasing heavy oil production can meet the challenge."

Transport and storage news

CO2 Stored gets new mapping tool

www.co2stored.co.uk

The upgrade improves access to information contained in CO2 Stored on storage sites under the UK seabed, enabling users to find out about storage locations, their characteristics and their storage capacity.

The Crown Estate and the British Geological Survey have launched a new online mapping tool for the CO2 Stored website.

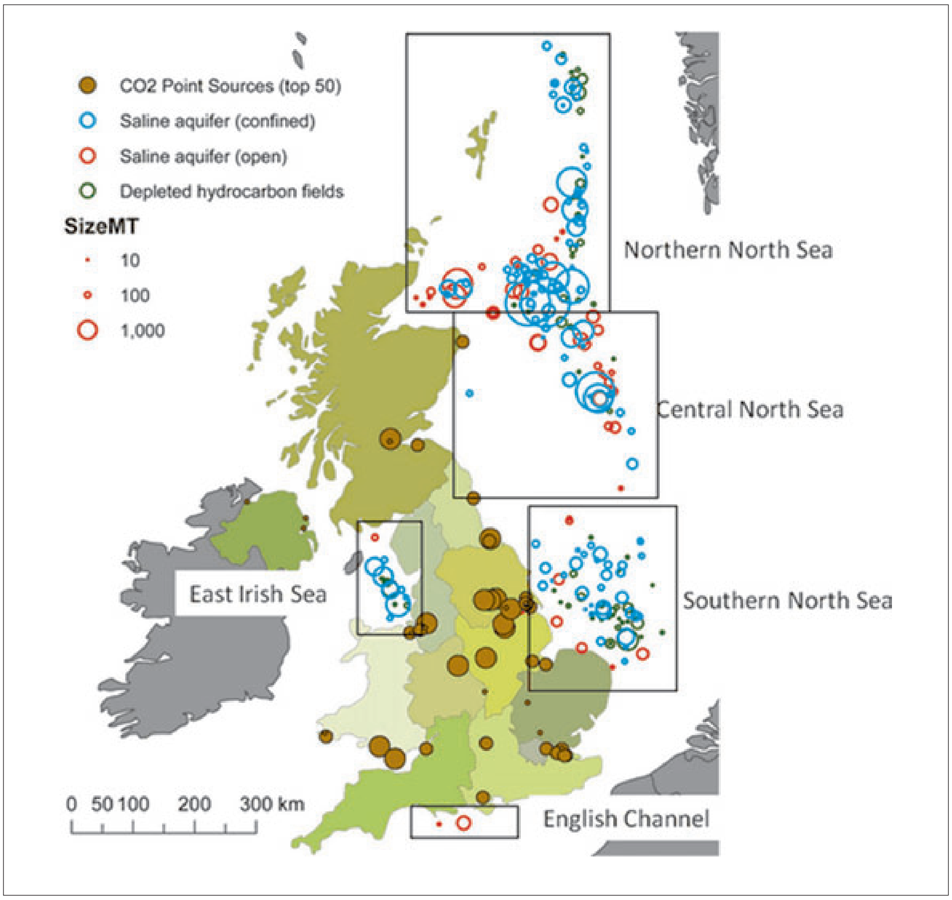
Through search and display functions the data can be sorted in a number of ways, including by:

• geological formation

- name of hydrocarbon (oil or gas) production area

• key attributes about the geological storage such as porosity, injectivity, fracture pressures and storage risks.

Stuart Haszeldine, Professor of Carbon Capture and Storage, University of Edinburgh said: "The new feature on CO2 Stored is a great step forward in making knowledge about UK geology deep beneath the North Sea available for investigating options for commercialising CO2 storage. All companies with subsurface expertise can now more easily access evidence-based knowledge which can make their evaluation of CO2 storage quicker and more accurate."



Major offshore areas covered by CO2 Stored (© Energy Technologies Insititute)


carbon capture journal
PLAY ON CO2 MOLECULE.
HOVER ABOVE POWER STATION IN CLOUD OF SMOKE. MISS A TURN.
FLOAT FREE INTO ATMOSPHERE, BE BREATHED IN BY SUPERMODEL. ROLL AGAIN.
BURNED AND SWIRLING IN SMOKE FROM KITCHEN FIRE. GO TO 58.
SPEND TIME AS EXHAUST FUMES. MISS A TURN.
FORMED INTO DRY ICE FOR PARTY. GO FORWARD 2 PLACES.
SPEND TIME IN FACTORY SMOKE. GO BACK 2
ARE PRESENT IN BAD HALITOSIS. GO BACK 1 SPACE.
PRESENT IN FIZZY DRINK! ROLL AGAIN!
ENJOY PHOTOSYNTHESIS IN OFFICE PLANT. GO FORWARD 5.
ENJOY PHOTO-SYNTHESIS IN VEGETABLE GARDEN. GO TO 29.
ENJOY PHOTO-SYNTHESIS IN LARGE DRUG PLANTATION. ROLL AGAIN.
ENJOY PHOTO-SYNTHESIS IN AMAZON GO TO 58.
22 PHOTO-SYNTHESISED IN ORANGE GROVE. VITAMIN C! GO FORWARD 10.
BREATHED OUT BY MAN. GO FORWARD 2
BREATHED IN BY WOMAN! GO FORWARD 2!
BURPED OUT BY MAN.
BREATHED IN BY CCS DELEGATE ON WAY TO CONFERENCE! ROLL AGAIN!
BURPED OUT SILENTLY. GO BACK TO 23.
TRAVEL ABOUT TUBE TRAIN IN BODY ODOUR. GO BACK 1.
TRAVEL ABOUT IN CONVERSATION AT CCS CONFERENCE. GO FORWARD 2.
WAFT ABOUT. ROLL AGAIN.
PASS BETWEEN TWO FLIRTATIOUS DELEGATES. GO FORWARD 2.
GET MIXED UP IN HOT DEBATE! GO FORWARD 5.
GET METABO-LISED BY PARTY POOPER. GO BACK TO 37.
WAFT ABOUT AFTER DINNER IN BURPS. MISS A TURN.
TRAVEL IN JET STREAM. FEEL GREENHOUSEY. MISS A TURN.
TEETER ON EDGE OF OZONE HOLE. MISS A TURN.
EXPERIENCE FREEDOM VIA AIR CONDITIONING ROLL AGAIN.
FEEL HOT AND GREENHOUSEY. MISS A TURN.
GO UP INTO ATMOSPHERE. ROLL AGAIN
TRAVEL IN WIND ACR DESERTIFIED LANDS BREATHED IN BY ENDANGERED CREA GO FORWARD
IN FINAL OF RARE CR HABIT DESTRO GO TO
DECOMPOSIT GO FORWAR
STOP AGAIN. EV
START

FIND SELF PART OF AQUISTORE PROJECT. GO TO FINISH.
SEISMIC DATA REQUIRING ANALYSIS HOLDS BACK PROJECT. MISS A TURN.
EXPERIENCE THE WONDER OF THE PETERHEAD CCS PROJECT. GO FORWARD 2.
ESCAPE THROUGH LEAK. GO BACK TO START.
AIR AND WATER SAMPLING. MISS A TURN.
FEEL LIKE JAMES BOND ON THE GOLDENEYE PLATFORM. ROLL AGAIN.
SPEND TIME IN AN ENHANCED OIL RECOVERY SITUATION. GO FORWARD 2.
SPELL DECARBONISE BACKWARDS. WITH YOUR EYES SHUT.
IN GAS GETTING TESTED AT MONGSTAD. FEEL THE WONDER OF PROGRESS. ROLL AGAIN.
LEAK DETECTED. GO BACK TO 57.
EXPERIENCE RUSH AS YOU ENTER PIPELINE. GO TO 60.
INJECTED INTO DEPLETED WELL. GO FORWARD 2.
FEEL EXCITED ABOUT BEING IN A PROJECT RUN BY SOMEONE CALLED GARY COOPER. ROLL AGAIN.
HAZARDOUS SUBSTANCES ASSOCIATED WITH AMINE EMISSIONS BLIGHT PROFILE OF CCS. GO BACK TO 78.
EXPERIENCE WONDER OF BOUNDARY DAM CCS PROJECT.
PASS THROUGH SALINE AQUIFER. GO FORWARD 2.
ASSIST HYDRO-CARBON RECOVERY GO FORWARD 2.
WAFT THROUGH CONSULTATION MEETING AT DRAX POWER STATION. FEEL THE WONDER OF PROGRESS. ROLL AGAIN.
PLUME STEADY. ROLL AGAIN.
REACT WITH DISSOLVED MINERALS. RESULT! ROLL AGAIN!
FEEL GOOD ABOUT BEING IN A PROJECT CAPABLE OF STORING 600BN TONNES OF CO2. GO TO FINISH.
ARE IN BREATH EXCHANGED IN CONVERSATION BY PEOPLE WHO WOULD WORK ON CONSTRUCTION SHOULD IT GO AHEAD. FEEL GOOD. GO TO 105.
EXPERIENCE THRILL OF ENTERING SLEIPNER CCS PROJECT. ROLL AGAIN.
ESCAPE THROUGH LEAK. GO BACK TO START.
DEEP SALINE CAPTURE SUCKS YOU UP. GO TO FINISH
SPELL BIOGEOCHEMICAL BACKWARDS. EYES SHUT.
STAY TRAPPED IN ROCK. GO FORWARD TO 110.
WAFT THROUGH IN SALAH PIPELINE. GO TO 109.
GEOLOGY TESTING HELD UP. MISS A TURN.
SPELL GEOENGINEERING BACKWARDS. EYES SHUT.
WAFT ALONG GIANT SNOHVIT PIPELINE TOWARD BARENTS SEA FIELD. GO TO FINISH.
LEAK DETECTED. GO TO 75.
SPELL SEQUESTRATION BACKWARDS, WITH YOUR EYES SHUT.
FINISH!