carbon capture journal

Review of 2013

KEPCO's new pilot plant

Algae biomass for CCS

UK CCS Research Centre

The importance of CCS for renewables

Jan / Feb 2014 Issue 37

CCS in the UK - an interview with the Carbon Capture & Storage Association

ZERO - policy instruments for large-scale CCS in Europe

How to unlock potential storage in the UK North Sea

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TCM is the world's largest and most advanced facility for testing and improving CO2 capture, and is a joint venture set up by the Norwegian state (75.12 %), Statoil (20 %), Shell (2.44 %) and Sasol (2.44 %).

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United House, North Road, London N7 9DP
www.carboncapturejournal.com
Tel +44 (0)207 017 3405
Fax +44 (0)207 251 9179

Editor
Keith Forward
editor@carboncapturejournal.com

Publisher
Karl Jeffery
jeffery@thedigitalship.com

Subscriptions
subs@carboncapturejournal.com

Advertising and Sponsorship
Richard McIntyre
Tel +44 (0)208 150 5296
rmcintyre@onlymedia.co.uk

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Front cover: Korea Electric Power Company's 10 MW wet CO2 capture plant is capable of capturing, with CO2 removal rate of more than 90%, approximately 70,000 tons of CO2 per year. It is a pilot-scale CO2 capture plant applied for the first time to coal-fired power plants in the Republic of Korea.

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Carbon Capture Journal Review of 2013

Several projects began capturing CO2 in 2013, and China included CCS in its Five Year Plan. However progress was still slow and the total number of large-scale integrated projects dropped by ten to 65, with only three new projects identified.

January

IEA says carbon capture delayed by high costs and poor policies - high costs and a lack of policy incentives are delaying the development of large scale CCS technologies, the International Energy Agency warns

First tonne of CO2 captured at RWE nPower pilot project - the carbon capture pilot plant at Aberthaw Power Station in Wales, UK begins operations with live flue gas, successfully capturing its first tonne of CO2

Carbon tax cost killed off ScottishPower's Longannet CCS plan - the UK Government's upcoming tax on carbon emissions was one of the key reasons behind the collapse of the Longannet carbon capture project, after the tax added around £250 million to the cost

Air Products' Texas large-scale industrial project begins carbon capture - the project in Port Arthur, Texas has begun capturing CO2 and piping it to an oilfield for use in enhanced oil recovery

Aberthaw Power Station in Wales, site of the RWE nPower carbon capture pilot that began capturing CO2 in January

February

TCM launches CCS test centre network - CO2 Technology Centre Mongstad forms an international test centre network for carbon capture test facilities around the world to share knowledge to accelerate the commercialisation of the technology

DNV KEMA launches new risk management guidance for the CCS industry - using the guidance will help gain public confidence that CCS can be delivered in a safe and responsible manner

FutureGen 2.0 moves to Phase II - the U.S. Energy Department moves to the next stage of project development with a new cooperative agreement with the FutureGen Industrial Alliance

DNV, PSE develop maritime carbon capture and storage - classification society Det Norske Veritas and process modelling firm Process Systems Enterprise develop a concept design for on-board capture, liquefaction and temporary carbon dioxide storage for ships in transit

UK Carbon Capture and Storage Research Centre launches RAPID research projects - the UKCCSRC offers funding to 11 research projects totalling £1.65 million

March

Swan Hills Synfuels project discontinued - the Alberta government and Swan Hills Synfuels agree to discontinue their $285 million CCS funding agreement as the project is put on hold

New EU carbon storage funding round to be launched - the European Commission launches a new contest to fund carbon capture and storage projects after an earlier round failed to find a winner

Preferred bidders announced in UK's £1bn CCS Competition - they are the Peterhead Project in Aberdeenshire, Scotland, and the White Rose Project in Yorkshire, England

Air Products' Port Arthur CO2 capture facility in Texas has begun capturing CO2 (Image courtesy of Air Products and Chemicals, Inc.

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April

Tauron Poland Energy to begin a pilot CO2 capture installation - Tauron, the first energy company in Poland to conduct research on CO2 capture from flue gases, opens a mobile pilot CO2 capture installation in the Laziska power plant

PGE ends Polish CCS project - the utility PGE Group cancels Poland's only planned carbon capture and storage project after it failed to receive money in the first round of the European Commission's clean energy funding competition

May

Aker Solutions to perform tests of cement industry CO2 capture - the company will test and study the capture of carbon dioxide from flue gas emitted by the cement industry at Norcem's plant in Brevik, Norway

South Korea carbon capture plant begins operating - South Korea opens its first carbon capture facility at a thermal power plant

June

Taiwan inaugurates advanced carbon capture plant - the plant is the largest to employ the calcium looping process to capture CO2

UK offshore CO2 storage database launched - the UK CO2 Storage Evaluation Database, CO2 Stored, is developed by the British Geological Survey and The Crown Estate

Heriot-Watt University launches full chain CCS research centre - the Centre for Innovation in Carbon Capture and Storage will study the entire carbon capture and storage chain

China launches first carbon market in Shenzhen - China's first domestic transaction in the right to discharge carbon dioxide occurs at the launch of its first pilot carbon market

July

CO2CRC: celebrating ten years of CCS research - the Cooperative Research Centre for Greenhouse Gas Technologies celebrates ten years of achievement and scientific excellence in CCS research and development

USGS releases national CO2 sequestration assessment - the U.S. Geological Survey concludes that the United States has the potential to store a mean of 3,000 metric gigatons of carbon dioxide in geologic basins

State of play on geological storage of CO2 in 28 European countries - the report gives a brief overview of the CO2 storage options, potentials and capacities in Europe

CO2 Capture Project launches CCS Browser - the CCS Browser is a multi-format digital resource aimed at helping the public learn about CCS

The EDF power plant in Le Havre, France is testing Alstom's carbon capture technology

First CO2 captured in ADEME, Alstom and EDF project - the first tonne of CO2 is captured at the EDF power plant in Le Havre, France

CCSNET: new drive for Australian carbon reduction research - led by CO2CRC, CCSNET is a new network of CCS research facilities aimed at boosting Australian development of commercial scale CCS technology

ICO2N report puts numbers to using CO2 for enhanced oil recovery - a new report analyzes the onsite and downstream GHG emissions from using CO2 for enhanced oil recovery

Skyonic secures $128M for CCS plant - the money supports the construction of the world's first commercial- cale carbon capture and mineralization plant, located in Texas

MRCSP begins field tests in Michigan - Battelle has announced the beginning of large scale CO2 injection by the Midwest Regional Carbon Sequestration Partnership program in the oil fields of Michigan

Australia moves closer to link with EU ETS - Prime Minister Kevin Rudd announces the Australian government's plans to replace a tax on carbon emissions with a market-based trading system a full year ahead of original plans to do so

UK survey finds public largely unaware of CCS - a three year research project has found the British public to be vastly unaware of both the technological aspects of CCS as well as its role toward a low-carbon society

August

Akermin pilot completes 1600 hours of CO2 capture - the pilot plant using biocatalytic technology completes 1,600 hours of operation capturing CO2 from the flue gas exhaust of a coal-fired power plant.

National Grid completes test drilling for North Sea CO2 storage site - National Grid successfully completes test drilling of a carbon dioxide storage site in the North Sea

Linde to build Saudi carbon capture and use plant - Saudi Basic Industries hires Germany's Linde Group to build the world's largest plant for capturing and using carbon dioxide

September

Oxy-firing viable for CO2 capture from refineries - a field demonstration project led by the CO2 Capture Project confirms the viability of the technology for capturing CO2 from oil refineries

Carbon capture and storage to be monitored by cosmic rays - UK scientists work with Nasa to develop new 'passive' methods for cheap monitoring of deep carbon repositories

Norway strengthens capture research at TCM - despite the cancelling of a full-scale test at Mongstad, CO2 capture research receives additional funding.

HTC technology selected for CO2 capture plant - HTC CO2 Systems is selected to build the CO2 capture unit at Husky Energy's Pikes Peak South heavy oil facility in Saskatchewan, Canada

EPA won't require carbon capture at existing coal plants - U.S. EPA announces new source performance standards

Skyonic Capitol SkyMine project breaks ground - Toyo Thai-USA Corporation starts construction on the largest commercial carbon capture and utilization plant in the U.S.

China and United Kingdom announce collaboration on CCUS - scientists and engineers from China and the United Kingdom form an initiative for research, development and demonstration of CCUS technologies

October

Progress still too slow says Global Status of CCS report - releasing The Global Status of CCS: 2013 report Global CCS Institute CEO Brad Page calls for a renewed focus on the significance of CCS in the portfolio of low carbon technologies required to deal with climate change

Boundary Dam carbon capture project over budget but on time - SaskPower says its carbon capture and storage project at the Boundary Dam power station near Estevan is about $115 million over bugdet but on schedule to be completed in early 2014

Tebodin wins order for carbon capture project in Abu Dhabi - Abu Dhabi Future Energy Company, also known as Masdar, initiates a carbon capture and storage project

November

DOE supports 18 projects to drive down costs of CCS - the U.S. Department of Energy selects 18 projects to research technologies that will help improve the efficiency and drive down costs of carbon capture for coal-fired power plants

Iberdrola reports on project using lasers to capture CO2 - the SIGMA project is developing a new system that will almost completely eliminate atmospheric emissions from electricity generation power plants and industrial facilities

Algae to absorb power station emissions - researchers from the University of Kentucky Center for Applied Energy Research demonstrate a system that uses algae to absorb carbon dioxide emissions at Duke Energy's East Bend power station in Northern Kentucky

Hitachi carbon capture test facility construction begins - Hitachi's Carbon Capture Test Facility at SaskPower's Shand power station is expected to be operational by the end of 2014

SaskPower's Boundary Dam project is on schedule despite delays and cost overruns - the image shows flue gas ducting running to the carbon capture plant (©Mark Greschner)

December

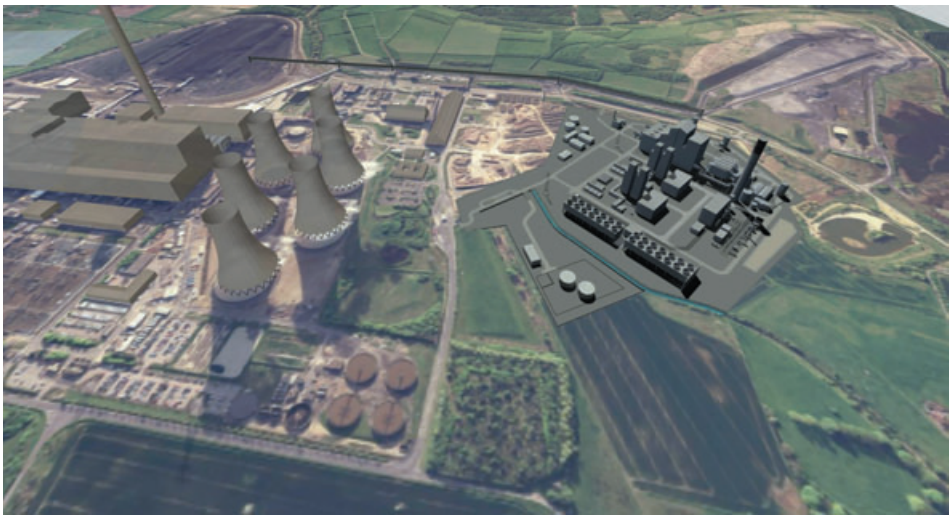
UK Government funds White Rose project FEED study - Capture Power, the consortium of Alstom, Drax and BOC, is awarded a Front End Engineering and Design contract for the White Rose CCS Project next to the Drax power station

NOK 100 million for pan-European carbon capture lab at NTNU - the Norwegian Government allocates €12 million to upgrade laboratories at the Norwegian University of Science and Technology for an EU research project on carbon capture and storage

$8B available for carbon capture, other advanced fossil energy projects - the Department of Energy makes available $8 billion in loan guarantee authority to support advanced fossil energy projects

EPA publishes carbon capture regulations - a final Environmental Protection Agency rule is meant to remove potential obstacles in the implementation of carbon capture and sequestration technology

Tees Valley City Deal supports industrial CCS - the UK Tees Valley region receives £1 million Government funding to help promote the technology and investigate the development of CCS infrastructure



An indicative illustration of Drax Power Station (left) and the White Rose Carbon Capture and Storage Project (right)

Korea's new pilot plant

KEPCO has constructed a 10MW post-combustion wet amine CO2 capture plant which is now operational testing the company's proprietary solvent.

By Ji Hyun Lee, Senior Researcher, Technology Commercialization Office, Korea Electric Power Research Institute

Coal-fired power generation is an attractive source of power in terms of electricity generation cost. Still, its critical weak point is greenhouse gas emission, cited as the main culprit of global warming. In the Republic of Korea the importance of thermal power generation is increasing due to the rapidly growing electricity demand.

According to the 6th Basic Plan of Korean Government for long-term electricity supply and demand for 2013 ~ 2027, 25 units of coal-fired power plants will be constructed by 2027. In such case, coal-fired power plants will account for approximately 35% (peak load basis) of the entire power-generating facilities. As the percentage of coal-fired power generation as the source of electricity increases, there are growing concerns over environmental problems including global warming resulting from greenhouse gas emission. Cognizant of such concerns, the government of the Republic of Korea also aims to reduce CO2 emissions by 30% in 2020.

According to this plan, the government departments of the Republic of Korea including the Ministry of Commerce, Industry, and Energy commenced the process of developing various CCS (Carbon Capture & Storage) technologies. In connection with the development of CCS technologies, Korea Electric Power Company (KEPCO), Korea's leading energy & power company, is leading the development of CO2 capturing technologies. In particular, the wet scrubbing CO2 capture technology using amine solvents is rated world-class in terms of performance and plant scale.

KEPCO together with it's 5 subsidiary power companies has been carrying a CO2 capture project, KoSol Process for CO2 Capture (KPCC), from 2008. The overall aims of this project are:

1. To develop a Korean amine based solvent with a regeneration of at least 30% less than that of MEA.

2. To demonstrate post-combustion CO2 capture technology at a coal fired power station starting with a 0.1 MW test bed and progressing to a 10 MW pilot plant.

The first stage of the research, which was completed 3 years ago, used a 0.1 MW test bed to demonstrate the performance of the proprietary solvent while the second

Figure 1 - the 0.1 MW scale post-combustion CO2 capture plant

stage, which recently started aims to further reduce the costs of capture by applying the capture technology in a 10 MW pilot plant. A commercial scale demonstration is planned to commence in the 2015-2020 timeframe.

During 2008-2011, to experiment on the performance of the KEPCO's proprietary solvent (KoSol) and CO2 capture process under the emission conditions of coal-fired power, KEPCO Research Institute constructed a 0.1 MW test bed capable of treating 2 tons of CO2 per day at the Boryeong power stationi of Korea Midland Power Co., Ltd., and started operating it in 2010.

Long-term, non-stop continuous operation for 1,000 hours (from April 2 to May 14, 2011) was done for the first time in Korea. Through such operation, KEPCO was able to demonstrate that their proprietary solvent KoSol-3 was able to capture more than 90% of the CO2 from the slipstream and at a purity of more than 99%. The regeneration energy for this solvent was between 3.1 and 3.3 GJ/ t CO2 – which is about 20% lower than the regeneration energy for MEA.

Based on those achievements, A 10 MW post-combustion wet CO2 capture pilot plant, the biggest scale in the Republic of Korea, was constructed on Unit 8 of the Boryeong power station of Korea Midland Power Co., Ltd. Boryeong power station is located approximately 150 km southwest of Seoul and consists of 2*500 MW and 6*500 MW supercritical units fired on bituminous coal and 9*150 MW combined cycle power plant (total generating capacity : 5,358 MW).

Currently, test operations are being carried out for the optimization of process. The 10 MW wet CO2 capture plant is capable of capturing (with CO2 removal rate of more than 90%) approximately 70,000 tons of CO2 per year. It is a pilot-scale CO2 capture plant applied for the first time to coal-fired power plants in the Republic of Korea.

The plant was constructed between March 2012 and May 2013. KEPCO's proprietary solvent KoSol-4 is used in this pilot plant and aims to capture more than 90% of the CO2 from the slipstream at a purity in excess of 99%. The pilot plant began operating on Friday 24 May 2013. The project is financially supported by the Korean Government and participating companies, including KEPCO, KOMIPO, KOSEP, KOWEPO, KOSPO, EWP, POSCO E&C, POSCO Engineering, Daelim, and KEPCO E&C.

Figure 2 - the 10 MW scale post-combustion CO2 capture plant

Also it has plans to re-use the captured high purity CO2 in the fields of precision welding and cultivation of agricultural products after 2014. From this, the company expects to reduce CO2 by up to 70,000 tons and save approximately 3.1 million USD on expenses. Korea Electric Power Company and 5 power companies plan to realize the best performance for the solvents (KoSol) developed by KEPCO Research Institute through the aforesaid project, gain process reliability through long-term continuous operation, and secure basic design data to upgrade to demonstration (100 ~ 500 MW) power plant.

The final goals of this project are:

1. To develop the amine-based CO2 capture technology with regeneration energy of below 2.8 GJ/tCO2 (with CO2 removal rate of more than 90%) from the continuous operation of the CO2 capture plant (over 1,000 hours)

2. To keep the cost of CO2 below 30 USD/tCO2.

Currently, the results of the initial operation of 10 MW CO2 Capture plant using KEPCO's proprietary solvent KoSol-4 showed stable operation and excellent performance, which satisfied the expectations of the research staff. Thus, if further research is carried out in the future on key process improvement and optimization, achieving the aforementioned research goals seems affirmative.

More information

www.kepco.co.kr

Completing the chain - a new age for Carbon Capture and Storage Research?

The recently founded UK Carbon Capture and Storage Research Centre links together over 200 researchers working in a diverse range of complementary projects. Jon Gibbins, Principal Investigator at the Centre, describes some of the work that is going on.

The challenge for CCS research capacity developers

While not progressing as fast or as smoothly as many had hoped, carbon capture and storage (CCS) delivery is moving quite rapidly, from mostly theory in the last years of the 20th century to 100 - 1000 GW power plants and also substantial deployment in other sectors in the second decade of the 21st.

Progressing CCS research to match this move to full-chain CCS project deployment raises difficulties, as well as opportunities, for the strategic planners in all CCS research organisations. This article describes some of the ways the recently-established UK Carbon Capture and Storage Research Centre (UKCCSRC) is responding. But there is always more that can be done, so if readers want to share relevant experiences, or even better collaborate, please get in touch!

Approximately 200 UK academic researchers working in the field of CCS have linked together in this virtual centre during its first 20 months of growth and it is still welcoming more. The range and diversity of the activities currently grouped together as 'CCS' also means that many other people will be undertaking research on topics that are, or will be, fundamental underpinning knowledge for aspects of CCS that they are not aware of or that may not, yet, have happened! An attempt to illustrate the breadth of possible topics for CCS activity, and hence related R&D, is shown in Figure 1.

The range of complementary ways in which fundamental knowledge can contribute is shown in Figure 2. In the longer run natural attrition between technologies may lead to some of the branches shown in Figure 1 withering, but the feedback loops to and from the research end of the technology delivery funnel in Figure 2 are expected to increase very rapidly to compensate.

To date there has been a reasonable expectation that fundamental CCS research will either:

(i) be relatively high-level exploration of a range of novel issues, with key outputs often intended to inform policy makers, or

(ii) be on the early stages of development for novel technologies.

In both cases there is an inevitable ten-

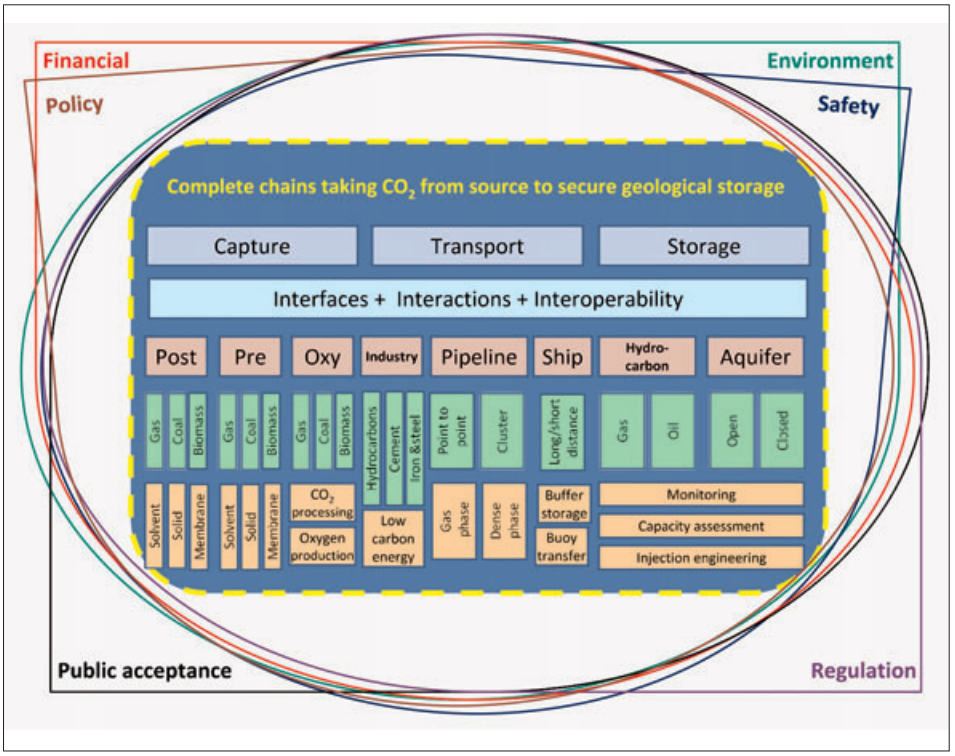


Figure 1 - CCS activities - a (partial) range of topics for implementation and research

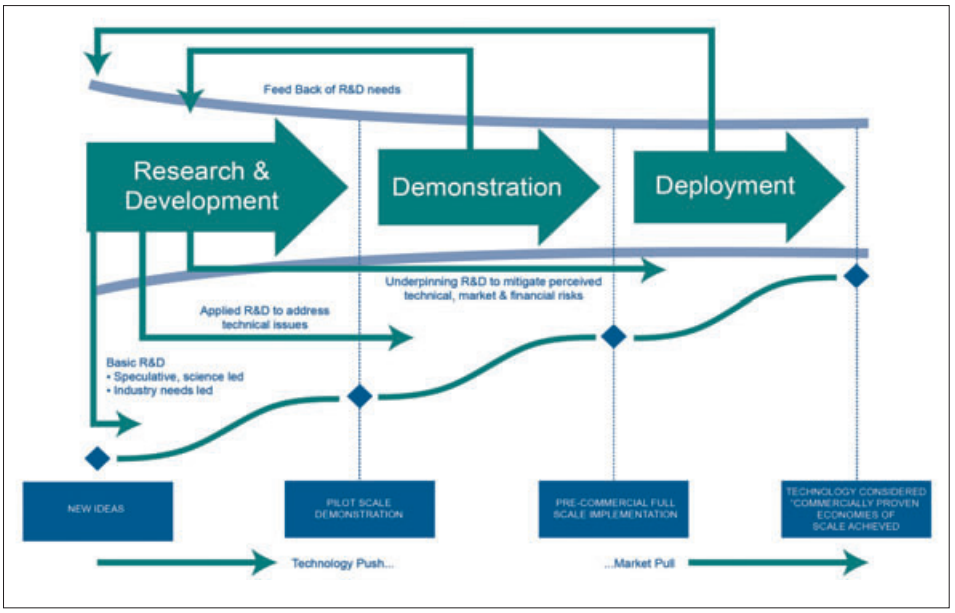


Figure 2 - the energy innovation process[2]

1. Initial core funding for the UKCCSRC is provided by £10M from the Engineering and Physical Sciences Research Council (EPSRC) as part of the Research Councils UK Energy Programme, with £2.5M in match funding from Centre partners. This is complemented by £3.3M in additional funding from the UK Department of Energy and Climate Change (DECC) to establish new capital facilities that will support innovative research.
2. www.energyresearchpartnership.org.uk

dency to focus on a limited range of issues rather than the more complex multidisciplinary mix of factors that determine successful and cost-effective technology application in practice.

The strategic challenge facing academic CCS research at present is therefore to get an understanding of 'real world' CCS deployment issues, in order to maximise future impact for ongoing research and human and infrastructure capacity development, as much as possible in advance of full-chain CCS deployment (i.e. before easy learning-by-doing opportunities exist) and certainly following on rapidly otherwise.

Within the UKCCSRC a number of complementary strategies are being used to meet this need to look ahead as much as possible, including:

A. Bringing together the best available mix of academics and other stakeholders to collectively and systematically identify what knowledge is required to deliver CCS, what options could be used to develop this capacity and what pathways can be used to ensure that research and capacity development has actual impact, through the UKCCSRC RAPID process;

B. Getting as much exposure to larger-scale pilot plants and trial storage injections for the UK academic community as possible, including development of the UKCCSRC PACT facilities and links with other relevant facilities within the UK and overseas;

C. Seeking to establish the closest possible links with relevant full-scale CCS projects and the people who are, or will be, developing, building and operating them (anywhere in the world since there are currently so few opportunities).

Research and Pathways to Impact Development Process

Although it appears complex, Figure 1 is still very far from describing CCS activities and associated knowledge requirements in sufficient detail to define research and capacity development. The first activity by the UKCCSRC was therefore to start much more detailed work on 'Research and Pathways to Impact Development', RAPID.

The first phase of the RAPID process, which involved mixed workgroups of academics, industrialists and other stakeholders, considered the questions posed in Table 1. The answers they came up with are in a 163 page report on the UKCCSRC website but this can still only be a preliminary work in progress, with the contents in many areas yet to be confirmed when, and if, practitioners who have had actual experience are available.

Phase 1 of RAPID was completed in mid-2012, and informed the first round of research projects funded by the Centre. As illustrated in Figure 3, 13 research projects have been awarded £2.2 million to address a broad range of CCS topics. Phase 2 of RAPID began in late 2013, and is focusing on knowledge sharing and capacity development.

It is expected that a revised RAPID handbook incorporating the key insights from this phase of work will be available in mid-2014.

RAPID area	Key questions to be addressed
A. **Application Impact Tables and Research Summaries**	• What knowledge and related capacity will be needed to implement CCS? • To what extent is necessary knowledge and capacity already available to users?
B. Research and Knowledge Activities	• How can gaps in knowledge be met?
X. Knowledge delivery/sharing activities	• Who is using academic outputs/information? • How is information made available to users? • What are our sources of knowledge exchange?
Δ. Capacity development and delivery	• What UKCCSRC-related capacity is required? • How can this be created, maintained and delivered?

Table 1 - the UKCCSRC's RAPID approach

Pilot-scale Advanced Capture Technology Facilities and storage trials

The PACT (Pilot-scale Advanced Capture Technology) facilities were established concurrently with the UKCCSRC in 2012, with £3.3M financial support from the UK Government Department for Energy and Climate Change to the PACT partners and £1.75M from the EPSRC (UK Engineering and Physical Sciences Research Council) via the UKCCSRC.

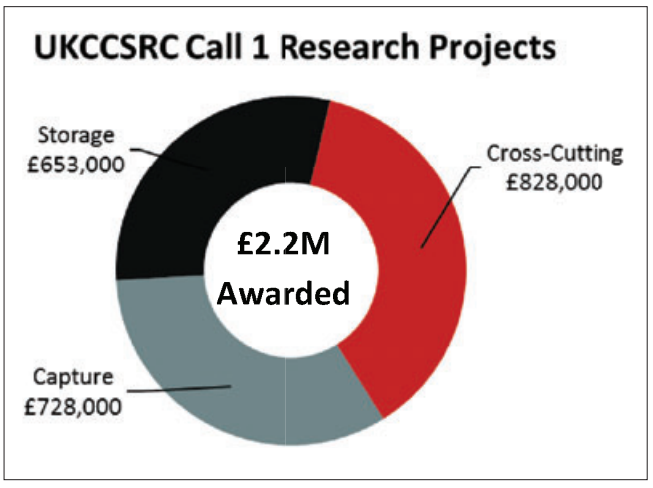


Figure 3 - breakdown of funding awarded in first round of UKCCSRC research projects

The PACT facilities form part of the UKCCSRC, and are a collaborative activity between the Universities of Cranfield, Edinburgh, Imperial College, Leeds, Nottingham and Sheffield. The PACT partners aim to support and catalyse industrial and academic R&D to accelerate the pilot scale development and commercialisation of novel technologies for carbon capture and clean power generation.

The PACT facilities are an important national-scale piece of research infrastructure. Facilities include combustion, gasification and carbon capture, using fossil fuel and bioenergy feedstocks and for both power generation and industrial applications. The core facilities are situated in Beighton near Sheffield, and there are satellite facilities in Cranfield and Edinburgh4. Some illustrative examples are shown in Figure 4. Overall, the facilities bring together a comprehensive range of integrated pilot-scale and accompanying specialist research and analytical facilities, supported by leading academic expertise. They bridge the gap between bench-scale R&D and industrial pilot-scale, providing important opportunities for researchers at all career stages to gain exposure to and experience of CO2 capture technologies operating in a 'real world' environment.

Large scale CO2 pilot injection trials are more difficult to arrange in the UK, with most suitable formations offshore. The immediate UKCCSRC strategy is therefore to

seek to partner with trials overseas. As an example, a group of UKCCSRC members from 6 different institutions visited Australia in November 2013 to explore the very exciting scope offered by CO2CRC's Otway project.

Additionally, the Centre has strong links to Europe and is working to develop formal partnership with a number of existing CCS projects and networks. For example, the Centre is investing significant resources in supporting European networks (particularly the European Energy Research Alliance – EERA) and is working to maximise UK academic participation in European CCS activities and programmes, including Horizon 2020.

Developing links with relevant full-scale CCS projects

The UKCCSRC approach to developing international partnerships combines both strategic and responsive engagement, with the aim of developing and facilitating "best with best" collaborations that will expand opportunities available for UK researchers, while enhancing existing international relationships and building innovative new partnerships to help boost the UK's CCS research capacity.

In particular, the Centre aims to build UK CCS research capability by strategically working with organisations that provide access to researchers, facilities and skill sets that complement UK capabilities. For example, the Centre has signed Memoranda of Understanding with Carbon Management Canada to jointly deliver a programme of early career researcher exchanges.

Specifically addressing links with full-scale projects, a three-year MOU was signed on May 23 between SaskPower and the UKCCSRC to facilitate research and related opportunities aimed at improving costs and performance of CCS. The UKCCSRC has allocated an initial budget of £250k to meet the additional costs to UK academic researchers participating in activities. A joint SaskPower/UKCCSRC panel will provide oversight and planning for the coordinated research activities. The MOU was developed when researchers from UKCCSRC and SaskPower officials met in 2012 on a visit to Canada supported by the UK Foreign and Commonwealth Office, followed by a visit to the UK made by SaskPower. Results and outcomes will be shared with members of both organizations, with scope for extended and expanded research projects in future years.

Figure 4a - The PACT core facilities at Beighton include a CO2 amine capture plant which can treat real flue gas produced by an air combustion/oxyfuel plant or carefully specified gas mixtures produced by on-site gas mixing facilities

Another collaboration, with longer-term prospects for large-scale project links, is an MOU between the UKCCSRC, the Scottish Carbon Capture and Storage Centre, the Guangdong Low-carbon Technology and Industry Research Centre and the Clean Fossil Energy Development Institute to establish an international CCUS network. This international network, which launched formally in December 2013 (see Figure 5), will promote joint research and development, provide advice for local and regional governments and develop ways to exchange knowledge.

Figure 4b - The PACT plant is complemented by facilities hosted by the University of Cranfield, including a chemical looping plant and the Advanced Capture Testing in a Transportable Remotely-Operated Mini-lab (ACTTROM) unit

Closer to home, UKCCSRC members are, of course, looking forward to opportunities to benefit from links to the FEED (Front End Engineering Design) studies for commercial-scale power plant CCS funded by the UK Government CCS Commercialisation Programme and also recently announced work to identify the best option to take forward an industrial CCS network in the Tees Valley.

Conclusions

CCS R&D is in a period of transition, and so is the field as a whole. As a number of large-scale, full-chain projects become operational over the next few years, CCS is expected to gain the greater technical certainty and industry structure that characterise other, more mature, energy technologies.

A stronger tendency to go ahead with

developments of what is now proven to work is likely, with correspondingly increased challenges for novel technologies that still need to progress through the first-of-a-kind development to progress to commercial deployment. Practical experience will, however, throw up an increasing number of demands for better fundamental understanding to interpret unexpected phenomena. And this R&D, that can piggy-back on established technology, will also find a very quick route to impact.

In addition, having an increased number and variety of tangible examples of CCS projects available will make a difference to the way CCS is viewed by policymakers and the public. If this leads to acceleration in the deployment of a second tranche of CCS project deployment then the need, and opportunities, for CCS R&D organisations to align more closely with actual industrial practice could rise even further.

In this new future for CCS the three approaches piloted so far by the UKCCSRC - the RAPID process, PACT and other pilot facilities and links to full scale projects respectively - are expected to provide a sound basis for informing and growing research and capacity. A further area that should be developed if at all possible, though, is exchange of staff between research and industry projects.

Programmes based around PhD research undertaken jointly with industry are already established (e.g. the EPSRC Industrial Doctorate Centres in the UK). In addition, more flexible secondment arrangements for a wider range of people, and not necessarily combined explicitly with research activities, are being examined as part of the UKCCSRC's Early Career Researcher programme. Previous, very successful, examples are a series of 1 month secondments to the DECC-funded Doosan/SSE/ Vattenfall CCPilot100+ unit at Ferrybridge (plus a range of shorter visits). Additional, shorter, staff exchanges would allow the industry-connected capacity base to be built up more quickly and could be tailored individually to suit the needs of industrial projects and their participants.

Figure 5- the name plaque for the UK-China (GD) CCUS Centre, founded under the Guangdong MOU, being handed over by Xie Zhenhua, a vice chairman of the National Development and Reform Commission and the lead negotiator for the People's Republic of China in the last three United Nations Climate Change Conferences. This was part of the launch ceremony for the Guangdong emission trading scheme, on 19 December 2013

More information

www.ukccsrc.ac.uk
www.pact.ac.uk
www.epsrc.ac.uk
Jon.Gibbins@ed.ac.uk

Keeping momentum with CCS

Carbon Capture Journal's conference on November 19 looked at how to keep CCS development moving. Professor Stuart Haszeldine moderated and speakers included Belinda Perriman from Shell.

Stuart Haszeldine opened with a summary of the current position of CCS in the UK.

"Starting in around 2002 there was an attempt to get going with the Peterhead project and then the first competition," he said. "We are now into competition two and about to enter into two FEED studies and the focus of that is to actually get two projects that work and to get the cost reduction down so that it becomes competitive with other forms of low carbon energy."

"The UK has made very rapid progress on a number of areas, he said, including claiming pore space, adopting the European Directive, licensing and forming regulatory systems, supporting FEED projects, putting up a share of £1 billion CAPEX prize, creating contracts for difference for follow-on projects, supporting research, communicating

Delegates networking at the Royal Geological Society in London

with all the stakeholder groups and forming international partnerships for knowledge exchange."

"The two things I am concentrating on in the future are, if we get these two projects running can we get the CO2 in the ground faster than 2019 and can we develop follow-on projects using the contracts for difference mechanism. We've got all the tools, but we now need to use them as rapidly as possible. We need to concentrate on actually getting CO2 in the ground."

"In Europe it is worse, because Europe has the legal and regulatory framework but it is very stuck in getting the investors and the money lined up as members states have not been as generous or as forward sighted as the Uk to allocate the enabling funds so Europe as a whole has to sort out the confidence and the politics and how to make this into a business as usual activity."

"What we've had is twelve projects and money allocated for part funding but that has failed, because of the trading scheme failure, to give out the signals that CCS is worth doing in terms of the normal electricity market."

"It is essential that CCS is in the strategic energy plan but again it's a question of can we accelerate that to make it sooner than 2020 before we can re-start CCS in Europe. SO the UK projects are really vital because they are likely to be the first end to end projects to be developed."

"What the U.S. did was to look not only at the power sector but at the industry sector as well and a piece of work we have done looked at CO2 from ammonia plants in the EU, and I wonder if we could use that to accelerate injection experiments, not to substitute for the end to end projects in the UK but to share that CO2 between member states to trial and validate the storage shared under the North Sea."

Belinda Perriman gave a personal perspective on applying for the UK CCS competition.

"The UK CCS competition gave us three months between the announcement and making a legally binding bid in July 2012, so that was quite a busy period," she said. "Together with SSE we answered something like 100 questions over the summer and then we were selected as one of four potential projects towards the end of October. After a brief period of elation, this then came with the requirement to resubmit a better bid in mid January, so many of us had a rather busy Christmas that year."

"The final preferred bidders were announced in the budget of 2013, which again gave us a few minutes of congratulations before some new conditions were introduced for continuing with the negotiations to enter into a front end design contract. Again we had to work for another three or four months very intensively to meet DECC's requirements to become a preferred bidder."

SSE's Peterhead power station on the Scottish coast

"So if we can keep the momentum, we are still on course to become the world's first full chain CCS project on a gas-fired power station. This is very important for Shell and a key reason why we are doing it, to demonstrate that gas can be used to generate clean electricity."

"Shell has been using amine capture technology in its downstream operations for a very long time for SO2 collection, and has a company called Cansolv which is now promoting and developing amines for CCS."

The project setup

There are already a number of existing pipelines into St. Fergus in the Northeast of Scotland and this project will reverse the direction of one of those lines to the Goldeneye platform operated by Shell, she explained..

"We drilled the wells and so we know it very well and we think it is very suitable for carbon storage. It is a very good reservoir, with high permeability that produced its gas in eight years, which is very fast and is reflection of the fantastic properties of the reservoir."

"There are five wells and we can use all of them, it is just a matter of re-completing the wells. So you pull the tubing out, put new tubing in and together with some minor modifications on the platform to install filters and additional pipework for that to stop anything getting into the wells, the offshore element of the project is really very well defined."

"The Goldeneye reservoir was in fact part of the Longannet project to take CO2 from a different power station and store it, so a FEED study was already done a few years ago."

"The Peterhead plant is located right on the beach around 20km south of the St. Fergus terminal and the plan is to build a new pipeline straight offshore to connect with the existing 100km long pipeline, which is already CO2 compliant as the gas reservoir produced CO2. So we are fortunate that we have an existing infrastructure for much of this project."

"We will be doing directional drilling under the beach so the pipeline will not be visible above ground, and we have had meetings with the Port Authority and all of the regulatory authorities and this seems a very simple route to go directly offshore."

"Peterhead has been going for a long time and used to burn fuel oil and then it was burning gas that was coming together with oil, and now it is burning natural gas, so there have been quite a lot of changes and this is just another in a series of adaptations for the site."

"It is a big site, so there is plenty of room for the capture pant within the existing location, and all the activity then is within the existing fence of the power station."

"We are due to start public engagement in 2014 and we will be setting up town halls in many of the surrounding communities and go along with story boards to explain what we are doing. We will have quite extensive periods of engagement listening to people's concerns and questions rather than doing a big tell."

More information

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Progress on CCS in the UK

We talked to the new Chief Executive of the UK Carbon Capture and Storage Association, Luke Warren, about his views on the future of CCS in the UK.

There has been much talk of the slow progress with CCS in the UK, but recent developments have created a more positive environment for CCS projects to get started and Mr. Warren is cautiously optimistic about the near-term outlook.

"If we look at the landscape now, there has been quite a lot of progress from the UK perspective," said Mr. Warren. "Negotiations around the competition are starting to edge towards a conclusion, and it looks like Peterhead will join the White Rose project and move into a FEED study."

"Government has started to think about what comes next for CCS, and that has been critically important. Around eighteen months or so ago, the Government set out its ambition to deliver an outcome of delivering commercial CCS in the 2020s - so we are not just trying to deliver a one-off demonstration programme we are seeking to develop a viable CCS industry in the UK."

"However the reality is that it has been very quiet between the selection of two projects in the competition and the Government's response to the recommendations of the CCS Cost Reduction Task Force. That was causing a lot of concern in the industry, particularly for the companies outside the competition and the broader supply chain. There was a real question mark over whether the Government was really focussed on trying to bring forward additional projects outside of the competition."

"The response to the Cost Reduction Task Force is very positive, three elements in particular: first we have this concept now of a second phase of projects, so the Government realises that the competition projects on their own will not be sufficient to deliver commercial CCS and we are going to need a second phase probably running parallel to the competition; secondly the possibility of supporting the Yorkshire and Humber CCS Trunk Line is very positive and indicates that the Government envisages additional projects coming forward; and finally they will be looking at the synergies with Enhanced oil Recovery (EOR). If you look at the Cost Reduction Task Force report it suggests that there could be some important cost reductions opportunities from CO2 EOR."

"So we are moving in the right direction, but much more still needs to be done: the Government has to deliver the two competition projects and it still has to allocate funding under the levy control framework for non-competition projects. However at least there is a signal now to the broader industry that a CCS market is starting to emerge. CCS needs to be an industry in its own right, equivalent to nuclear or offshore wind, and we think that is achievable and ultimately necessary if we are going to address climate change."

However the focus has changed. Looking back to 2007 there was an idea that the UK would develop CCS and would then export the technology. "Now, the focus is on UK opportunity and UK benefits to deploying CCS here," said Mr. Warren. "The analysis shows that if we are going to decarbonise, the least cost route is to have CCS as part of the energy mix alongside nuclear and renewables."

"Internationally the UK is demonstrably now not in the lead on CCS, and we have to accept that and use the positive CCS developments elsewhere in the world to give us confidence to develop our own industry. What the does have is the EMR (Electricity Market Reform) which could enable the commercial deployment of CCS. If you look at other regions, there are ad-hoc pots of funding for CCS, and that has resulted in projects being successfully deployed, but no-one quite yet has a mechanism that actually starts to develop an industry, and that is what the CfDs (Contracts for Difference) potentially do."

"Also we should not forget that we have a world leading oil and gas industry with the skills and expertise to deploy CCS, and coupled with the fact that we have some of Europe's largest CO2 storage resources, there is no doubt that we can still be a leading country on CCS."

And it is not all about the power sector. Another aspect that the CCSA has been pushing is the role of CCS in industrial sectors. "Actually CCS is even more essential to the survival of energy intensive industries," explained Mr. Warren. "The power industry in theory has options, but for other industry sectors CCS is the only solution if you want to decarbonise."

"In the UK to date there has very much been a focus on CCS in the power sector and there are logical reasons why you would focus on that sector first as modelling studies suggest that the power sector should decarbonise before other parts of the economy. However the decarbonisation of energy intensive industries is equally important and an area of policy that is not as well developed. It is also a more complex discussion as each of the industrial sectors will have their own technology requirements."

We want to develop a viable CCS industry in the UK - Luke Warren

Ending on a positive note, Mr. Warren said that the UK competition was much better placed to deliver now compared with the previous competition. "The £1 billion is just part of the funding mechanism now, as we have the CfD framework that allows you to recover investment in ongoing costs rather than just paying the capital costs of the project."

There has also been much progress elsewhere, he said. "People always say CCS is not moving, but if I think back to where CCS was when I started in this industry in 2006, we didn't have the CCS Directive, we never thought about putting CCS on an equivalent basis to renewables, CCS wasn't considered a valid technology under the UN FCC process, there were a few projects around like Sleipner and some EOR projects in the U.S., but since then much has happened. We have now had positive investment decisions made on the Gorgon project which will be the world's biggest CO2 storage project when that starts operations next year, we have investment decisions on the Kemper County and Boundary Dam power CCS projects, and the Snøhvit and Air Products plant in Texas are operating."

"So when I look at the sector I think we have come a long way. The economic crisis has been devastating for the industry, particularly in Europe, but the progress has been impressive in many ways."

More information

www.ccsassociation.org.uk

Why we need CCS to secure future renewables

The irony of renewables is that their inherent intermittency means that for technologies such as wind, solar and wave to be adopted at scale, they must be supported by flexible fossil fuel power, at least in the medium term, to cope with demand, says **Frank Ellingsen, Managing Director, CO2 Technology Centre Mongstad.**

Take Germany, for example, its Energiewende has given rise to major renewables reliance; producing at their peak, up to 60% of Germany's electricity. That's great news on the surface, but the intermittency issue plays havoc with European power grids. For example, at periods of low generation and high demand, Germany is forced to rely upon French nuclear power plants, as well as using coal-generated power from neighbours such as Poland to meet demand.

CO2 emissions rose last year as coal-fired power plants became cheaper to operate than gas; an issue the US Environmental Protection Agency (EPA) proposes to tackle by limiting emissions from new coal plants to 500 kilograms per MWh, and from gas plants, to 450 kg per MWh. However, despite rising legislation, market forces dictate that the prevalence of fossil fuels, combined with their ability to flexibly manage power surges, will prolong their use as a crutch for renewables.

Carbon capture technologies are already established which can manage the rapid dynamic transition that's needed between renewable and fossil fuel generated power, whilst limiting the release of CO2. TCM's amine carbon capture unit can scale the CO2 capture rate from zero to 90% CO2 removal (3,2 tonnes of CO2 per hour) in less than two hours - mimicking a power surge scenario of the grid going from full renewables reliance to reliance on fossil fuels.

Another example of where CCS makes renewables more viable is in the industrial sector. Cement, iron, steel, chemical and refining plants together make up 20 percent of global emissions. Renewables, especially solar, hold huge potential for reducing costs of the industrial sector. Carbon capture is one of the few viable ways to enable the sector to transition to a large proportion of renewable generation, whilst limiting greenhouse gases. The flexibility of CCS can bridge the gap between fossil fuels and renewables, encouraging investment in both to meet the IEA's target for renewables to make up 23% of global emissions reductions and CCS to make up 17% in 2050.

The major challenge for CCS is to adapt the technology so that power plants, refineries, cement plants and other industrial facilities can use it, at the right price. Capture testing is continuing at TCM to reduce the financial, technical and environmental risks of carbon capture. The Norwegian Government recently strengthened its support for TCM by providing it with an additional NOK 450 million ($67.7m) for carbon capture technology testing over the next four years..

Understanding of the economic risk of carbon reliance is rising. HSBC has estimated that in a world where carbon emissions are constrained, oil and gas companies could lose 40-60 per cent of their market capitalisation. Yet the colossal amount of fossil fuels investment in existing fossil fuel reserves will take some time to be transitioned. As a result there are huge economic prizes on offer to technologists that can rise to the challenge of protecting that economic value, by decarbonising fossil fuels.

The Obama administration has announced plans to provide $8 billion in loan guarantees for low-carbon fossil projects to promote further carbon capture. Similarly, China is planning to double its budget for carbon-capture projects, hoping to attract some $380 million in investment over the next five years for the carbon-capture industry.

There are also notable projects coming on stream. In Europe, for example, the Rotterdam Capture and Storage Demonstration Project (ROAD) is an initiative of E.ON Benelux and GDF SUEZ Energie Nederland. As of 2015, ROAD plans to capture 1.1 million tonnes of CO2 per year from a new power plant at the Maasvlakte and will store the captured CO2 in a depleted gas reservoir under the North Sea.

In Canada, the 'Boundary Dam project' will be on stream in 2014 and plans to capture 1Mt/year of CO2. The total cost of the project is estimated to be $1.355 billion, and revenue from the sale of CO2 is expected to offset the project costs. Sulphur dioxide (SO2) will also be captured and sold.

We can't wait for emission trading systems and carbon taxes to drive the industrialisation of CCS. Based upon experience up to now, we need to face the reality that we're unlikely to see a carbon tax any time soon that's strong enough for remaining fossil carbon to be left underground forever. To solve the challenge of our global energy demand rising by over one third up to 2035, whilst bringing intermittent renewable sources on stream, flexible fossil-fired plants, retrofitted with carbon capture will play an indispensable role.

Technologists, such as Siemens, GE and Mitsubishi, which have a foot in both the CCS and renewable energy camps, have the opportunity to synergize the adoption of these technologies to bring power providers low carbon technologies with low operating costs and flexibility.

We can't wait for emission trading systems and carbon taxes to drive the industrialisation of CCS - Frank Ellingsen, Managing Director, CO2 Technology Centre Mongstad

More information

www.tcmda.com

Putting it back – how to deploy large-scale CCS

ZERO recently released a report about policy instruments for large-scale CCS, which offers a thorough analysis of the policy-making instruments and suggestions on how to best implement CCS in Europe.

CCS has been met with some major setbacks lately, but it is not because of the lack of available technology. We know how to do it, but the problem seems to be on the policy-making side of CCS, says Camilla Svendsen Skriung, Policy Adviser for CCS with ZERO.

Once we create a market mechanism for CCS, the conditions for the industry will improve. We suggest a shared responsibility system, where the producers of fossil fuels have the obligation to buy a certificate from the developers of CCS projects. This way the industry will have an incentive and a possibility to deploy CCS.

Considerable improvements in framework conditions are required to trigger sufficient development and implementation of CCS. In order to meet this major challenge, ZERO has carried out an analysis to contribute to bringing CCS instruments onto the political agenda and closer to implementation.

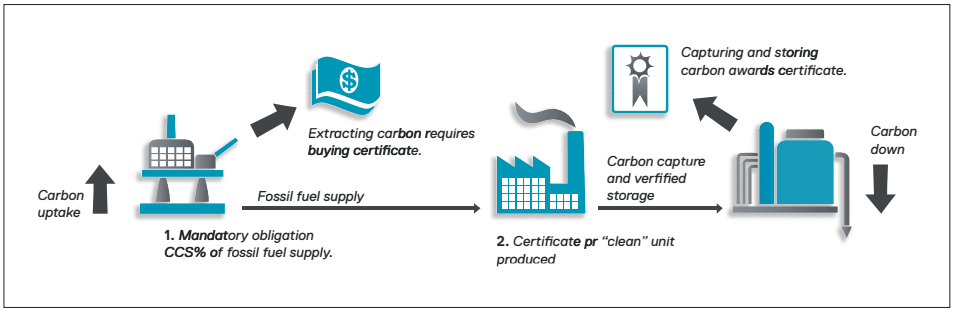
The overall target of the report is to carry out a study of policy instruments for realisation of large-scale deployment of CCS, to identify the instruments best suited and to propose specific recommendations for the way forward towards sufficient large-scale CCS implementation.

The report is part of ZERO's work to achieve the necessary deployment of large-scale carbon capture and storage (CCS), as one important mitigation solution to solve the climate challenge.

There are many studies concerning the question of how to ensure the technological up-scaling of CCS and instruments for this learning phase, but we have gone one step further and considered the following question: What are the policy instruments that will take development beyond the first demonstration projects, to the several hundreds of CCS projects?

Long-term predictable frameworks are crucial to boost the speed of needed investments and development. Short-term challenges are important but must not take the focus away from putting long-term policy instruments in place.

In order to ensure large-scale deployment of CCS, ZERO considers a mix of instruments indispensable: at the core, an instrument giving sufficient incentive to make business cases for CCS viable and trigger investments in deployment and innovation.



Simple illustration of a CCS certificate system

For industry to embark on large-scale investments, a long-term predictable framework is needed.

The best policy instrument for up-scaling of CCS deployment to emerge from this analysis is a CCS certificate system combined with an appropriate EPS. The certificate system finances the cost for CCS deployment through a cost-sharing model, while the EPS sets a very clear regulation, stopping investments in high-emission conventional solutions.

ZERO hopes, and thinks, this work will be of interest and contribute to spark the deployment of CCS on a large scale. The next step is of course to develop an effective framework for CCS, and not the least: to implement it and get it to work.

The existing CCS strategies

The EU has previously tried different strategies to establish more CCS and deal with greenhouse gases within the EU countries. The European Union Emissions Trading System (ETS) is not only directed at CCS, but the hope was that the cap and trade system would reduce emissions within the EU and EFTA countries by giving the incentive to emit less CO2.

The results so far have not been convincing, and there has not been a substantial emission reduction in the EU countries. This is mainly because the price of ETS CO2 has not been as robust as previously predicted. Low prices means that the industry has few incentives to develop CCS technology, because it is less expensive to buy Emissions Unit Allowances (EUA).

The second and more directly CCS related instrument is NER300, which is a program aimed at subsidizing renewable energy and the installation of carbon capture and storage technology on fossil fuel plants. So far the program has failed to support any actual CCS projects, with all the funds being allocated to renewable projects instead, and critics feel it is time to look at other solutions for the development of CCS in the EU.

Other initiatives includes the European Economic Recovery Programmewhich was established after the economic crisis in 2008, and which allocated around € 1 billion to CCS demonstration projects. While directing funds towards demonstration projects is commendable, only few of the projects remain. This highlights another issue with this type of funding, namely that it does not lead to permanent CCS projects.

Solutions for the future

The challenge for the EU countries is to get the industry on board to clean up their emissions. Unfortunately a large part of the EU system seems to be hung up on ETS and NER300, despite the lack of results.DG Energy expects the Energy Road Map 2030 to suggest back loading allowances of ETS towards 2030 and use the profit to finance CCS projects.

Today the support for a certificate system is fairly low within the EU, and the focus is on the development of CCS demonstration projects and strengthening the ETS system. However, it seems to be time for the EU member states to question the existing strategy and consider other and more efficient instruments to reach the emission goals.

More information
www.zero.no

Policy, projects and regulation news

UK Government funds White Rose project FEED study

www.whiteroseccs.co.uk

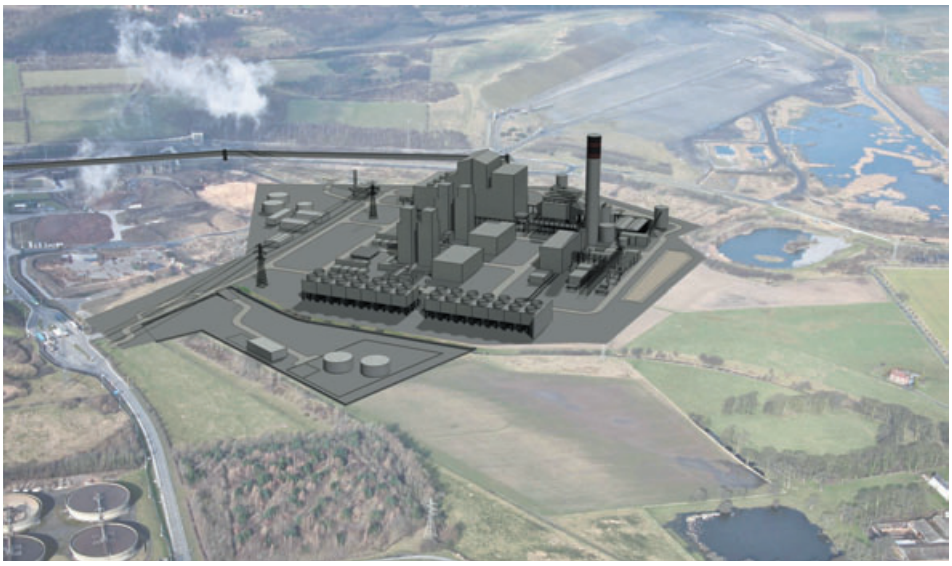
Capture Power Limited, the consortium of Alstom, Drax and BOC, has been awarded a Front End Engineering and Design (FEED) contract for the White Rose CCS Project.

The FEED contract also includes the planned development of a carbon dioxide transportation and storage solution – the Yorkshire Humber CCS Trunkline – to be undertaken by National Grid Carbon Limited.

The award of the contract marks the next step in the UK CCS Commercialisation Programme. The FEED study is a two year programme of detailed engineering, planning and financial work to finalise and de-risk all aspects of the proposal ahead of taking the final investment decision, and proceeding to financial close and the commencement of construction.

During FEED, Capture Power, together with National Grid Carbon, will continue to work with the Department of Energy and Climate Change (DECC) with a view to concluding a Project Contract for the construction and operation of the full chain CCS project.

The White Rose proposal is to build a new 426MW (gross) clean coal power plant with full carbon capture and storage, capturing approximately 2 million tonnes of CO2 per year. The CO2 will be transported through National Grid's proposed Yorkshire Humber CCS Trunkline for permanent undersea storage in the North Sea.



An illustration of the White Rose CCS project located next to Drax Power Station in the UK

Former U.S. Energy Secretary Steven Chu joins board of Inventys

www.inventysinc.com

Dr.Steven Chu has joined the Board of Directors of Inventys Thermal Technologies, the Vancouver based carbon capture company.

"Carbon capture is a critical technology to move us to a clean energy future and Inventys has developed a practical, compact, and low cost system that allows existing fossil fuel power plants to dramatically lower their carbon emissions," Dr. Chu said.

The Inventys system, called VeloxoTherm™, uses significantly less energy than competing systems, the company says, and this, combined with low capital costs, results in a capture cost of about $15 per ton of CO2, less than 1/5th the cost of current processes. In addition, the Inventys system is less than 1/10th the size of competing systems and is small enough to retrofit to existing power plants by connecting it directly to the flue stack.

Dr. Chu is currently the William R. Kenan, Jr. Professor of Physics and Professor of Molecular and Cellular Physiology at Stanford University. Before serving as Secretary of Energy in the first Obama administration, Dr. Chu was Director of the Lawrence Berkeley National Laboratory (LBNL) and Professor of Molecular and Cellular Biology at the University of California, Berkeley.

The Inventys VeloxoTherm™ system is based on a Low Pressure Thermal Swing method. A slowly rotating structure holds a proprietary material that traps carbon dioxide when it is cool and releases it when it is hot. On half of the rotation cycle, flue gas from the power plant is passed through the material and the CO2 in the flue gas is captured. On the other half of the cycle, steam is injected into the material to release the CO2, the leftover steam is condensed out leaving pure CO2, and the material cools down to be ready for the next cycle.

CCEMC shortlists 55 projects for $35M Grand Challenge

www.ccemc.ca

The Climate Change and Emissions Management (CCEMC) Corporation has invited full proposals from 55 projects from around the world for the first round of its $35 million Grand Challenge to create new products and markets based on the utilization and conversion of carbon dioxide.

Winning projects will be announced on April 15 at the Zero2014 conference in Edmonton. Shortlisted projects include chemical synthesis, carbonate production, liquid fuels, bacteria bio-fixation, methanol production, solid carbon products, polymer processing, syngas production, fertilizer production, algae bio-fixation and water treatment.

The CCEMC launched the Grand Challenge in February 2013. The first round is seeking to identify up to 20 semi-finalists who will be awarded a grant of $500,000 to support development of their technologies. To be eligible, applicants were required to demonstrate potential to reduce greenhouse gas emissions through the utilization and conversion of carbon dioxide to create valuable carbon-based products. Projects could be at any stage of development from initial proof-of-concept to commercial deployment in Alberta. The CCEMC received 344 applications from around the world.

The second round of the CCEMC Grand Challenge: Innovative Carbon Uses will open for submissions in March 2015. It will be open to both new entrants and all applicants from the first round. Up to five projects will receive grants of up to $3 million each to develop their technologies. The final winning solution will be announced in 2018, with the winner receiving a $10 million grant to help commercialize their technology in Alberta.

In addition to the Grand Challenge, twice each year the CCEMC invites submissions for projects that will reduce greenhouse gas emissions. The organization currently has $40 million available for projects that reduce GHG emissions or enhance carbon sequestration from biological sources.

Carbon Capture and Reuse with Algae

Using CO2 as a feedstock for growing algae has the potential to create a revenue stream from carbon dioxide by turning it into renewable fuels and chemicals while reducing greenhouse gas emissions.

By Dr. Margaret McCormick, Board Chair, Algae Biomass Organization and CEO of Matrix Genetics

The Environmental Protection Agency's recent proposed rules on limits to CO2 emissions from power plants drew the expected howls of approval from greens and disapproval from power generators and fossil fuel industries.

The EPA's proposal endorses Carbon Capture and Sequestration (CCS) as an approved technology for power plants to reduce their emissions. While decades of research and development and billions of dollars of federal funding have advanced these technologies, there has yet to be a CCS technology that is economically feasible. As such, the power generation industry is left between a rock and a hard place – a mandate to reduce emissions but no viable method to use.

Help may be on the way. A new crop of technologies are being developed that offer a new route to emissions reductions, but with a twist. These new approaches treat CO2 as an input rather than waste, flipping the notion of sequestration on its head.

This process - using industrial CO2 emissions as a feedstock for products that otherwise would be produced from petroleum is known as Carbon Capture and Reuse (CCR). It has also been referred to as Carbon Capture and Recycling, Carbon Capture and Utilization (CCU) and even Carbon Dioxide Utilization (CDU).

These newer technologies are being commercialized today, and will soon present power generators with viable options to recycle their carbon dioxide into high-volume products such as fuels, fertilizers, chemicals, plastics and many more. The size of these markets make it possible for power generators to reduce emissions and see a return on investment, a prospect that does not exist for most geological sequestration options.

CCS technologies are expected to remain costly, even when used for Enhanced Oil Recovery (EOR). Building the infrastructure to capture and carry CO2 to the required sequestration locations is daunting. Regulatory challenges around site selection, permitting, and long-term liability are barriers that, in many cases, may take years to resolve.

Despite these drawbacks the sheer potential impact CCS technologies can have on emissions makes them an attractive approach to our need to reduce overall greenhouse gas forming emissions from fossil fuels. Nonetheless, regulatory agencies would be wise to consider the growing potential of CCR technologies.

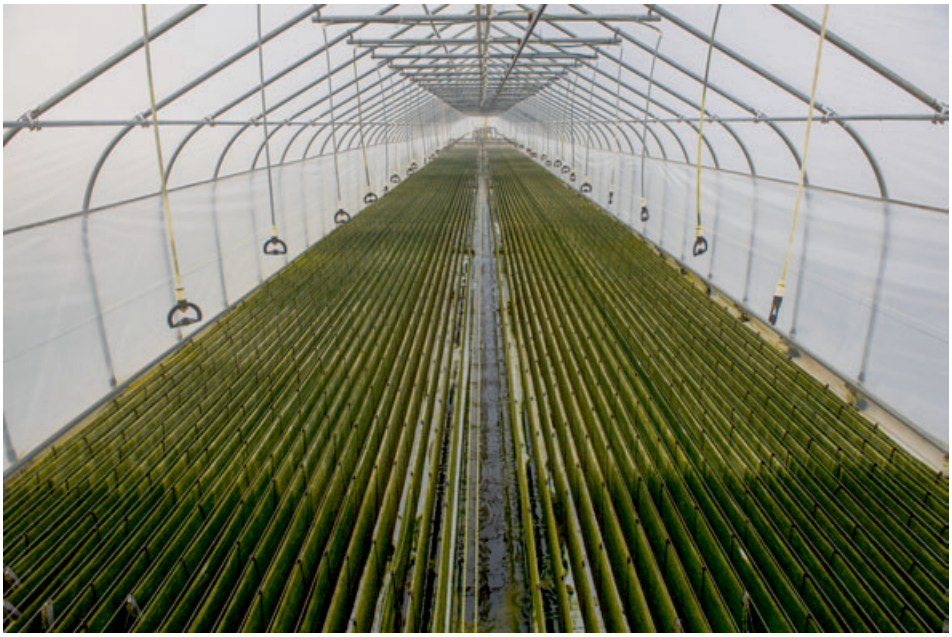


Figure 1 - BioProcess Algae is using CO2 emissions from an ethanol production facility to grow algae in greenhouses

In the past few years, companies that use CO2 to produce commodities have achieved significant progress towards commercialization. Nowhere has this progress been more evident than in the algae industry

Potential of algae

Algae are voracious consumers of CO2, converting the carbon in the gas into carbohydrates and lipids (oils) via photosynthesis. In many cases a culture of algae can double its biomass in less than 24 hours, rivaling almost any other photosynthetic organism. Harvests of this crop can occur weekly, rather than seasonally like corn or soybeans.

Nearly half the dry weight of algal biomass can be derived from CO2; producing 100 tons of algal biomass fixes (or, sequesters) roughly 183 tons of carbon dioxide. Depending on the type of algal strain and the production environment, algae can produce more than 5,000 gallons of oil per acre (corn typically produces 400 gallons per acre and soybeans produce around 100 gallons per acre).

Algae are also one of the few crops that can be grown in saltwater or wastewater and on otherwise non-arable land (such as that typically surrounding major power generation facilities), avoiding resource competition with other food and fiber crops.

Only the range of products that can be derived from algae matches these advantages. These products include animal feeds, nutritional supplements, specialty oils, chemicals and plastics.

Perhaps most enticing is the potential for algae to become a renewable source of drop-in fuels like gasoline, diesel, jet fuel and ethanol. Drop-in fuels made from algae are cleaner than their petroleum-based counterparts when combusted in an engine, emitting fewer pollutants such as sulfur dioxide, carbon monoxide and particulates.

While some algae farming has occurred for centuries, and cultivating algae for biofuels and similar purposes has been researched for decades, only recently have the first large-scale demonstrations shown that commercial production of large volumes of algae is technologically and economically

feasible. Several companies that have completed these demonstrations are now planning construction of their first commercial production facilities.

These commercial algae farms will need CO2 feedstock to produce marketable products. Given the volume and value of these products, the quantities of CO2 required could be significant. With CCS costs estimated to be around $60 per tonne, an emerging demand to recycle their emissions could stimulate a new interest in carbon capture from power generators.

Commercialising the technology

A number of algae companies are already making plans to find CO2 sources that can supply their operations:

Sapphire Energy is growing and harvesting algae at a 100-acre facility in New Mexico. Through a partnership with **The Linde Group** they are developing a system to deliver anthropogenic CO2 to their commercial-scale algae farming operations. The algae are used to make Sapphire's Green Crude oil that can be refined into transportation fuels that meet ASTM standards for gasoline, jet fuel, and diesel.

Algenol Biofuels in Ft. Meyers, Florida is using algae to produce ethanol and other transportation fuels at yields approaching 10,000 gallons per acre per year. Currently the company operates a 36-acre pilot scale integrated biorefinery and is planning to construct its first commercial facility, collocated with a CO2 source, in the next year.

In Iowa, **BioProcess Algae** is using CO2 emissions from an ethanol production facility to grow algae for animal feed markets as well as fuel. An expansion in 2014 will increase biomass production to one ton of biomass per day. The company expects the technology could be producing 375,000 tons of biomass per day by 2020.

Houston-based **Accelergy Corporation** is currently working with partners in China to recycle the process CO2 from coal-to-liquid and coal-to-ammonia plants with an algae cultivation system. The algae can then be processed into bio-fertilizers that sequester carbon in agricultural soils.

Other companies rapidly developing their technologies include **Cellana** (Hawaii), **Heliae** (Arizona), **Solix Biofuels** (Colorado), and **Phycal** (Hawaii).

Emissions impact

Algae's rapid growth rate and the size of the product markets available to them mean they can be used to great effect in industrial carbon capture.

For example, Algenol's technology is capable of producing at least 144 gallons of fuel per tonne of CO2. The company estimates that 200 million tonnes of CO2 – equivalent to approximately 67 coal fired power plants – can be recycled into 29 billion gallons of ethanol, diesel, jet fuel, and gasoline.

A life cycle analysis of ethanol production using Algenol's technology found a reduction in greenhouse gases of near 80% compared to gasoline.

A life cycle analysis (LCA) of Sapphire's operations recently published in Bioresource Technology showed algae-derived gasoline reduced greenhouse gas emissions 68 percent over petroleum. The same analysis showed the energy returns of algae-derived biofuels are approaching those of petroleum, and that improvements in both figures can be expected when commercial production takes hold.

One difference CCR holds over geologic sequestration and EOR is that every barrel of renewable fuels produced from recycled CO2 emissions is a barrel of fossil oil that does not have to be extracted from underground. Recycling carbon dioxide keeps already-sequestered carbon in the same geologic formations in which it has rested for millions of years.

Of course, cultivating algae is not the lone approach to recycling carbon emissions on a large scale. A number of high-volume applications are being pursued. Linde Group, for example, will soon be building in Saudi Arabia a carbon dioxide liquefaction plant that will produce industrial chemicals, reducing half a million tonnes of CO2 emissions each year.

Figure 2 - Sapphire Energy is growing and harvesting algae at a 100-acre facility in New Mexico

The regulatory environment will lead the way

Research and development of geologic sequestration technology has made it an attractive option for the EPA as it seeks to regulate emissions from power plants, but the agency must take care that its interest in this approach does not hobble future technologies that are just beginning to mature.

The EPA's sparse emphasis on carbon reuse technologies in the recently proposed New Source Performance Standard is not sufficient to ensure these new technologies can find a place in emission reduction strategies. Reuse is only briefly mentioned in the EPA's regulatory impact analysis of the proposed standards, a document that concludes that there has been no adequate evaluation of the technologies with respect to their emission reduction potentials.

As it finalizes this rule the EPA should explicitly include carbon capture and reuse (CCR) as an approved strategy for compliance under its New Source Performance Standard.

Carbon reuse technologies are developing quickly enough that a thorough evaluation of their carbon reduction impacts is long overdue. An inter-agency approach to examine the best and most efficient ways to integrate CCR into carbon reduction strategies would introduce a new tool for stationary sources of greenhouse gases.

Much like the EPA acknowledges with EOR, these approaches would improve power generation economics and could play a role in continued CCS deployment, as well as other carbon reduction approaches.

A roadmap for CCR research and deployment would establish how carbon reuse impacts can be assessed with uniform guidelines and standards, how demonstrations can be supported, and how the approach can be integrated with existing regulations, carbon trading regimes, carbon taxes or other approaches.

Geologic sequestration and carbon reuse will play a big role in the future of energy production, it is time both strategies received a comparable level of support from policy makers.

Reuse makes sense

The principle of carbon reuse tracks just as close to environmental stewardship approaches as geologic sequestration, with or without EOR. CCS is nothing more than a form of waste disposal, which according to EPA's Waste Management Hierarchy and the Pollution Prevention Act on 1990 (42 USC 13101), should be employed only as the last resort.

In both the Waste Management Hierarchy and the Pollution Prevention Act, "pollution that cannot be prevented should be recycled in an environmentally safe manner, whenever feasible" and "disposal or other release into the environment should be employed only as a last resort and should be conducted in an environmentally safe manner."

By turning what is essentially a waste product and a cost center into a new revenue stream, we can achieve a rare trifecta – overall emissions reductions, return on investment, and increased domestic production of commodities such as fuels, chemicals and food.

More information
www.algaebiomass.org

Figure 2 - Accelergy Corporation's photo bioreactor

Capture and utilisation news

Hitachi carbon capture test facility construction begins

www.hitachi.com

Hitachi's Carbon Capture Test Facility (CCTF) at SaskPower's Shand power station is expected to be operational by the end of 2014.

The goal of the demonstration project is to determine the necessary properties required to scale up to a large, commercial-size facility, and demonstration tests will be conducted to comprehensively evaluate the facility's overall reliability and economic feasibility.

SaskPower's experience in integrating CCS into commercial projects combined with Hitachi's expertise in Carbon Capture Technology will enable the parties to comprehensively test and evaluate the technology's overall reliability, economic feasibility, and the necessary properties required to scale up to a large, commercial-size facility, said Hitachi.

The CCTF will have capabilities to capture 120 tons of CO2 per day from the flue gas emitted from SaskPower's Shand Power Station (298MW) located near the city of Estevan, Saskatchewan, using a chemical scrubbing method with an amine based absorbent. Hitachi will produce and supply its CO2 capture solvent (H3-1) and the main equipment for the facility. Hitachi Group companies Babcock-Hitachi K.K. and Hitachi Power Systems Canada, Ltd. from the Province of Saskatchewan will be in charge of production and supply.

Through this demonstration project with SaskPower, Hitachi will focus on achieving commercial operations, reducing costs, realizing innovative technologies and will contribute to the realization of a low-carbon society.

Hitachi began researching and developing technology to capture CO2 in the 1990s. Since then, the company has conducted demonstration projects using its own research equipment and it is using pilot facilities in Japan and overseas.

SaskPower's Shand power station will host Hitachi's Carbon Capture Test Facility (©SaskPower)

CarbonCure signs manufacturing agreement with Anchor

www.carboncure.com

CarbonCure and New Jersey-based Anchor Concrete Products (Anchor) have signed a deal to manufacture CarbonCure's innovative green concrete products.

CarbonCure's retrofit technology chemically converts waste CO2 into limestone to make stronger, greener concrete products. The technology is currently available for concrete blocks, pavers and segmental retaining walls, and the company has plans to expand to the precast and ready mix markets next year.

Under the agreement, Anchor will install CarbonCure's retrofit technology in their flagship plant in New Jersey, and has capabilities to manufacture the product in the greater Washington DC, Philadelphia, New York, Hartford, Providence, and Boston markets.

There is significant demand in the market for green concrete products, with CarbonCure concrete masonry manufactured by Anchor being one of the products currently specified for the 855 Avenue of the Americas building, a project by The Durst Organization. "CarbonCure's technology provides a timely differentiator for the concrete industry,", said Amanda Kaminsky, Sustainable Construction Manager at The Durst Organization. Durst is one of New York City's largest developers with internationally acclaimed projects such as the One World Trade Center, the tallest building in the Western Hemisphere.

The Anchor deal expands CarbonCure's relationship with Oldcastle – the largest producer of concrete masonry and precast products in North America. CarbonCure signed an agreement earlier this year with Illinois-based Northfield Block, also a division of Oldcastle APG, Inc., and plans to form additional partnerships over the next year with other leading concrete manufacturers.

Algae to absorb power station emissions

uknow.uky.edu

Researchers from the University of Kentucky Center for Applied Energy Research (CAER) have demonstrated a system that uses algae to absorb carbon dioxide emissions at Duke Energy's East Bend power station in Northern Kentucky.

The pilot-scale system, built with $1.8 million in funding from the Kentucky Energy and Environment Cabinet and UK with in-kind contributions from Duke Energy, is the only one of its kind currently operating in a "real-world" setting at a coal-fired power plant.

Duke invited scientists to present their work to a small group of special guests, including representatives from the Cincinnati Enquirer and radio station WUKY.

"UK has been a great partner to work with on this project," said Duke Energy's Emerging Technology Senior Project Manager Doug Durst. "This pilot-scale system provides Duke Energy with actual results from the algae cultivation, using flue gas from our coal-fired unit as the carbon dioxide source, while UK works on lowering the costs for a possible future larger-scale demonstration."

Representing UK at the event were project coinvestigator Mark Crocker, CAER associate director in biofuels and environmental catalysis, CAER Research Program Manager Jack Groppo, research engineer Mike Wilson and researcher Stephanie Graham.

The system works by pumping CO2-rich flue gas into a tank full of liquid medium containing tiny, single-celled, plantlike organisms called microalgae. While taking up the carbon dioxide, the algae circulates through a "photobioreactor" — a long course of clear plastic tubes — to absorb sunlight, after which it is returned to the tank and the entire process repeats.

The algae uses carbon dioxide and sunlight for photosynthesis to create the energy it needs to grow, which — in the enriched environment of the photobioreactor — it does very rapidly. Algae biomass is harvested from the system at regular intervals, after which it is dried and formed into sheets. Algae grown in this manner could potentially be used to make a variety of products, such as renewable diesel fuel.

"We talk about carbon dioxide as 'pollution,' but it's also plant food," Groppo said. "Algae not only does a great job of capturing and sequestering carbon dioxide, but it also gives us a useful raw material."

That's key, researchers say, because the value created by converting flue gas to biomass can help to offset the costs of the carbon capture technology. At a certain scale, it could even prove profitable. The pilot-scale photobioreactor occupies less than 1,000 square feet and contains 23,000 liters (roughly 6,000 gallons) of medium in an array of 8-foot-tall tubes. A full-scale system might occupy as much as 100 acres.

Qatar University and Sasol research amine capture

www.qu.edu.qa

An MOU has been signed between Qatar University (QU) and Sasol to establish a project that will advance research in the use of amines for CO2 capture from flue gases.

The 3-year project, titled, "Characterization of Degraded Amine Solvents to Identify Oxidation Products" will be conducted through QU's Gas Processing Center (GPC).

According to the terms of the agreement, Sasol will fund and provide expertise to support the research project which will identify degradation products in the absorption of CO2. Qatar University, through the GPC, will provide laboratory space, equipment, and manpower for the duration of the project.

Both parties will collaborate on exchange of information, joint monitoring of the program, as well as joint activities such as workshops and conferences and supporting student projects.

Sasol Qatar President Marjo Louw commented: "Sasol is pleased to support Qatar University's engineering students through this partnership with the Gas Processing Center. As a company that was built on innovation, this agreement demonstrates Sasol's commitment to support research and development based initiatives that contribute to achieve Qatar's National Vision 2030 towards building a knowledge-based economy. We are pleased to support this research which is an important step towards advancing the application of CO2 capture technology, and its findings will have application locally".

Transport and storage news

A methodological guide for the assessment of CO2 storage sites

www.sitechar-co2.eu

The European SiteChar project held a conference to discuss the results.

The project aimed to produce a methodological guide for the assessment of CO2 storage sites, incorporating all the technical and economic data as well as the social dimension, and provide a valuable tool for the roll-out of geological storage of CO2 on an industrial scale in Europe.

Coordinated by IFP Energies nouvelles, experts from academia, industry and government from 17 organisations in 9 EU countries (Denmark, France, Germany, Italy, the Netherlands, Norway, Poland, Sweden, United Kingdom) gathered their experience and skills in the collaborative SiteChar project.

The objective was to supply a methodological guide adapted to European geological contexts and European legislation for use by storage site operators and regulatory bodies. The project, launched in January 2011, was supported by the European Commission, Enel, PGNiG, Statoil, Vattenfall, Veolia Environnement, the Scottish Government and Gassnova.

The SiteChar research focused on five potential European storage sites, representative of the various geological contexts, as test sites for the research work: a North Sea multi-store site (hydrocarbon field and aquifer) offshore Scotland, an onshore aquifer in Denmark, an onshore gas field in Poland, an offshore aquifer in Norway and an aquifer in the Southern Adriatic Sea. At the Danish and Scottish sites, dry-run storage permit applications have been developed on the basis of criteria defined by the relevant European legislation and evaluated by a group of independent experts.

The studies conducted at the other sites have investigated some specific barriers related to the site characterization methodology. SiteChar has considered the important aspect of the public awareness and public opinions of these new technologies in addition to technical problems.

Lessons learned from the SiteChar project, and the resulting transferable knowledge, inform assessment and permitting needs for CO2 storage sites in Europe. These sites could be developed for the secure and permanent containment of millions of tonnes of CO2 captured from power plants and industrial facilities.

Crucially, the knowledge gained will help operators and researchers to conduct a proper assessment of potential CO2 storage sites aiming at demonstrating safe and permanent storage. Results will feed into the development of regulatory frameworks for the CO2 geological storage considered as a critical component in a portfolio of low-carbon energy technologies.

Dr Florence Delprat-Jannaud, of IFPEN and coordinator of the SiteChar project, said: "SiteChar provides a unique opportunity to test and improve the process of site characterisation so that it is both fit for purpose and meets the challenge of gaining a storage permit."

François Kalaydjian, IFPEN, said: In some extent SiteChar has been able to supplement the lack of industrial demonstrations by delivering both technical and social related results that should enable to optimize and better shape the future CCS industrial projects. SiteChar is certainly a major contribution to the implementation of CO2 storage and should help kick starting CCS industrial activities when the market conditions will be met."

Lionel Perrette, French Ministry of Environment and Sustainable Development and Energy said: "During the development of exploration permits and storage permits, the operator, the Competent Authority and the citizens learn about each other and learn about the project. The way this process has been addressed in SiteChar is an illustration of how to gain the required confidence."

How to unlock the North Sea's potential CO2 storage

Europe can meet its climate change targets and achieve a low-carbon economy by unlocking the North Sea's huge potential as a shared CO2 storage resource, says a report from Scottish Carbon Capture & Storage.

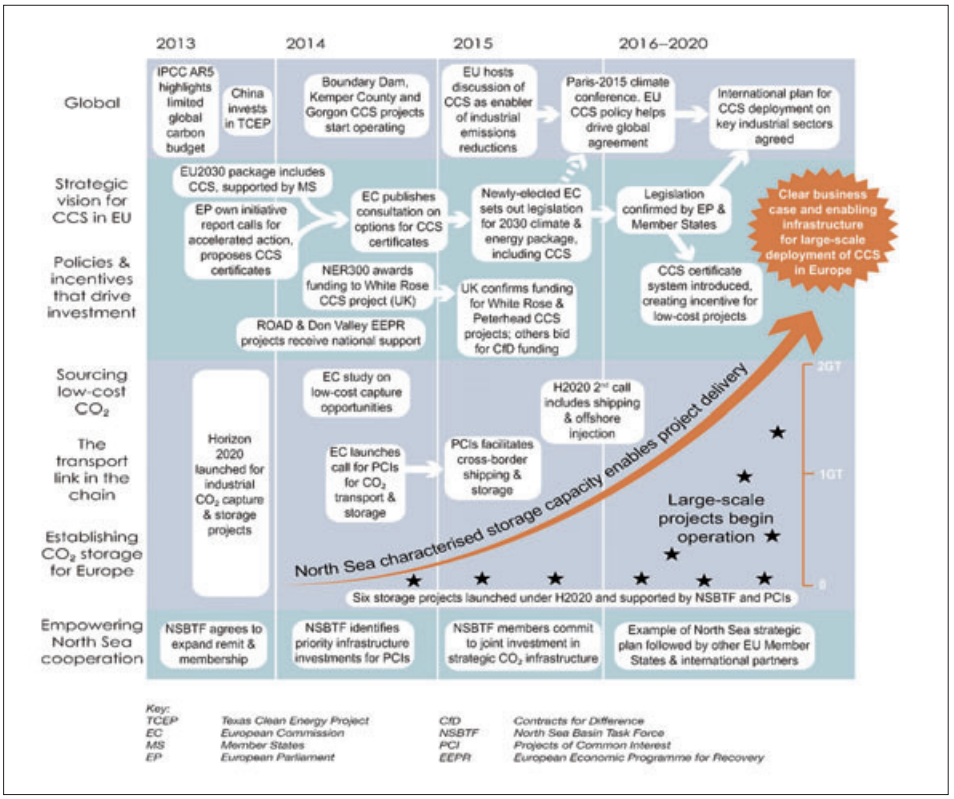
Scottish Carbon Capture & Storage (SCCS) launched the report, "Unlocking North Sea CO2 Storage for Europe", at a special gathering of European Union politicians and policy makers in Brussels, ahead of a European Parliament debate on the future of EU CCS policy. It comes one week after EU climate change ministers set out their vision for a low-carbon economy.

The report recommends a combination of practical actions and policy incentives for the next five years. If taken, these efforts will validate many gigatonnes of CO2 storage capacity needed by Europe's power and industry sectors, and build a strong business case for attracting investment in a carbon capture and storage (CCS) industry. In particular, governments around the North Sea are urged to develop a shared CO2 storage infrastructure.

The report's five-year action framework drew on the results of a conference of leading European CCS experts held in Edinburgh in September 2013.

The report's release coincides with a meeting of the European Parliament's Environment Committee, which is debating proposals urging Member States to revitalise and strengthen their support for CCS. These include an EU-wide target to capture and store 10 million tonnes of CO2 each year by 2020, and undertaking projects to validate storage sites –supported by a robust mechanism for ensuring CO2 clean-up at power plants and industrial facilities, such as a CCS certificates on hydrocarbon production or imports.

"The deployment of CCS on industrial CO2 sources and power generation is essential if Europe is to meet its long-term climate change objectives, retain jobs and improve low-carbon competitiveness," said Prof Stuart Haszeldine, SCCS Director. "But CCS is impossible without the availability of CO2 storage. The recommendations set out in our report identify how Europe can unlock the North Sea as a shared CO2 storage resource."



Key recommendations

Recommendation 1: A strategic vision for CCS in 2030

Position CCS for deployment sufficient for EU industrial emissions and power generation

Ensure CCS is explicitly addressed in the EU's 2030 framework for climate and energy policy, and in line with emissions reductions required across the economy by 2050.

Recommendation 2: Policies and incentives that drive investment

Incentivise CCS through 'sticks' and 'carrots' applied to fossil fuel producers

Targeted policy and financial incentives to engage industry and the oil and gas sector as the key delivery agents for CO2 storage at commercial scale.

Recommendation 3: Sourcing low-cost CO2

Accelerate CCS by sourcing high-purity CO2 captured from industry

Utilise available industrial sources of high-purity CO2 in pre-commercial test injection projects to prove storage assets and de-risk long-term CCS operations.

Recommendation 4: The transport link in the chain

Advance CCS by developing CO2 infrastructure as Projects of Common Interest

A specific European Commission call for CO2 transport projects during 2014 as a means of supporting the characterisation of North Sea storage sites.

Recommendation 5: Establishing CO2 storage for Europe

Validate North Sea storage capacity through six early projects

A five-year focus on delivering six pre-commercial operational CO2 storage sites to validate a variety of storage options and prove at least 1 to 2 gigatonnes of bankable storage capacity.

Recommendation 6: empowering North Sea cooperation

Support CCS efforts by reinvigorating government and industry collaboration

Revitalise and empower the North Sea Basin Task Force as a forum for strategic collaboration, to secure Projects of Common Interest and a supportive EU policy framework.

More information

www.sccs.org.uk

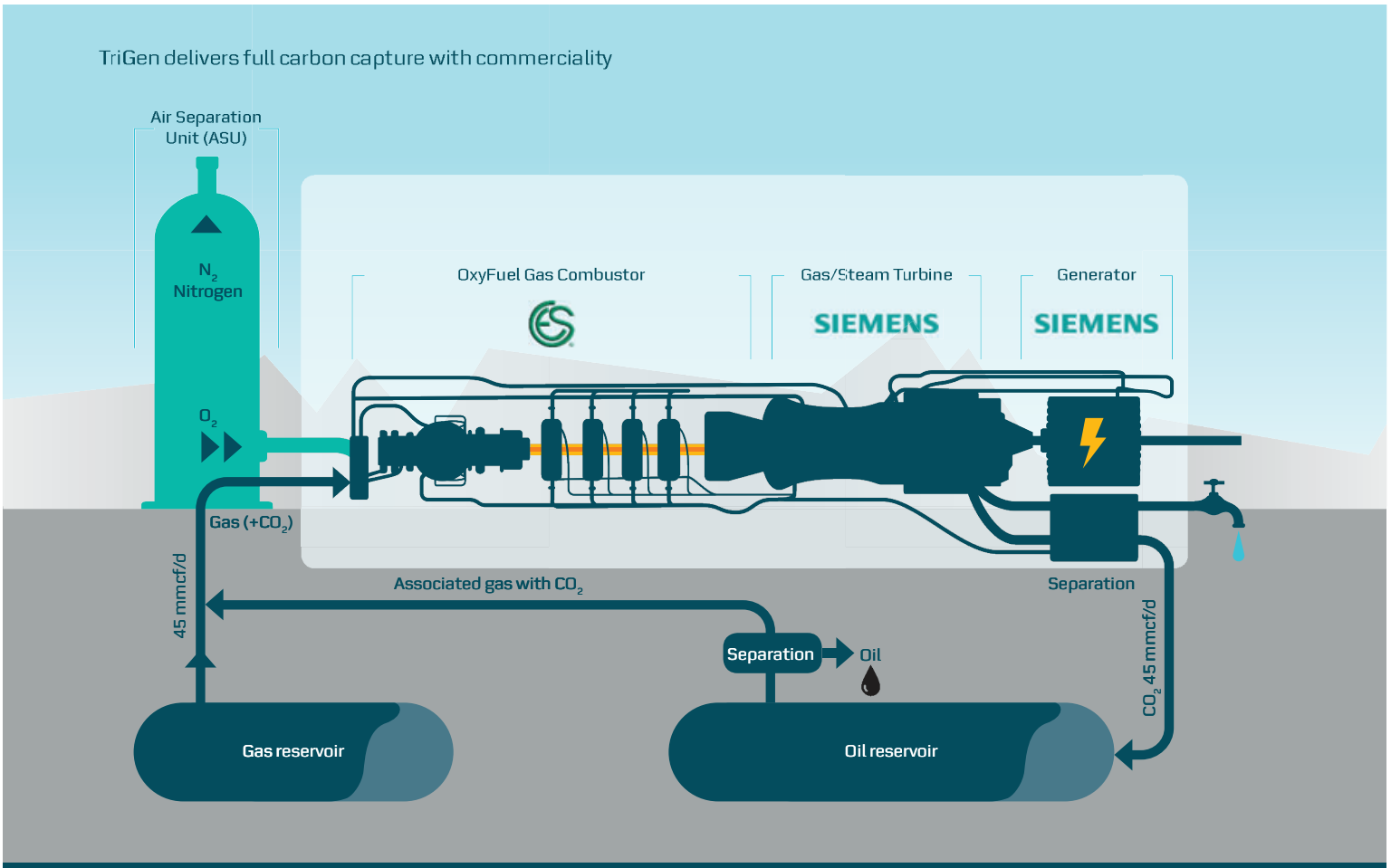
Status of CCS projects

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

For the full list, with the latest data as it becomes available, please download a spreadsheet at:
www.globalccsinstitute.com/data/status-ccs-project-database

Asset Lifecycle Stage	Project Name	Description
Operate	**Century Plant**	Occidental Petroleum, in partnership with Sandridge Energy, is operating a gas processing plant in West Texas that at present can capture 5 Mtpa of carbon dioxide for use in enhanced oil recovery. Capture capacity will be increased to 8.5 Mtpa in 2012.
Operate	**Enid Fertilizer CO2-EOR Project**	Since 1982, the Enid Fertilizer plant has sent around 680,000 tonnes per annum of carbon dioxide to be used in enhanced oil recovery operations in Oklahoma.
Operate	**Great Plains Synfuel Plant and Weyburn-Midale Project**	About 3 Mtpa of carbon dioxide is captured from the Great Plains Synfuel plant in North Dakota. Since 2000 the carbon dioxide has been transported by pipeline into Canada for enhanced oil recovery in the Weyburn Field, and since 2005 in Midale Field.
Operate	**In Salah CO2 Storage**	In Salah is a fully operational CCS project in Algeria. Since 2004, around 1 million tonnes per annum of carbon dioxide are separated from produced gas, transported by pipeline and injected for storage in a deep saline formation.
Operate	**Shute Creek Gas Processing Facility**	Around 7 million tonnes per annum of carbon dioxide are recovered from ExxonMobil's Shute Creek gas processing plant in Wyoming, and transported by pipeline to various oil fields for enhanced oil recovery. This project has been operational since 1986.
Operate	**Sleipner CO2 Injection**	Sleipner is the second largest gas development in the North Sea. Carbon dioxide is separated from produced gas at Sleipner T and reinjected into a deep saline formation above the hydrocarbon reservoir zone. This project has been in operation since 1996.
Operate	**Snøhvit CO2 Injection**	The Snøhvit offshore gas field and related CCS activities have been in operation since 2007. Carbon dioxide separated from the gas produced at an onshore liquid natural gas plant is reinjected into a deep saline formation below the reservoir zones.
Operate	**Val Verde Natural Gas Plants**	This operating enhanced oil recovery project uses carbon dioxide sourced from the Mitchell, Gray Ranch, Puckett, Pikes Peak and Terrell gas processing plants and transported via the Val Verde and CRC pipelines.
Operate	**Air Products Steam Methane Reformer EOR Project**	This project is capturing more than 1 million tonnes per year of carbon dioxide from two steam methane reformers, transported via Denbury's Midwest pipeline to the Hastings and Oyster Bayou oil fields for enhanced oil recovery.
Execute	**Alberta Carbon Trunk Line ("ACTL") with Agrium CO2 Stream**	Agrium's fertiliser plant in Alberta is currently being retrofitted with a carbon dioxide capture unit. Around 585,000 tonnes per annum of carbon dioxide will be captured and transported via the Alberta Carbon Trunk Line (ACTL) for enhanced oil recovery.
Execute	**Alberta Carbon Trunk Line ("ACTL") with North West Sturgeon Refinery CO2 Stream**	Up to 1.2 million tonnes per annum of carbon dioxide will be captured at this new heavy oil upgrader in Alberta. In partnership with Enhance Energy, the carbon dioxide will be transported via the Alberta Carbon Trunk Line (ACTL) for enhanced oil recovery.
Execute	**Boundary Dam Integrated Carbon Capture and Sequestration Demonstration Project**	SaskPower is currently retrofitting a coal-based power generator with carbon capture technology near Estevan, Saskatchewan. When fully operational in 2014, this project will capture around 1 million tonnes per annum of carbon dioxide.
Execute	**Gorgon Carbon Dioxide Injection Project**	This component of a larger gas production and LNG processing project will inject 3.4 to 4.1 million tonnes of carbon dioxide per annum into a deep geologic formation. Construction is under way after a final investment decision was made in September 2009.
Execute	**Illinois Industrial Carbon Capture and Storage Project**	The project will capture around 1 million tonnes per annum of carbon dioxide from ethanol production. Carbon dioxide will be stored approximately 2.1 km underground in the Mount Simon Sandstone, a deep saline formation.
Execute	**Kemper County IGCC Project**	Mississippi Power (Southern Company) is constructing an air-blown 582 Mwe IGCC plant using a coal-based transport gasifier. Up to 3.5 million tonnes per annum of carbon dioxide will be captured at the plant and used for enhanced oil recovery.
Execute	**Lost Cabin Gas Plant**	This project will retrofit the Lost Cabin natural gas processing plant in Wyoming with CCS facilities, capturing around 1 million tonnes per annum of carbon dioxide to be used for enhanced oil recovery.
Execute	**Quest**	Quest will capture up to 1.2 million tonnes of carbon dioxide per annum from the Scotford upgrader, and transport it by pipeline for injection into a deep saline formation.
Define	**Coffeyville Gasification Plant**	CVR Energy is developing a new compression facility at its fertiliser plant in Kansas. The plant currently produces approximately 850,000 tonnes of carbon dioxide which will be transported to the mid-continental region for use in enhanced oil recovery.

State / District	Country	Volume CO_2	Operation Date	Facility Details	Capture Type	Transport Length	Transport Type	Storage Type	Project URL
Texas	UNITED STATES	8.4 Mtpa	2010	Natural Gas Processing	Pre-Combustion (Gas Processing)	256 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.oxy.com/
Oklahoma	UNITED STATES	0.68 Mtpa	1982	Fertiliser Production	Pre-Combustion	225 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.kochfertilizer.com/
Saskatchewan	CANADA	3 Mtpa	2000	Synthetic Natural Gas	Pre-Combustion	315 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.cenovus.com/
Wilaya de Ouargla	ALGERIA	1 Mtpa	2004	Natural Gas Processing	Pre-Combustion (Gas Processing)	14 km	Onshore to onshore pipeline	Onshore Deep Saline Formations	http://www.insalahco2.com/
Wyoming	UNITED STATES	7 Mtpa	1986	Natural Gas Processing	Pre-Combustion (Gas Processing)	190 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.exxonmobil.com
North Sea	NORWAY	1 Mtpa	1996	Natural Gas Processing	Pre-Combustion (Gas Processing)	0 km	Direct injection	Offshore Deep Saline Formations	http://www.statoil.com/en/
Barents Sea	NORWAY	0.7 Mtpa	2008	Natural Gas Processing	Pre-Combustion (Gas Processing)	152 km	Onshore to offshore pipeline	Offshore Deep Saline Formations	http://www.statoil.com/en/
Texas	UNITED STATES	1.3 Mtpa	1972	Natural Gas Processing	Pre-Combustion (Gas Processing)	132 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.exxonmobil.com/
Texas	UNITED STATES	1 Mtpa	2013	Hydrogen Production	Post-Combustion	101 – 150 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.airproducts.com/
Alberta	CANADA	Up to 0.59 Mtpa (initially 0.29 Mtpa)	2014	Fertiliser Production	Pre-Combustion	240 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.agrium.com/
Alberta	CANADA	1.2 Mtpa	2015	Oil Refining	Pre-Combustion	240 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.northwestupgrading.com/
Saskatchewan	CANADA	1 Mtpa	2014	Power Generation	Post-Combustion	100 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.saskpower.com/
Western Australia	AUSTRALIA	3.4 - 4.1Mtpa	2015	Natural Gas Processing	Pre-Combustion (Gas Processing)	7 km	Onshore to onshore pipeline	Onshore Deep Saline Formations	http://www.chevronaustralia.com/
Illinois	UNITED STATES	1 Mtpa	2013	Chemical Production	Industrial Separation	1.6 km	Onshore to onshore pipeline	Onshore Deep Saline Formations	http://www.adm.com/
Mississippi	UNITED STATES	3.5 Mtpa	2014	Power Generation	Pre-Combustion	75 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.mississippipower.com/
Wyoming	UNITED STATES	1 Mtpa	2013	Natural Gas Processing	Pre-Combustion (Gas Processing)	Not specified	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.conocophillips.com/
Alberta	CANADA	1.08 Mtpa	2015	Hydrogen Production	Pre-Combustion	84 km	Onshore to onshore pipeline	Onshore Deep Saline Formations	http://www.shell.ca/
Kansas	UNITED STATES	0.85 Mtpa	2013	Fertiliser Production	Pre-Combustion	112 km	Onshore to onshore pipeline	Enhanced Oil Recovery	http://www.cvrenergy.com/



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