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Issue 38

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China's CCS program

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Global Status of CCS: latest update



CO2CRC report: keep Australia's CCS options open

CCS in Europe - climate goals could be achieved without CCS says report

A UK vision and technology strategy for CCS

CO2-EOR - the view from Texas

CATCHING OUR FUTURE

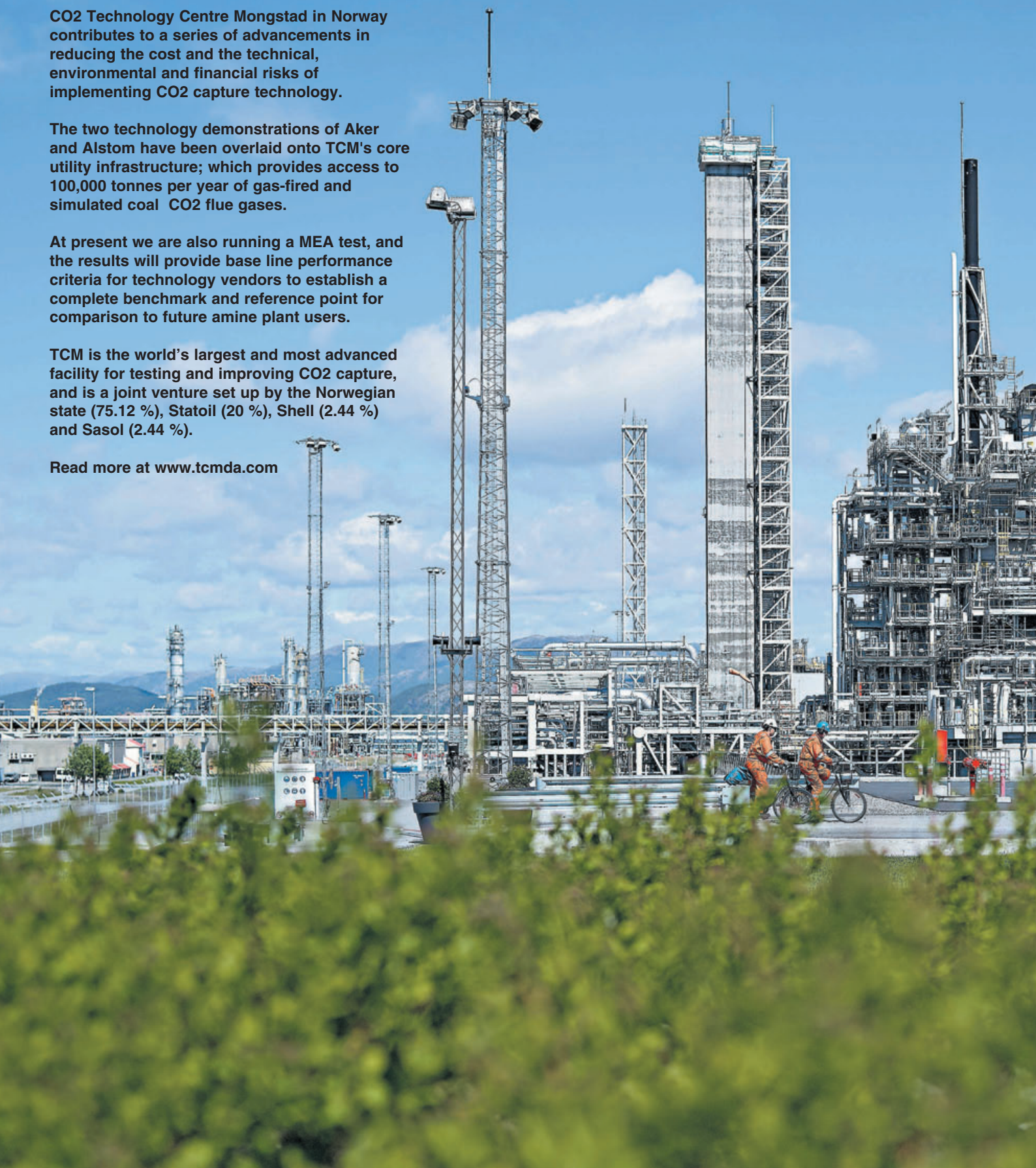
CO2 Technology Centre Mongstad in Norway contributes to a series of advancements in reducing the cost and the technical, environmental and financial risks of implementing CO2 capture technology.

The two technology demonstrations of Aker and Alstom have been overlaid onto TCM's core utility infrastructure; which provides access to 100,000 tonnes per year of gas-fired and simulated coal CO2 flue gases.

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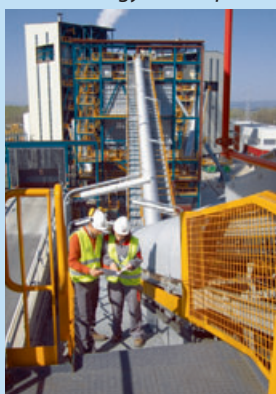
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Front cover: Foundation Ciudad de la Energía's (CIUDEN's) Technology Development Plant in Spain is a test centre for the development of oxy-combustion technologies, with the aim to validate those technologies for application at commercial scale and to be a site for technical training



Leaders

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CIUDEN progresses full chain CCS research

Foundation Ciudad de la Energía (CIUDEN) has two sites in Spain working on oxy-combustion carbon capture, CO₂ transport and geological storage. Recent results have shown that carbon capture can be successfully achieved with a circulating fluidised bed (CFB) boiler.



CIUDEN's Technology Development Plant in Spain is a test centre for the development of oxy-combustion technologies, with the aim to validate those technologies for application at commercial scale and to be a site for technical training

Foundation Ciudad de la Energía, CIUDEN, was created by the Spanish Government in 2006 as a non-profit R&D institution fully conceived for collaborative research, development and demonstration of efficient, cost effective and reliable Carbon Capture and Storage (CCS). CIUDEN is leading Spain's CCS research efforts with programmes covering the whole chain, and has become one of the most relevant European R&D initiatives focussed on CCS.

CIUDEN's technological installation, es.CO₂ Centre, is divided into two main facilities for the research and development of technologies of the whole CCS chain, including transport, employing 80 people in total. Both sites, the Technology Development Plant for CO₂ Capture and Transport and the Hontomin Technology Development Plant for CO₂ Geological Storage, were built as part of one of the six demonstration projects funded through the European Energy Programme for Recovery of the European Commission.

Technology Development Plant for CO₂ Capture and Transport

The TDP for CO₂ Capture and Transport, located in Cubillos del Sil (NW Spain), with an industrial site area of 65,000m², incorporates advanced equipment for the development of oxycombustion technologies, with the aim to validate close-to-market and emerging technologies for application at commercial scale and to be an installation for technical training.

At the core of the TDP are two boilers: 20 MWth pulverised coal (PC) and 30 MWth circulating fluidised bed (CFB). Both boilers are designed to use air or a mixture of recirculated flue gas and commercial oxygen to produce the oxidant stream and are capable of burning a wide range of coal, even biomass co-firing.

Oxycombustion, by using a mixture of pure oxygen and recirculated flue gases instead of air, produces a concentrated CO₂ flow, ideal to be applied in CO₂ capture installations.

The TDP also includes the systems to study the whole integration of the carbon capture and transport process:

- fuel preparation
- flue gas cleaning
- flue gas recirculation (FGR)
- CO₂ compression and purification unit (CPU) able to treat in the warm part a flue gas flow of around 200 tpd, and getting a production in the cold part of 10 tpd of liquid CO₂ (>99% purity)
- CO₂ transport experimental rig (with a length of 3,000 m of 2" diameter pipelines, aiming to simulate a 150 km long real pipeline)

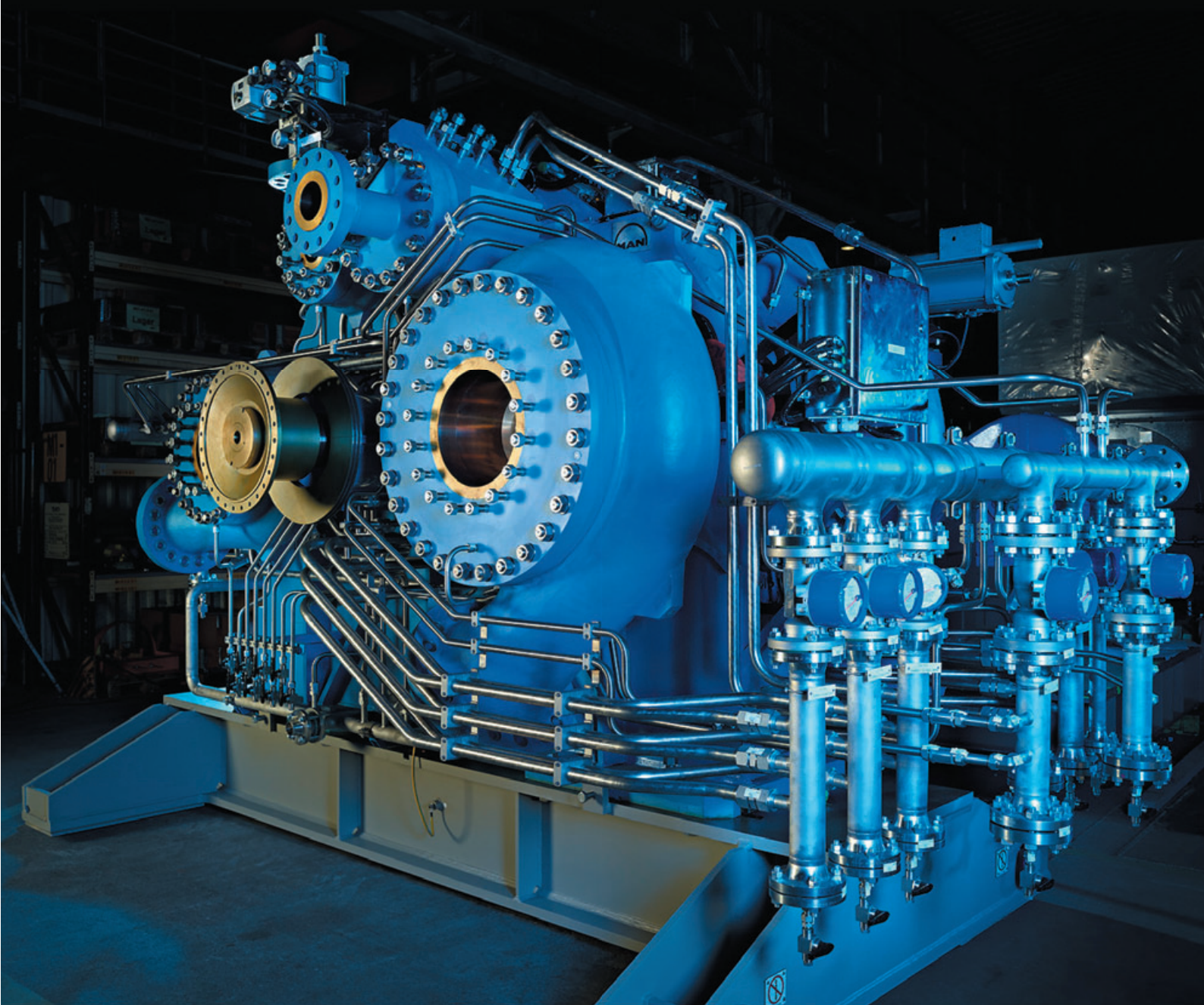
The TDP for CO₂ Capture and Transport is also completed with a biomass gasifier (3 MWth) and a pilot plant for CO₂ injection into soils (PISCO₂).

At this technological site, the full chain of processes from fuel preparation to CO₂ purification can be validated, producing a stream ready for transport and storage.

Extensive testing work has been carried

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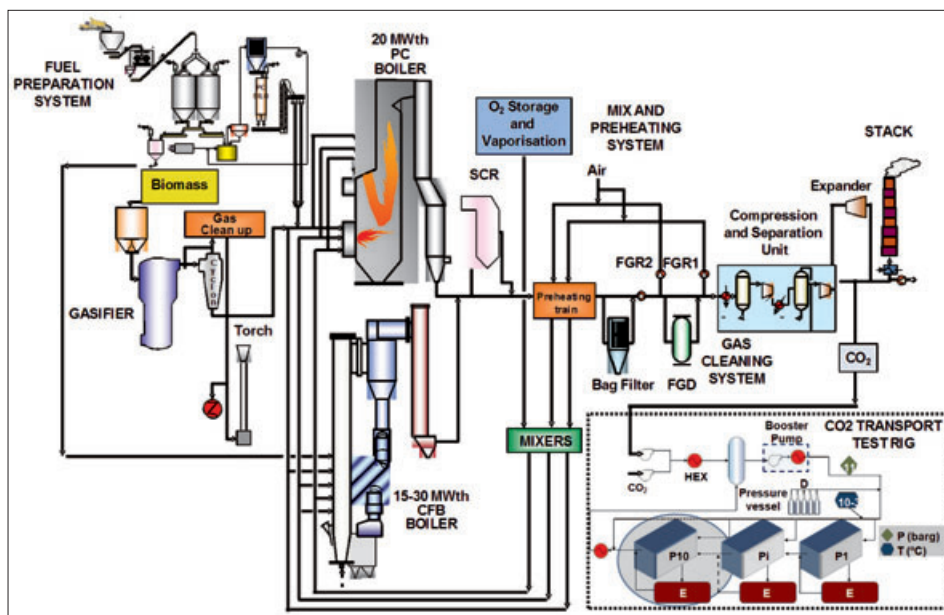
Acquired data is paramount for scaling-up the PC, CFB, and CPU technologies. The flexibility of the boilers for oxy-combustion and CO₂ capture with a range of different fuel types including biomass has also been tested.

The Plant for R&D on CO₂ Geological Storage is situated in Hontomín (N Spain), and consists of an installation devoted to performing real scale experiments in deep porous rock formations to test and develop new technologies in storage engineering, CO₂ injection strategies and safe operation.

The location fulfils the internationally established geological criteria for installations of this kind, such as depth, porosity, thickness of the seal and reservoir formations and water salinity.

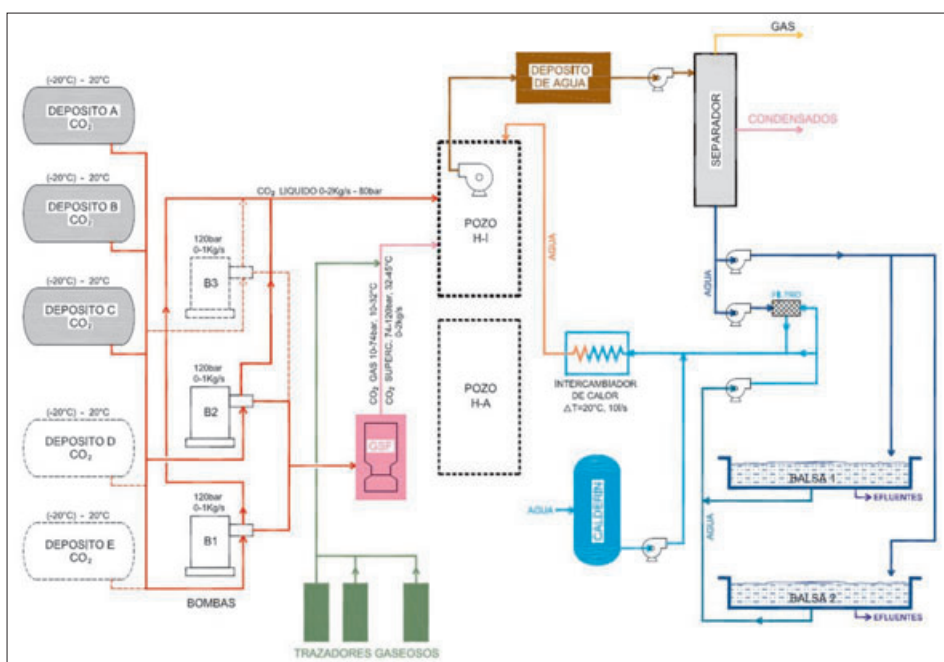
The high number of techniques deployed at this site, both deep underground and near surface and in the atmosphere, give an outstanding opportunity of validating the best available techniques and elaborating protocols; these activities will be focused on assuring a safe operation, including well integrity and leakage prediction techniques. Given the setting of the facility, the possibility to arrange training activities is also opened.

One of the main milestones achieved at CIUDEN's es.CO2 Centre, was the successful firing of the CFB boiler in oxycombustion mode in September 2011, being the biggest CFB boiler operating in the world in oxycombustion.



Another fundamental milestone reached in November 2011, was the start-up of the CO₂ compression and purification unit (CPU), completing the integration of the CO₂ capture system, and being the first time in the world that CO₂ was captured using oxycombustion of coal in CFB technology.

Several fuels and blends of coals, pet coke and biomass have been used in both boilers, proving the flexibility of the instal-



9 9 9 7 9

lation, and enabling study of the best configuration and parameters for the most efficient combustion and emissions reduction with such fuels.

The tests carried out in the CFB boiler produced important data for the optimization of the window temperature for combustion performance and sulphur retention in the CFB boiler. Experience has also been gained on the fly ash recirculation to reduce unburnt material. The tests carried out include different ammonia injection ratios studying the influence in NO_x and SO₂ emissions. Bed temperature control has been made by using an external heat exchanger (Intrex™). Additional control of bed temperature has been studied through O₂ partial pressure variations.

A systematic dynamic behaviour characterization of the CFB boiler has been carried out through different tests, enabling the establishment of shut-down and starting up routines, and a dramatic reduction of specific emissions compared to those in air mode has also been achieved.

Through several tests, it has been proven that a CFB boiler can be successfully integrated and operated with the CPU in a safe and reliable way in order to obtain a near-zero emission plant proving load follow-up capabilities (CFB & CPU) of up to 3% / min.

Related to the operation of the plant, other issues have arisen, among others:

- Solid handling, fine coal particles, agglomeration and slagging. One of the technical difficulties found were those related to the fuel feeding system. A fuel feeding system has been redesigned that allows the operation of the boiler with reliability and safety.

- Optimal configuration in oxidant distribution

- Operational flexibility

- Design: leakages, acid dew point, health and safety issues

It has been proved that a CFB boiler can be successfully operated in air and oxy modes (similar temperature), and fundamental data for the design of a commercial size oxy CFB boiler have been collected. Also some design tools have been validated. Test campaigns run, and the data and experience gained, will help to do the scaling up of the technologies by process optimization and are fundamental for the design of a commercial size oxy CFB boiler, and will foster the step to 2nd and 3rd generation technologies. It will also help to reduce risks for future commercial projects.

Summarizing, it can be said that the integrated oxyfuel CFB concept has been proven, but there is still room for future optimization.



Figure 3 - the control room at the Technology Demonstration Plant for CO₂ capture and transport

Transport

At the Experimental facility for CO₂ transport, some experiments have been carried out during the commissioning of the installation and after it.

Pressure and temperature changes have been studied along the installation, changing variables such as composition of the flow, pumping pressure, different lengths of the piping, etc. The behaviour of the installation to some transitions has been gathered, such as the start up and shut down of the pump. Stagnant conditions and system evolution

has also been evaluated, and some depressurization tests have been carried out. Commercial CO₂ has been used, but also CO₂ from the oxycombustion process. During these tests, CO₂ flow was in liquid form, reaching dense phase properties, but also supercritical conditions.

The pressure loss of the flow along the installation versus different output pressures of the pump has also been studied. The response of the CO₂ rich flow to temperature changes was looked at, as was the influence of the pumping pressure in the temperature

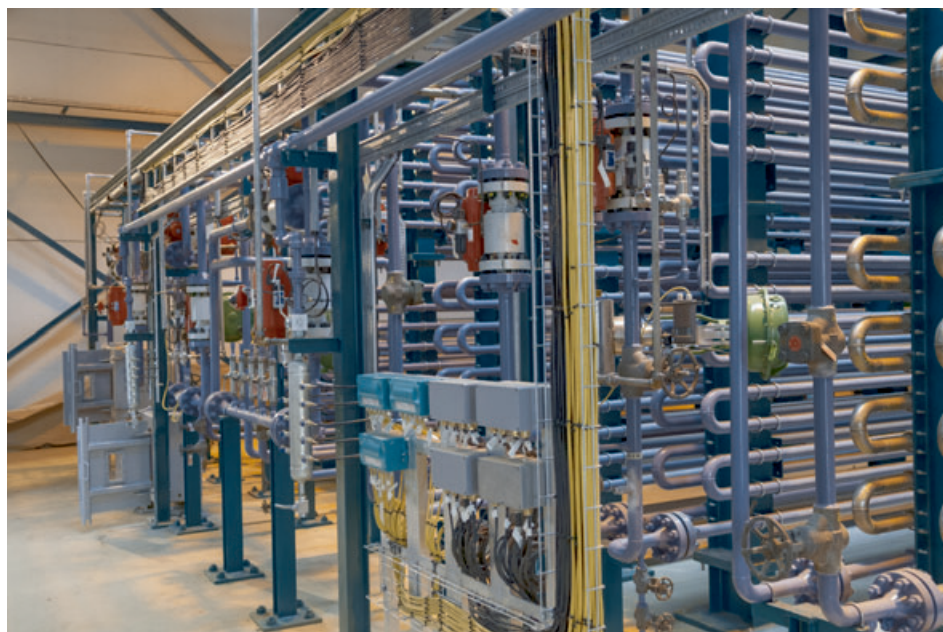


Figure 4 - the CO₂ transport experimental facility



Figure 5 - the Hontomin Technology Development Plant for CO₂ Geological Storage in northern Spain

of the CO₂ with different CO₂ compositions. Design problems and characteristics related to the pump have been studied.

The facility has demonstrated its capabilities to simulate transport conditions in dense phase.

CO₂ Geological Storage

Cost-effective actions have been achieved, such as the drilling of the wells with light drilling equipment, with 2,5M€ of investment per well, achieving a 60% cost reduction when compared with Oil&Gas techniques.

More lessons are still to come, after analyzing the different baselines with real data, checking the reliability of the monitoring techniques leading to a substantial saving while assuring safe operation.

A risk assessment model has also been developed and updated with the existing data.

The Technology Development Plant for CO₂ Geological Storage aims to acquire new knowledge regarding CO₂ injection and monitoring techniques which will lead to an increase in technical feasibility and safety issues.

Public engagement

A comprehensive program has been developed in communication and public perception, allowing the creation of trustworthy relationship with key stakeholders and the local community where both technology sites are located. This work has been part of a site specific communication plan, where flexibility, transparency and proactive methods are the keywords.

CIUDEN has gained a valuable experience in dissemination and public engagement with stakeholders.

What's next

Due to the lack of a market driver for CCS, nowadays there is not any commercial full scale CCS project in operation in Europe. CCS is not developing as planned according to the European Commission roadmaps and most of the international agencies or organisms trying to reduce greenhouse emissions.

Taking into account that the social-economic climate doesn't allow a clear and positive FID to move forward to the commercial size plants, an opportunity for a demo project arises as a solution for keeping on track with CCS technological development.

CIUDEN has been mentioned by MEP Chris Davies in the Motion for a European parliament resolution on implementation report 2013: developing and applying carbon capture and storage technology in Europe (2013/2079(INI)), where regarding EU regulation and funding, the European Parliament "requests that the Commission assess the benefits of adopting and developing the Ciuden CCS pilot project in Spain, which has received some EUR 100 million in support funding from EU sources, as a European test facility for capture technologies and inland CO₂ storage".

CIUDEN proposes to become a Demo Plant for the full CCUS chain in an integral project, with over 7,000 hours of operation available for demonstration and R&D, creating a European Centre of Excellence for continuous R&D and technological develop-

ment "near to market technologies". The large size facilities in CIUDEN will contribute to achieve cost reductions in CCS technologies, enabling a positive public perception that will lead to the maturity of the technologies at a reasonable cost.

This proposal includes the construction of an air separation unit (ASU) to provide the oxygen for the oxycombustion, a steam turbine, a CPU cold section enlargement and a NGCC at the Capture TDP, and increasing temporary storage (CO₂ tanks) and pumping capacities at Hontomin TDP to be able to inject up to a 3kg/s flow rate

CIUDEN aims to be a European CCS asset, able to provide support for:

- Keeping the momentum for CCS development
- Enabling knowledge sharing and technological development
- Carrying out additional developments in near-to-market technologies, minimizing technological risks
- Working on improving public perception
- Technical training by qualified staff
- Acting as an advisor to develop regulations and standards for technologies of the CCS chain



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China's policies for addressing climate change and efforts to develop CCUS technology

China has moved to the forefront of the global CCUS development and industrial demonstration effort and now boasts the largest number of CCUS industrial demonstration projects in the world, several of which are rapidly developing.

China is one of the largest energy-producing and -consuming countries in the world. Coal has historically been the country's dominant source of primary energy, which has resulted in high CO₂ emissions. Finding a way to effectively reduce CO₂ emissions while meeting the ever increasing energy demand is a pressing issue that must be tackled by the Chinese government.

Due to the unique potential to dramatically reduce CO₂ emissions from large, centralized fossil energy consumption sources, carbon capture, utilization, and storage (CCUS) technology is attracting global attention.

The authors of this article have been closely monitoring CCUS development in China since its inception, and also have been actively participating in CCUS-related R&D, commercialization, and policy-making efforts. In the hopes of expanding the knowledge base around China's efforts in climate change mitigation and CCUS development, this article introduces China's policies and technical efforts, including R&D and industrial-scale demonstrations, to address this global challenge.

We believe that China is now playing a leading role in the collective campaign to develop CCUS and will contribute significantly to climate change mitigation. We suggest that the world should pay close attention to China's CCUS progress and boost cooperation with China to increase the rate of development and adoption of this technology globally.

China's Energy Resources Coal's Role in Providing Primary Energy

China's economy has been growing quickly in recent years; a significant portion of that growth can be attributed to large-scale infrastructure construction, which has been accompanied by rapid growth in energy consumption. In 2012, the total amount of primary energy consumption in China reached 2.74 Btoe (billion tonnes of oil equivalent)¹

Given its extensive coal reserves, coal accounts for 68.49% of China's primary energy consumption,² as is shown in Figure 1. Coal provides 75% of China's industrial fuel, 76% of the fuel for power generation,



International collaborative efforts, such as technology transfer (for example, the meeting shown above between Chinese and Japanese researchers) and jointly sponsored projects, are critical to accelerating the development and deployment of CCUS

80% of household fuel, and 60% of raw materials for the chemical production industry.

Therefore, from the perspective of energy security, China must continue to rely on its domestic coal resources to meet energy demand in the mid- and long-term future. Without an unforeseen change in resource estimates and a significant reduction in cost for other energy options, coal's dominant role in China's energy mix will not change.

Environmental Pressure

Large-scale utilization of coal has made China one of the largest CO₂ emitters in the world.⁴ The power industry, which is responsible for more than half of China's total consumption, which is shown in Figure 2, contributes about 40% of CO₂ emissions. China and other major emitters are facing increased international pressure to reduce CO₂ emissions or, at the very least, cut the rate of growth. The power industry, as the biggest emitter with centralized emissions, will inevitably bear the brunt of policies to address these concerns.

CCUS is a technology suitable for CO₂ reduction from large point sources and therefore has attracted significant attention from the Chinese government, industry, and research institutions. China has focused on CO₂ utilization, rather than only storage, based on the current reality that pure CCS projects are expensive and difficult to move forward at the industrial scale.

China's Climate Change Mitigation Efforts

The Chinese government has demonstrated its dedication to addressing climate change by developing a comprehensive scheme for climate change mitigation efforts that takes into account China's current stage of devel-

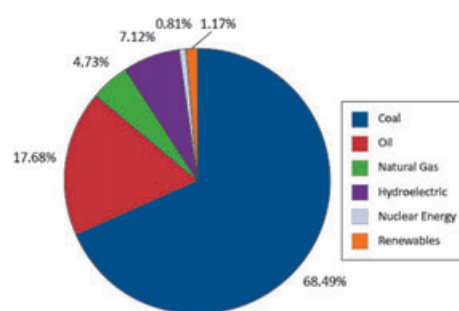


Figure 1 - China's 2012 primary energy consumption³

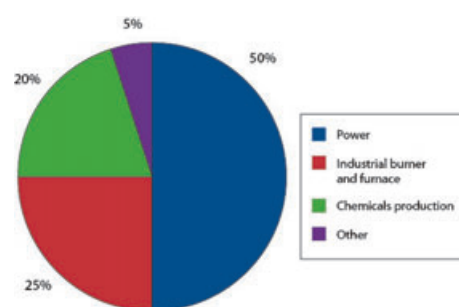


Figure 2 - Coal consumption by sector

opment.

At the 2009 UN Climate Change Summit, President Hu Jintao vowed that China would make progress in two key areas: 1) improve energy conservation and increase energy efficiency and 2) develop renewable energy and nuclear energy to reduce the proportion of fossil fuels in China's energy mix.⁵ In accordance with these promises, in November of the same year the State Council of China declared that CO₂ intensity per unit GDP would be reduced by 40–45% compared to 2005 by the end of 2020.⁶

Relevant Policies

China was one of the first countries to propose measures to mitigate climate change, and has continued to follow up with corresponding policies on those measures, as is outlined by timeline in Figure 3.^{7–14}

Science and Technology

Although CCUS has progressed to the industrial scale, reducing costs and long-term competitiveness will require continued investment in smaller-scale R&D. Such work is being carried out globally, but China's central government has been particularly supportive of such research projects.

Many important CCUS-related R&D collaboration programs have been carried out among universities, research institutes, and energy corporations. Figure 4 shows the number of nationally supported programs for CCUS-related technologies, which are categorized by type, as well as their sponsoring sources. Most programs are sponsored by MOST (Ministry of Science & Technology of China), which is now leading national support for CCUS development and covers a wide range of CCUS-related technologies.

In addition to the government-supported domestic projects, China is also actively participating in several CCUS-related international collaborations (see Table 1). This



Figure 3 - Timeline of select CCUS-related policies in China Note: S&T is science and technology

provides experts in China the opportunity to learn about the latest international achievements in CCUS technologies, which can help increase the rate of development and deployment of domestic CCUS projects. This collaboration is also useful to share China's progress on climate change mitigation internationally.

With the support from these government-dominated or international-collaboration R&D programs, China has made great progress related to CCUS. However, to move CCUS forward, industrial-scale demonstrations are critically important.

CCUS Demonstration Projects Throughout China

In the last five years China's largest energy companies have carried out a dozen CCUS demonstration projects, some comprehensive (i.e., capture and utilization and/or storage) and some partial (i.e., capture or utilization and/or storage). These projects were carried out either independently or through collaboration (often with government support). Implementation of such demonstration projects is necessary to verify the technical and economic viability of CCUS; in addition, these demonstrations are laying a technical foundation for future large-scale implementation of CCUS in China.

Major CCUS industrial-scale demonstration projects being carried out in China in recent years are listed in Tables 2–4. The projects in Table 2 are pure CO₂ capture projects; projects in Table 3 are pure CO₂ storage or utilization projects; and projects in Table 4 are integrated projects that include CO₂ capture and storage and/or utilization. These projects are geographically distributed throughout much of China.

There is a tremendous amount of CCUS activity occurring in China; therefore, only select demonstration projects with global significance, such as first-of-a-kind or industrial-scale projects, are discussed in greater detail in subsequent sections.

Select CO₂ Capture Demonstrations

Huaneng Shidongkou CO₂ Capture Project: Based on the successful experience with the Gaobeidian demonstration project, Huaneng Group established a larger flue gas CO₂ capture demonstration at Shanghai Shidongkou No. 2 Power Plant.

The project adopted the same technology and process as the Gaobeidian project, but at a much larger scale; the new project scale was 100,000–120,000 tonnes CO₂/yr. This was the largest post-combustion CO₂ capture demonstration in the world at the time operation began. The captured CO₂ is sold to chemical plants nearby as raw material. Constrained by a limited market, the CO₂ is sold at a price only offsetting the cost.

HUST CO₂ Capture Project: Huazhong University of S&T (HUST) established China's first, and the world's third, 3-MWth oxy-fuel combustion pilot plant in Wuhan. This pilot is capable of capturing more than 7000 tonnes CO₂/yr. Based on that project, HUST is collaborating with power-sector companies to establish the world's largest (35 MWth) oxy-fuel combustion demonstration in Yingcheng, Hubei. The demonstration plant will be able to capture more than 100,000 tonnes CO₂/year. This progress clearly demonstrates that China has become a global leader in the development of oxy-fuel combustion technology.

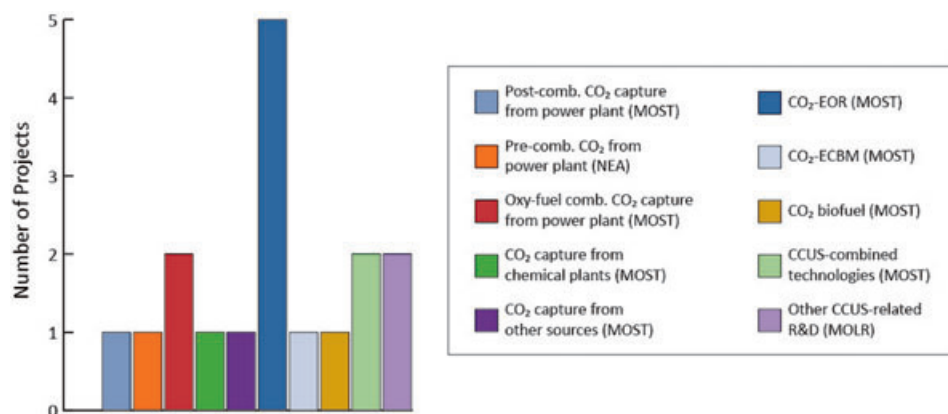
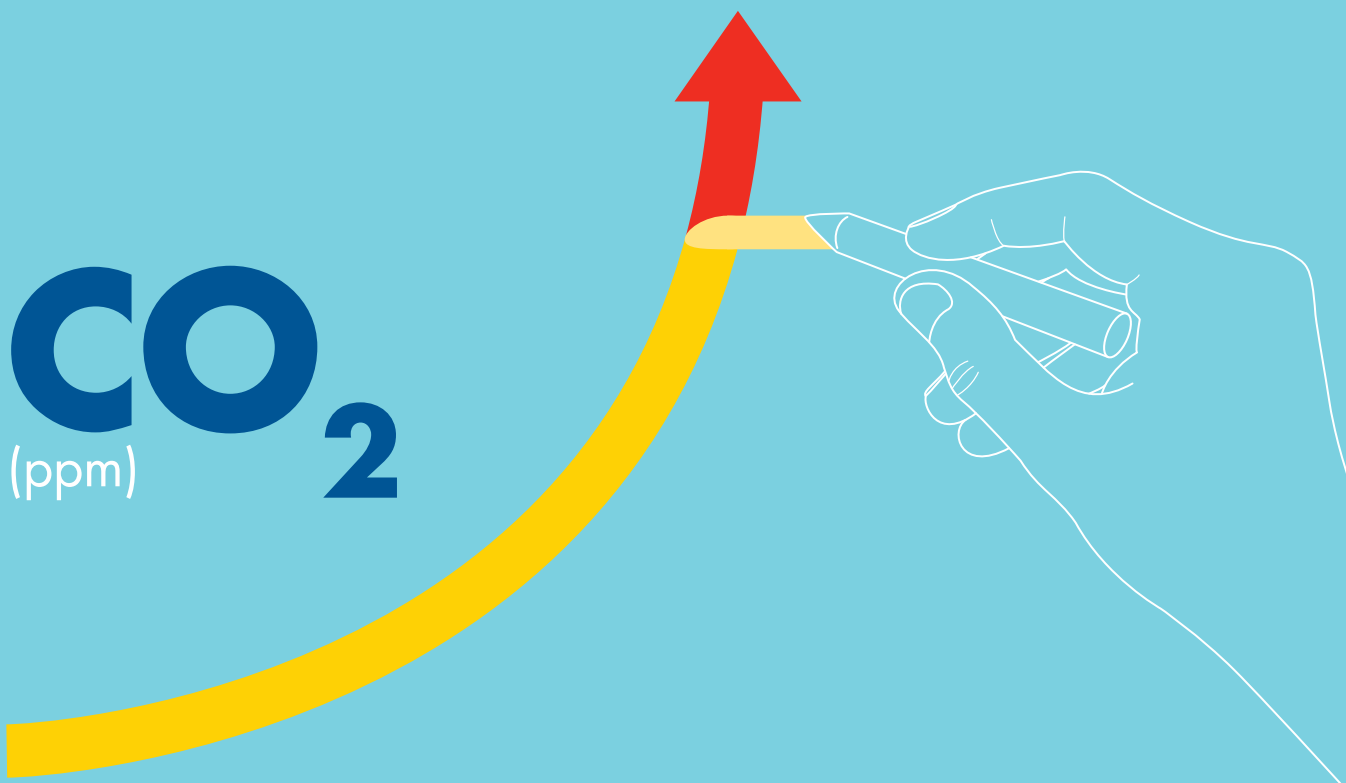


Figure 4 - Major government-supported CCUS-related programs

Notes: NEA is National Energy Administration of China; MOLR is Ministry of Land & Resources of China; EOR is enhanced oil recovery; ECBM is enhanced coal-bed methane recovery



CO₂
(ppm)

CO₂ Concentration evolution in atmosphere

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Select CO₂ Storage/Utilization

Demonstration

Jilin Oilfield Project: Since 1997, PetroChina has been executing an industrial-scale CO₂-EOR demonstration at Jilin Oilfield. Presently 150,000 tonnes of CO₂ separated from a nearby natural gas field are injected into an oil reservoir each year; as a result, oil field productivity has increased by 80%.

PetroChina plans to increase the CO₂ injection rate from the current level to 300,000–1,000,000 tonnes CO₂/yr. Although CO₂-EOR is a mature technology in the U.S., the geology of China's oilfields is quite different, so this demonstration is critically important to understand and implement large-scale CO₂-EOR with storage under China's complicated geological conditions.

Select Integrated CCUS Demonstration

Integrated CCUS Project by GreenGen, Huaneng: In 2009, Huaneng began cooperation with Peabody Energy (U.S.) to establish China's first 265-MW IGCC demonstration project in Tianjin, which was placed into service on 12 December 2012. Huaneng also plans to implement a Selexol physical absorption-based CO₂ capture retrofit for part of the fuel gas at this plant by 2015.

This project, which will capture 60,000–100,000 tonnes of CO₂/yr, will be the first pre-combustion CO₂ capture demonstration on an IGCC plant in China and also the world. If successful, Huaneng

Project Name	Sources of Financial Support	Execution Period	Major Participants
<i>The China-Australia Geological Storage of CO₂ (CAGS) Project</i>	MOST and Department of Resources, Energy and Tourism of Australia	2009–2011	<i>China:</i> The Administrative Centre for China's Agenda 21, China Geological Survey, Tsinghua University, etc. <i>Australia:</i> GeoScience Australia
<i>Joint Research on Lower Emission IGCC Technology between China and U.S</i>	MOST, U.S. Department of Energy	2010–2012	<i>China:</i> Chinese Academy of Sciences (CAS) <i>U.S.:</i> National Energy Technology Laboratory, Pacific Northwest National Laboratory
<i>Sino-Italian CCS Technology Cooperation Project</i>	Cooperation Action within CCS China-EU, (COACH), Italian Ministry for the Environment, Land and Sea	2010–2012	<i>China:</i> The Administrative Centre for China's Agenda 21, Huaneng, Tsinghua University, Chinese Academy of Sciences, etc. <i>Italy:</i> Ministry for the Environment, Land and Sea, Enel, etc.
<i>(COACH)</i>	MOST and EU	2006–2009	<i>China:</i> The Administrative Centre for China's Agenda 21, Huaneng, Tsinghua University, Zhejiang University, Chinese Academy of Sciences, etc. <i>EU:</i> Imperial College, Air Products, Alstom, Shell, British Geological Survey, SINTEF, etc.
<i>UK-China Near-Zero Emissions Coal project (NZE)</i>	MOST, Department of Environment, Food and Rural Affairs of UK	2007–2009 (Phase I) 2010–2012 (Phase II)	<i>China:</i> Administrative Centre for China's Agenda 21, Xi'an Thermal Power Research Institute, Tsinghua University, Zhejiang University, CAS, SINOPEC Shengli Oilfield, etc. <i>UK:</i> Alstom, British Geological Survey, BP, Shell, Schlumberger, Doosan Babcock, Cambridge University, etc.
<i>U.S.-China Clean Energy Research Center</i>	MOST and U.S. Department of Energy	2010–2015	<i>China:</i> Huazhong University of S&T, S&T and Industrialization Center of Ministry of Housing and Urban-Rural Development, Tsinghua University, etc. <i>U.S.:</i> West Virginia University, Lawrence Berkeley National Laboratory, University of Michigan, etc.

Table 1 - Recent international collaborative projects related to CCUS

will conduct a full-scale pre-combustion CO₂ capture retrofit, resulting in a near-zero pollutants/near-zero CO₂ coal-based power plant. Huaneng plans to store the captured CO₂ in depleted oil/gas fields or saline aquifers nearby; the region around Dagang Oilfield has been preliminarily selected.

Conclusions

Today China has moved to the forefront of the global CCUS development and industrial demonstration effort. China now boasts the largest number of CCUS industrial demonstration projects in the world, several which are rapidly developing.

These projects are a tangible contribution made by China to the field of climate change mitigation. Therefore, the authors suggest that the world should keep an eye on CCUS progress in China.

It is worthwhile for international organizations to consider providing technical or financial aid or to enhance bilateral or multilateral collaboration with China, in the hopes of further advancing and encouraging adoption of CCUS technology. Thus, the efforts of China can be leveraged to play an even larger role to help reduce the increase in global CO₂ emissions.

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No.	Project Name	Type	Site	Scale (tonnes CO ₂ /yr)	Year Begun
1	Huaneng Gaobeidian CO ₂ Capture Project	Post-combustion capture (PCC) from power plant flue gas	Chaoyang, Beijing	3000	2008
2	Huaneng Shidongkou CO ₂ Capture Project	PCC from power plant flue gas	Baoshan, Shanghai	100,000	2010
3	China Power Investment Co. Shuanghuai CO ₂ Capture Project	PCC from power plant flue gas	Hechuan, Chungking	10,000	2010
4	CO ₂ Capture Project by Institute of Advanced Energy & Power, CAS	Pre-combustion capture from IGCC fuel gas	Lianyungang, Jiangsu	~10,000	2013
5	HUST CO ₂ Capture Project	CO ₂ capture from oxy-fuel combustion	Yingcheng, Hubei	100,000	2013

Table 2 - Pure CO₂ capture demonstration projects in China

No.	Project Name	Type	Site	Rate (tonnes CO ₂ /yr)	Year Begun
6	Jilin Oilfield Project	CO ₂ -EOR/storage	Songyuan, Jilin	300,000–1,000,000*	1997
7	CUCBM Project	CO ₂ -ECBM/storage	Jincheng, Shanxi	~1900**	2005
8	ENN Project	CO ₂ utilized for microalgae cultivation	Dalate, Inner Mongolia	20,000	2010

Table 3 Pure CO₂ storage/utilization demonstration projects in China

*Plans are to soon increase injection to this rate; to date, the capture demonstration facility capacity of 150,000 tonnes of CO₂/yr has been completed.

**This project is a short-term pilot CO₂-ECBM project co-established by China and Canada, with CO₂ injection operation lasting for only 13 days. Approximately 1900 tonnes of CO₂ was injected into the coal bed. Although this was a relatively small in total injection amount, this was the first trial of CO₂-ECBM production in China; therefore it is included in this article

No.	Project Name	Type	Site	Scale (tonnes CO ₂ /yr)	Year Begun
9	Integrated CCUS Project by Shengli Oilfield Power Plant	PCC from power plant flue gas + CO ₂ -EOR with storage	Dongying, Shandong	30,000	2010
10	Integrated CCUS Project by GreenGen, Huaneng	Pre-combustion capture from coal-based fuel gas of IGCC plant + CO ₂ -EOR/storage	Binhai, Tianjin	60,000–100,000	2012
11	Integrated CCUS Project by Shenhua Coal-to-Liquid Co., Ltd.	Capture from gasification unit of a coal-to-chemicals plant + saline aquifer storage	Ordos, Inner Mongolia	100,000	2011

Table 4 - Integrated CCUS demonstration projects in China

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More information

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Japan's FY2014 draft budget and CCS-related actions explained

Terufumi Kawasaki, who served as Hitachi's representative for the Global CCS Institute, outlines Japan's CCS budget and projects to demonstrate the technology and facilitate CCS adoption

Japan's economic measures, often referred to as the 'Abenomics' of Prime Minister Shinzo Abe, are under review as its Diet (parliament) convenes for a 150-day ordinary session and discussions taking place over the Financial Year (FY) 2014 draft budget.

CCS has been chosen as an important energy policy to combat global warming. This Insight will provide details on the CCS measures included in draft budgets released by both the Ministry of Economy, Trade and Industry (METI) and the Ministry of the Environment (MOE) and what this might mean for the industry.

Resources and energy measures

For measures related to resources and energy, METI aims for Japan to be 'the world's most advanced country in terms of

energy' by diversifying energy sources through significantly increasing renewable energy and achieving higher efficiency in coal-fired power generation. An important theme is the development and accelerated application of highly efficient thermal power generation and in that context, the implementation of CCS is mentioned.

A budget of Yen11.3 billion is comparable to the FY2013 budget level (Yen12.6 billion), which shows the willingness of METI to continuously invest in the advancement of CCS.

Moreover, as a diplomatic strategy contributing to the global greenhouse gas (GHG) emission reduction, METI also included the cost of the Bilateral Offset Credit Mechanism through which Japan can diffuse its own advanced technologies in partner countries.

CCS to help reduce GHG emissions by 80%

MOE called for the need to accelerate the advancement of CCS in order to help reduce Japan's GHG emissions by 80% by 2050. It drew up a new Yen1.25 billion plan to tackle this task. According to the plan, MOE will carry out exploration of suitable CO₂ storage sites in the surrounding waters including offshore areas. It also considers the transportation system necessary for CO₂ storage, and plans demonstration tests which is expected to be started in three years.

Since Japan consists of mountainous islands, there is not much free space onshore and the coastal areas are already highly developed for many different uses. For that reason, tapping into surrounding waters including offshore areas could help accelerate the CCS implementation in Japan.

Key projects to facilitate CCS implementation

Below are the descriptions of specific project proposals that the Japanese government is trying to put forward:

Support for Tomakomai CCS project

METI proposed to allocate 8.5 billion yen for the FY 2014 to the Tomakomai CCS demonstration project in Hokkaido, which began in 2013 with a planned total budget of Yen50 billion. The project is currently at plant construction stage and it will be promoted for four years including the demonstration test period.

Identification of new CO2 storage sites

The Ministry proposed new projects starting from FY2014. They include identification of CO2 storage sites in Japan for CCS implementation, which will be done in cooperation with MOE. Some geological surveys to identify suitable CO2 storage sites have already been carried out, but more detailed surveys are needed for large-scale implementation. Moreover, it has become increasingly important to consider seabed storages in the surrounding waters including offshore areas.

Transportation for offshore storage

The plan to identify CO2 storage sites in Japan will also estimate the viability of the CO2 transportation system to offshore storage sites by ships. This concept originated as a two-year Global CCS Institute project in 2011 with the research team led by Professor Ozaki of Tokyo University and was developed in collaboration with Global CCS Institute's Japanese Members such as Chiyoda Corporation. The Japanese Government is now actively supporting this plan. This is one example of the Japan-Australia cooperation facilitated by Global CCS Institute.

Japan's CO2 transport and storage system with 'Shuttle Ships'

Europe considered a transportation system using ships to carry CO2 to offshore facilities, but Japan has come up with a different system which sends relatively small shuttle ships back and forth between power stations (CO2 capture plants) along the coast and offshore storage sites. By installing injection equipment on shuttle ships, offshore facilities at the storage sites would not be necessary, and by using small tankers (3,000 ton), the CO2 tanks at the power stations could also be down-sized.

Such ideas could make this system highly extendable, allowing flexible application to multiple capture and storage sites at low costs. Setting up a number of offshore

Institute's 10th Study Meeting in Tokyo

On 13 February 2014, the Global CCS Institute hosted its tenth study meeting in Tokyo. The meeting gave Members the opportunity to listen to a presentation by Mr Masayuki Igarashi of Nippon Steel & Sumikin Engineering Co., Ltd., on their carbon capture system called 'ESCAP'. This facility adopts their original amine solvent and heat integration technologies to enable the large reduction of heat consumption. The process was co-developed with RITE, a Japanese public sector institution. The technology was developed through a part of the research named 'Course 50' which was commissioned from NEDO, another Japanese public sector institution.

Mr Shunsuke Kawai of the Electric Power Development Co., Ltd. or 'J-Power' then presented on their oxygen blown coal gasification pilot plant called 'EAGLE'. They are working to utilize this technology over so-called IGCC electric generation plants to reduce CO2 emissions. At the facility, they developed and then compared two CO2 capture technologies, chemical absorption and physical absorption. The series of tests at EAGLE were successfully completed last year. The tests were also commissioned by NEDO. J-Power is now collaborating with Chugoku Electric Power Co. Ltd., to establish and manage a demonstration plant called 'Osaki CoolGen' where they will engage in some verification tests related to the carbon capture technology.

View the presentations at the Institute's website: www.globalccsinstitute.com

Injection into two formations of different depths



Construction of onshore facilities for the demonstration project



The Tomakomai CCS demonstration project in Hokkaido (Source: Japan CCS Co. Ltd.)

storage site expands the potential of CO2 storage, making CCS a viable option in other countries as well.

More information

This article originally appeared as a blog post on the Global CCS Institute website: www.globalccsinstitute.com

Global Status of CCS update

Global uptake of CCS has seen significant progress in the US, Canada and China while Europe lags behind, says the most recent update to the Global CCS Institute's flagship report, which found 21 CCS projects in construction or operation worldwide, a 50% increase since 2011.

Despite continuing progress in large-scale CCS projects moving into construction and operation in most regions, the overall global effort to date has been slower than ideal, says the Global CCS Institute's latest update to its Global Status of CCS report.

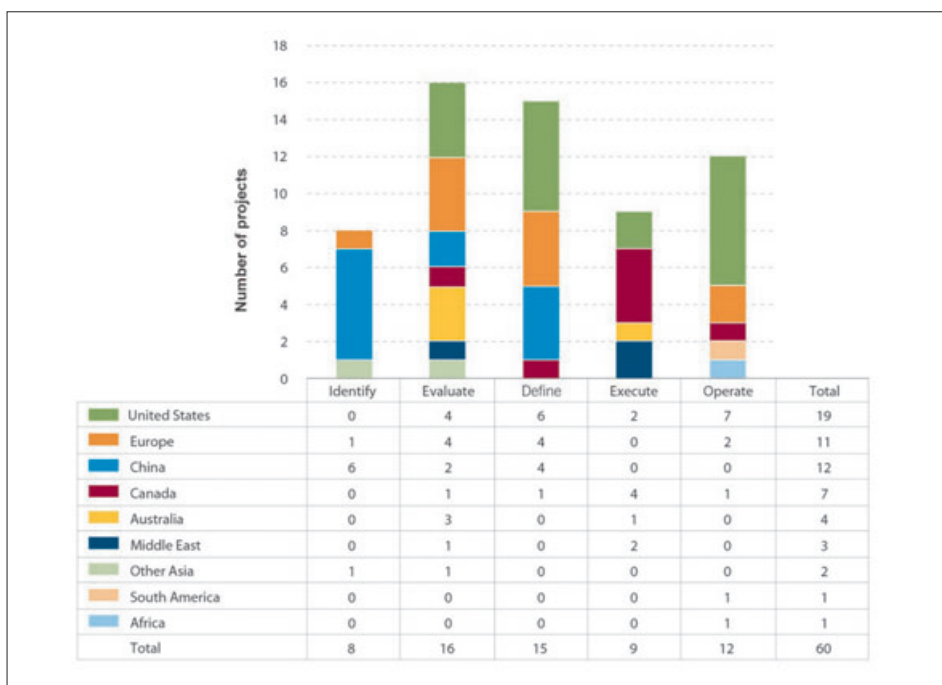
Nonetheless, there are positive signals that decision makers may act to accelerate CCS implementation. The 5th Carbon Sequestration Leadership Forum (CSLF) Ministerial Meeting in November 2013 emphasised the importance of CCS in tackling climate change and identified actions to reenergise the global momentum for the deployment of CCS. This is needed to support existing activity and advance new projects.

As of February 2014 there are 12 projects in operation globally, nine under construction and another 39 in various stages of development planning, of which six may make a final investment decision during 2014. The 21 projects in operation or under construction represent a 50% increase since 2011, a sign of growing confidence in the application of CCS technology at large scale.

North America is leading in the implementation of CCS technology and China is quickly increasing in importance. Momentum has been regained in the United Kingdom (UK) though prospective project start dates are towards the end of this decade. Continental Europe on the other hand has lost a project leadership position that it aspired to several years ago, though the importance of CCS technologies at large scale and continued robust research and development efforts have been recognised by a number of European bodies in recent months.

The first large-scale CCS projects in the power sector - the Boundary Dam Integrated Carbon Capture and Sequestration Project and the Kemper County Integrated Gasification Combined Cycle (IGCC) Project - are nearing operational status in North America. These projects are of global importance to the development of CCS. Similarly, in the Middle East, the world's first large-scale CCS project in the iron and steel sector has progressed into construction.

Projects such as these will build confidence by showing the technology in action, and through innovation combined with advances in capture technology, bring down costs.



Large-scale CCS projects by project lifecycle stage and region/country as of February 2014

Key actions

Notwithstanding the significant progress in CCS development in recent years, the momentum for further development and widespread deployment must be increased. CCS has a vital role to play in a portfolio of low-carbon technologies to tackle climate change at least cost to the world economy.

Key actions that would act as a stimulus to momentum include:

- boosting short-term support for the implementation of demonstration projects globally, especially in continental Europe where project development has stalled

- introducing long-term commitments to climate change mitigation and strong policy action and market-based mechanisms that ensure CCS is not disadvantaged compared to other low-carbon technologies

- implementing measures to deal with the remaining critical regulatory uncertainties, such as long-term liabilities, and continuing funding support for CCS research and development activities along with fostering collaborative approaches to knowledge sharing.

Projects summary

Overall, there are 21 'active' large-scale CCS projects (those in operation or under construction) globally, with a total capture capacity of almost 40 million tonnes of CO₂ per annum.

There are currently 12 large-scale projects operational in markets around the world with one more project expected to begin operation in the first half of 2014 and another later in the year. The two CCS projects nearing operation, located in North America, mark a particularly important development as they are the first CCS projects to be developed at large scale in the power sector.

Another significant development is that a large-scale CCS project in the iron and steel sector has progressed to the 'Execute' or construction stage. This project, located in the Middle East, takes the number of projects in execution to nine (including the two above mentioned projects in the power sector).

There are indications that the steady progress of large-scale CCS projects into construction will continue. Six projects in

Projects and Policy

advanced stages of development planning, with a combined capture capacity of over 10 million tonnes of CO₂ per annum, may be in a position to make a final investment decision during 2014.

These are the Lake Charles CCS Project, the NRG Energy Parish CCS Project and the Texas Clean Energy Project in the United States (US), the Yanchang Integrated Carbon Capture and Storage Demonstration Project and the Sinopec Qilu Petrochemical CCS Project in China, and the ROAD Project in the Netherlands.

Policy developments

In recent months there have been a number of important national and regional policy, legal and regulatory developments, with emphasis on CO₂ emissions standards and targets.

- The US Environmental Protection Agency (EPA) recently released proposals dealing with power plant CO₂ emissions and geologic carbon storage.

- The UK Energy Act received Royal Assent and became law in December 2013 critical parts impacting CCS include the establishment of emissions performance standards and the eligibility of CCS projects for Contract for Difference (CfD) payments.

- The EC in January 2014 proposed a new package of measures aimed at addressing climate and energy targets to 2030, including a 40% EU-wide reduction target for greenhouse gas emissions (below 1990 levels). Also in January 2014 the European Parliament adopted by vote a report released by Member of the European Parliament (MEP) Chris Davies on Developing and applying carbon capture and storage technology in Europe.

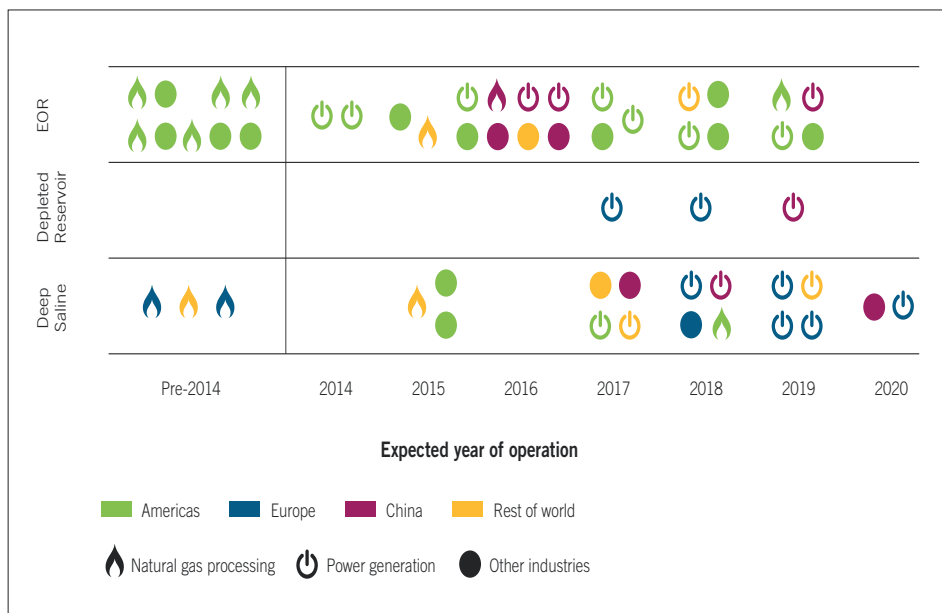
- At the provincial level, the Government of Alberta issued a final draft of the Alberta Regulatory Framework Assessment (RFA) report in August 2013, which evaluated Alberta's CCS regulatory regime and global best practice.

Key project observations

There are a number of positive project developments in North America:

- The Boundary Dam Integrated Carbon Capture and Sequestration Demonstration Project is expected to be in operation in the first half of 2014 while the Kemper County IGCC Project is expected to be in operation before the end of the year.

- The US Department of Energy (DOE) has approved formal funding for the Lake Charles CCS Project (US\$264.1 million) and for the FutureGen 2.0 Oxy-Combustion Project (approximately US\$1 billion) under a cooperative agreement with the respective



Expected start date for large-scale CCS projects by industry sector, storage type and region as of February 2014

project proponents.

- The Emirates Steel Industries (ESI) CCS project has progressed to the 'Execute' stage after the joint venture between Masdar and the Abu Dhabi National Oil Company (ADNOC) awarded an engineering, procurement and construction (EPC) contract to the Dodsall Group.

- In China, the Yanchang Integrated Carbon Capture and Storage Demonstration Project has progressed to the 'Define' stage after the project proponents approved construction of compression and dehydration facilities for 360,000 tonnes of CO₂ per annum.

- Twenty of the 27 projects in operation, under construction or likely to make a final investment decision during 2014 (74%) use or intend to use captured CO₂ for enhanced oil recovery (CO₂-EOR) purposes.

- CO₂-EOR can provide added impetus for a number of first mover projects. The approach is most evident in regions of mature oil extraction such as North America, the Middle East and China, where market opportunities to utilise CO₂ as a commodity with value are strongest.

- In the UK, the Department of Energy and Climate Change (DECC) has awarded funding from its CCS Commercialisation Programme to the White Rose CCS Project to support FEED studies, thereby advancing the project to the 'Define' stage of planning. Discussions between the Programme's other 'preferred bidder', the Peterhead Gas CCS Project, and the UK Government to support FEED studies are at an advanced stage.

- In continental Europe, four projects

have been cancelled or put on hold since the production of The Global Status of CCS: 2013 report:

- The OXYCFB 300 Compostilla Project in Spain and the Porto Tolle Project in Italy, both of which were at the 'Define' stage

- The Getica CCS Demonstration Project in Romania and the Full-scale CO₂ Capture Mongstad (CCM) Project in Norway, both of which were at the 'Evaluate' stage.

- The number of large-scale CCS projects in continental Europe has fallen sharply from 14 in 2011 to just five in February 2014. Two of these are operating CCS projects in the gas processing industry sector (the Snøhvit and Sleipner CO₂ injection projects in Norway) leaving only three projects in the planning stage - the most advanced being the ROAD project in the Netherlands.

- In Europe as a whole (including the UK), planned CCS projects, mostly in the power sector, are not anticipated to begin operation until the 2018-20 period

- Supporting European projects into operation is particularly important in broadening the successful demonstration of large-scale carbon capture in power and industrial applications in combination with geologic/non-EOR storage options

More information

The Global Status of CCS: February 2014 report can be downloaded on the Institute's website:

www.globalccsinstitute.com

CO2CRC - keep Australia's CCS options open

CO2CRC, one of the world's leading CCS research and development organisations, has submitted a report outlining its advice and recommendations on the state of the technology and its role in securing the option to deploy CCS in Australia.

In a submission to the Australian Government's Energy White Paper, the Cooperative Research Centre for Greenhouse Gas Technologies (CO2CRC) has called for Australia to build on its CCS research skills, demonstration projects and strong knowledge base in the developing technology.

"CCS is currently the only technology that can deal with the very large quantity of CO2 emissions from fossil fuel combustion," said Dr Richard Aldous, Chief Executive of CO2CRC.

"Our heavy reliance on fossil fuels domestically, as well as our globally significant fossil fuel exports, make CCS technology highly important for Australia.

The report says that by continuing RD&D and securing the option to deploy CCS, Australia will:

- . preserve an opportunity to move to much lower emissions in the future
- . assist to keep flexibility and reliability in energy supply, whilst leveraging current energy infrastructure
- . have a technology and industrial process available that can complement renewable energy in the grid while dealing with large industrial emissions and
- . contribute to the lowest cost emission reduction solution for Australia

"Studies from the International Energy Agency, the US Department of Energy and others have concluded that CCS, as part of a strategic mix of low emission technologies, is likely to give us both emission reductions and reliable energy supply at the lowest possible cost. CCS is a vital part of the lowest cost pathway to meeting the global 2050 emission reduction targets that most countries have committed to.

"At a high level there are no major technology gaps or impediments to CCS. However as an integrated system the technology is still in the early stages of its development and costs need to be driven down. Large-scale CCS plants currently being built around the world are providing real cost insights and paving the way for cost reductions through learning by doing.

"Australia has played a significant role in CCS technology development and demonstration over the last ten years, and maintaining this capacity will address the many aspects of CCS that are unique to Australia, in-

Recommendations

Preserve the option to deploy CCS

Australia should further develop and preserve the option to deploy CCS in readiness for possible deep cuts in emissions. CCS technology is highly important for Australia, both for domestic application and internationally to preserve the environmental reputation of our exports. It is too significant a technology to be disregarded or sidelined in national energy strategies to reduce CO2 emissions.

Finalise and endorse a national technology road map for CCS

Australia needs a CCS Roadmap with national objectives for CCS development and demonstration and an options pathway to possible CCS deployment. This should be developed as part of the white paper process and ultimately endorsed by the COAG Standing Council on Energy and Resources. Australia must continue to be abreast of international developments in CCS technology and to evaluate and develop Australia's CCS plans and options in the context of its own energy market and emissions reduction strategies.

Continue to support CCS technology and knowledge building in CCS

In order to retain the option to deploy CCS, Australia needs to:

- . continue to develop its CCS technology, capability and knowledge base
- . demonstrate, refine and adapt the technology to Australian conditions
- . contribute to the international effort on technology development

Continue to train specialist engineers and technologists in CCS

Australia should continue to train local specialist engineers and technologists and enhance its international links and collaboration on CCS RD&D, particularly where this might be important to Australia's future energy resource development and exports.

Direct support needed for technology development

To underpin the option to deploy CCS, Australia needs to directly support CCS technology RD&D in the absence of commercial incentives.

Large scale demonstration is important

Support for large scale demonstrations should be continued, to develop construction and operating experience and to retain Australia's option to deploy CCS. Demonstration will be most valuable near significant stranded energy resources, where CCS is essential to development or where a number of emission sources can link into one hub. The lack of commercial incentives to develop CCS technologies and explore for storage in advance of significant commercial deployment also requires attention.

Develop a road map for exploration of the nation's storage resources

Develop a roadmap and key gates for the development of precompetitive exploration and characterisation for CO2 storage, building on Geoscience Australia's regional work. This is an important subset of the roadmap in Recommendation 2.

Continue public education and outreach

It is important to ensure that public outreach continues on CCS. It is also important for the White Paper to acknowledge that CCS (and the associated R&D and large scale demonstration) is a vital part of Australia's energy and emissions reduction strategy.

cluding our geology, the chemistry of our coals, our energy system and the climate itself."

The CO2CRC submission recommends that CCS development in Australia is continued and strengthened, and calls for Australian governments, industry and research organisations to:

- Support continued large-scale demonstration and CCS RD&D in Australia

- Continue to develop the nation's pre-competitive data on CCS geology

- Ensure that any policy settings or incentives for clean energy are technology neutral

carbon
capture
journal

More information

www.co2crc.com.au

Dr Graeme Sweeney – where we are with CCS in Europe

Dr Graeme Sweeney, Chairman of the Zero Emissions Platform, was interviewed by Henry Edwardes-Evans of Platts, a few weeks before Platts' 8th Annual European Carbon Capture and Storage conference about the latest status of CCS in Europe. This article is based on his comments.

On the subject of the European Commissions' Jan 2014 proposals for a 40 per cent reduction in carbon emissions and a strategic reserve for the Emissions Trading Scheme (ETS), Dr Sweeney said, "We commended the effort that EC had put into drafting what I think is a very important proposal."

"We think introducing structural measures to improve ETS is crucial to ensure a robust carbon price, and in that context we supported the proposal for a cap for ETS in 2030," he said.

"The issue of the market stability reserve is I think quite a complex one. Whilst I'm sure that we should have a more definitive view as soon as possible, the Platform is going to take a bit of time to reflect on that, to see what it thinks about overall."

"Directionally we support a strong ETS because we think in the long run that should be the instrument for deploying CCS."

"I think the reiteration of the commitment to CCS as well as recognition in the value in a range of so-called complementary policies in energy intensive industries in the power sector was also extremely helpful," he said.

"The power sector in Europe can't be cost effectively decarbonised without CCS, and CCS is the only decarbonisation option for those energy intensive industries."

But "it seems to us that there is something missing," he said. "We still need an ambitious EU milestone for CCS to be part of the proposed governance process for the member state energy plan."

There could be "individual CCS roadmaps by member states," he said. "This is something we're in favour of. It would give member states flexibility to operate in different ways. We think that could be good for CCS"

"But it needs to be embedded in this overall ambitious milestone at a European level."

The core point with CCS is that "we need to settle how much of this we need to do," he said.

This means "doing enough, first of all now, by pushing on with the demos that are available to us, then resetting our ambition in

2020s to do a volume of activity which does drive the cost down."

"There's an opportunity for us to engage in a conversation about what does that actually look like and how might it be done."

The European Commission has also been talking about auctioning emission allowances within the EU emissions trading system.

"I think the auction revenue idea ... is something the platform has always supported," he said. "It would enable the demonstration projects to take place, it would support them for the energy intensive industries as well."

"You would probably need some operating support as well as the capital grant to make all of that happen."

Slow pace

"The Platform's view is that the pace at which we are proceeding in Europe is too slow," he said. "That's not specifically aimed at any particular member state, or at the EC, but it is a reflection of where we are."

"It was a message that I received very clearly when I was at the CSLF (Carbon Sequestration Leadership Forum) Ministerial (meeting) in December. Others - the Canadians, US, Chinese, Australians - see themselves as clearly demonstrating their commitment by acting, and are concerned that we operating slower than we had previously anticipated. So I think we can't but think that this is a disappointment."

"We know we have one project still progressing in the NER300 - we wish White Rose good fortune in securing that funding. We think it is important it has secured its FEED study [with funding from UK government]."

"We trust that the SSE Shell Peterhead gas plant will also secure FEED study funding with the UK government soon, and the whole process on Contracts for Difference can proceed."

"We are encouraged by the fact that ROAD continues to look to close its funding gap."

"We've got the small sets in Europe. Horizon 2020 gives us the opportunity to do



Dr Graeme Sweeney, Chairman of the Zero Emissions Platform

some storage opportunity, all of which constitutes an overall action set over the next 4-5 years, but less than we thought.

"I think it's crucial that we liaise internationally. That's best done in a relatively informal sort of way."

"But out of the European project network, we look to share best practise with the rest of the world, so we can all seek to drive those costs down."

I believe that at the CSLF there was a clear invitation for us to collaborate on the outcomes and we need to rise to that challenge over the course of this year."

Do we need CCS?

The Zero Emissions Platform has been doing computer modelling to try to work out the most effective way society in Europe can decarbonise and which is the best technology to use, he said. The computer models showed that the best solution is a mixture of renewables and CCS.

"We always argued that that the 2050 energy mix was going to be an appropriate set of technologies. It would include a sub-

stantial renewables component – hydro, wind, solar, geothermal – but that [renewables] was unlikely to provide a secure and robust and low cost solution in isolation,” he said.

“In the back end of last year – we did a lot of work on Pan European modelling – with some real member state granularity,” he said.

“We did two things which I think have not been always by others. We measured the number of onshore square km which could be turned over to onshore wind. We measured and input the number of sunshine hours according to the normal record.”

“We also input to the model a reasonable assumption on storage capacity for CCS. Just to make sure it was reasonably pessimistic, we made that long pipeline offshore CCS.”

“Then we asked, what is the lowest cost solution if you want to hit the decarbonisation target.

The answer was unequivocally clear in multiple runs with many sets of assumptions, low fossil fuel prices,, high fossil fuel prices, even relatively low carbon prices. The model relentlessly chooses a mix of renewables and fossil fuels with CCS, and (where it is permitted) a range of nuclear to give you the most robust outcome.”

“If we do the demo stuff in the front end, we are ready in 2030 for true commercial rollout, we'll only need a carbon price in the high Eur 30 a ton in order to deliver that, given the progress you'll make with a relatively modest volume of CCS on the cost front.

An ultimate price of CCS of Eur 30 per ton “is both feasible and achievable,” he said.

“It reduces the total cost of decarbonisation by something like 30-40 per cent.”

“But it is part of a complementary system, with a very substantial component of renewable energy in it.”

The most important discussion to have in Europe is how to ensure there is a properly level playing field (between CCS and renewables) and how to establish what the milestone looks like for CCS, he said. “I think that's the core matter from my perspective.”

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CCS not essential to Europe climate goals and costs could be moderate

A report by the Potsdam Institute for Climate Impact Research finds that a target of reducing CO₂ emissions by 40% from 1990 levels by 2030 could be achieved without CCS at moderate cost.

The costs of achieving a more ambitious EU climate target are estimated to be moderate, says the report. Upscaling greenhouse-gas emissions reduction from the current 20 percent by 2020 to 40 percent by 2030 would be likely to cost less than an additional 0.7 percent of economic activity.

The report also found that the 40 percent by 2030 target could be achieved without CCS, although nonetheless CCS would be needed to achieve an affordable world-wide transformation.

“In the next two decades, it is possible to achieve the transformation using existing technologies,” says Brigitte Knopf of the Potsdam Institute for Climate Impact Research, who led the study conducted by a dozen research groups. Thereafter, however, energy-economy system models project different costs. Some simulations show a steep increase after 2040, while others show only a linear increase.

One determining factor is the degree to which new technologies can replace old ones. This indicates that technological progress is needed to keep costs in check. “A clear price signal has to be set today, for instance in the European Emissions Trading System,” says Knopf. “It would provide an incentive for innovation that would prevent energy systems from being locked into long-lasting investments in CO₂-intensive technologies, such as coal-fired power plants.”

Current CO₂ reductions fall short of achieving long-term climate targets

“The current 20 percent emission reductions by 2020 could fall short of achieving the long-term climate targets set by the EU,” explains Enrica De Cian of the Fondazione Eni Enrico Mattei and the Euro-Mediterranean Center on Climate Change, Italy.

“Short-term emissions reductions of at least 40 percent by 2030 are necessary to eventually meet the long-term target of an 80 percent reduction by 2050 aspired by the EU.” The reference year is 1990. The models in the study would actually suggest an even more ambitious short-term target than those 40 percent that are currently under debate.

The analysis confirms the core findings of the much debated EU Energy Roadmap,

which details the EU climate and energy strategy. “By setting targets for 2030, the EU would signal its willingness to contribute to the global climate mitigation effort”, De Cian points out. “And a positive reaction of other countries to this signal could foster technological change and innovation within Europe as well.”

Many options to choose from - wind power could expand sevenfold

Options explored by the study to reach the EU climate target range from renewable energies to nuclear energy and energy-efficiency increases. “There’s a wide choice for decision-makers, depending on their preferences, so that’s a good thing,” says Detlef van Vuuren of the PBL Netherlands Environmental Assessment Agency and Utrecht University.

“Still, most model calculations optimizing the change of the electricity system project energy from biomass to expand threefold, and from wind even sevenfold by 2050.” This would have to be reflected in a potential future EU target on renewable energy.

Robust multi-model assessment of EU Roadmap

The new study is the most systematic comparison of computer simulations of the European energy-economy system to date. It includes the PRIMES model, which had attracted criticism in the past for being the only one used by the European Commission for previous assessments of the energy system.

“The more comprehensive approach now allows for a more robust assessment of technologies, costs and infrastructure requirements,” John Weyant says, who leads the Stanford Energy Modeling Forum EMF. This is detailed in the Special Issue of Climate Change Economics. “It shows some very promising opportunities to avoid the risks of unabated climate change.”

Conclusions

The study shows that there are several pathways for achieving ambitious climate change mitigation in Europe. Nearly all the models considered can achieve the long-term target of reducing GHG emissions by 80%, with only a moderate reduction in GDP (less than

0.7% by 2030 and below 2.3% by 2040). However, in some models, costs increase considerably after 2040, while others show costs increasing in a linear manner.

“This allows us to conclude that the 80% GHG reduction target is indeed challenging, especially after 2040 when a substantial amount of effort is required. It is important to mention that these results are derived from models that do not consider technical and political obstacles that could hinder the technological developments prescribed by our results.”

The study also shows that it is critical to start a structural transformation of the fossil fuel-based energy system prior to 2030. It is necessary to set the right price signals in order to prevent the energy system from being locked into long-lasting investments in carbon technologies, such as coal-fired power plants. In general, policies should be designed to facilitate this transition through infrastructure development and behavioral and societal transformation.

The findings show that the short-term target of a 20% GHG reduction by 2020 is not consistent with the cost-minimizing pathways for the long-term target of reducing GHG emissions by 80% in 2050. Therefore, to facilitate the long-term transformation, a clear indication of binding targets for the period beyond 2020 would help investors to take the right strategic decisions.

In comparison to the EU Energy Roadmap 2050, one noticeable difference is the importance of CCS: While CCS plays an important role in the Energy Roadmap, especially as includes no scenario completely without CCS, in the model considered in the report CCS only plays a role in scenarios where CCS is available, and the alternative technology scenarios show that CCS is not required to meet the mitigation target.

More information

PIK is part of a global network of scientific and academic institutions working on questions of global environmental change and plays an active role in activities such as the Intergovernmental Panel on Climate Change (IPCC).

www.pik-potsdam.de

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A UK vision for CCS

A report by the Carbon Capture and Storage Association (CCSA) and the Trades Union Congress (TUC) says that UK electricity prices would be lower if CCS is implemented in the power sector.

Based on modelling by the Energy Technologies Institute (ETI) the report shows that including CCS in the mix of technologies for power generation results in a 15 per cent reduction in the wholesale price of electricity compared with alternative scenarios in which CCS is not deployed.

This is equivalent to an additional 1 per cent on UK GDP if CCS is not deployed at all. The cost saving is mainly due to the fact that without CCS there is an increase of approximately 20–25 per cent in electricity generation capacity as well as a requirement for additional investment in electricity transmission capacity.

CCS would also bring economic benefits through additional jobs in construction and plant maintenance and running. The report estimates that around 15–20 thousand jobs could be created by 2030 depending on the scale of CCS adoption. The UK also has the potential to capitalise on expertise in the sector and develop a world-class domestic industry that can form the basis for meeting the anticipated high growth in the global CCS markets.

CCS is also vitally important to maintain the competitiveness of energy intensive industries such as steel, cement, chemicals and refining, for which it is the only technology that can further decarbonise the sector.

The UK has reached a defining moment with regards to the future of a successful CCS industry, says the report. Decisions taken now, and actions taken over the next 7–10 years, will determine the ability of 'UK plc' to take advantage of its natural assets (physical and human) and capitalise on the investment, employment and export potential of the sector.

Although Government initiatives such as the competition and Contracts for Difference (CfD) in the Electricity Market Reform have advanced CCS, there are significant

Recommendations

- A strongly endorsed long-term Government vision for the CCS sector.
- Immediate and steady rollout of CCS projects: including a minimum of 2 projects from the current CCS competition, ready to begin operating from 2018; and positive final investment decisions for shovel ready projects outside the competition within the next parliament.
- Successful implementation of the Government's Electricity Market Reform, particularly through the development of low-carbon support mechanisms, such as the Feed in Tariff with Contracts for Difference, that catalyse CCS investment.
- Development of CO₂ transport and storage infrastructure that can service the needs of not just current emitters, but also future power and industrial facilities.
- The development of support mechanisms for CCS in industrial applications.

policy gaps that will hinder the successful development of the sector. Urgent action is needed to fill these gaps and ensure that the CCS industry develops in a timely manner, delivering significant economic benefits and contributing towards the realisation of carbon reduction targets.

To ensure a pipeline of projects after the competition, Investors need clear signs that the Government will continue to support CCS infrastructure through the CfD framework and that the returns on investment are transparent and not subject to change.

"We need CfDs for CCS in such a way as they make projects investable and they must be available to more than just the two projects currently involved in the competition," commented Michael Gibbons, co-chair of the Government CCS Development Forum. "The allocation processes have to be clear and predictable so that investors can see the route to market."

Scenarios

Four scenarios were modelled as alternative means of meeting the 80% carbon emissions reduction target by 2050:

No CCS: high growth in offshore wind and geothermal which account for 13% and

10% of total electricity generation respectively.

Power CCS: 15 GW of gas CCS installed between 2020 and 2030. No investment in industry CCS, and relatively small increase in offshore wind capacity.

Full CCS: investment in both gas and industry CCS, but no coal CCS.

Full CCS with coal: investment in both power and industry CCS, but with the power sector split between 6 GW of coal and 6 GW of gas by 2030.

Wholesale electricity prices were shown to be significantly less in all CCS scenarios than in the No CCS scenario by 2030, with a 15% reduction in the two optimal scenarios (Power CCS and Full CCS), see Figure. Household bills were estimated to be £82 lower per year, by 2030, in the optimal CCS scenario, compared with the baseline, which would have a positive effect on disposable income and consumption. The divergence in cost could begin as early as 2023, but this will not be realised unless the pace of CCS rollout is increased.



More information

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A technology strategy for CCS in the UK

The UK Advanced Power Generation Technology Forum, an industry-led stakeholder group that provides a technology focus for the power generation sector in the UK on carbon abatement technologies for fossil fuels including CCS, has produced a strategy for adoption of CCS in the UK.

The technology strategy aims not only to confront the challenge and help unleash the potential but also to keep the UK at the vanguard of CCS technology development and commercialisation.

“Decarbonising the UK’s energy system; achieving major cuts in industrial carbon emissions; boosting energy security; generating billions of pounds in income and tens of thousands of jobs for “UK plc” – these benefits are all within reach if large-scale deployment of CCS becomes a reality in this country,” the report says.

Taking full and realistic account of work currently under way and wider developments in the UK and worldwide, as well as the recommendations of the UK’s CCS Cost Reduction Task Force (CRTF), the strategy sets out a clear vision that has three components:

- Adoption of a target of around 10% of UK electricity to be generated from fossil fuel plant fitted with CCS by 2025.
- Creation of capability that enables CCS to make a major contribution to meeting the UK’s target of an 80% cut in greenhouse gas emissions by 2050.
- Positioning of the UK to succeed in global CCS markets and to play an influential role in the CCS policy dialogue at both European Union (EU) and global level.

Realising this vision presents several challenges. These include: cutting costs and risks so that CCS is economically competitive with other low-carbon technologies; putting appropriate, effective market frameworks in place; and removing a range of barriers to deployment.

CCS in the UK Today

In the UK – and worldwide – confidence is growing that CCS can be safely employed at the necessary scale and at a cost at least comparable to other low-carbon power generation options. Nevertheless, gaps and barriers remain that, if not addressed, will hamper not just the pursuit of CCS projects in this country but also the building of globally marketable expertise within the UK.

Despite sluggish progress on large-scale CCS projects, the last three years have nevertheless seen several positive developments. For example, 2012 saw publication of the Government’s CCS Roadmap and in

December 2013 it was announced that, with funding from the Commercialisation Programme set out in the Roadmap, a front-end engineering design (FEED) study would go ahead on the White Rose CCS project in Yorkshire.

A huge amount of RD&D has also been completed or is under way, supported by public funding agencies and private companies and covering every stage in the innovation chain. In addition, significant progress has been achieved in developing relevant skills and research/test facilities, in securing international collaboration and in enhancing knowledge exchange.

What Next? A Platform for Progress

This strategy aims to capitalise on progress to date while focusing on remaining barriers. In consultation with APGTF members, the Carbon Capture and Storage Association (CCSA) and the UK CCS Research Centre (UKCCSRC), the APGTF has therefore developed a list of over 150 RD&D recommendations.

These focus on five fields of activity: whole systems and cross-cutting issues; CO₂ capture; industrial CCS; CO₂ transport; and CO₂ storage. The aim is to assist identification of projects most useful in terms of cutting the costs of CCS, and to make it easier to identify the budgets required to conduct RD&D that can ensure CCS meets its full potential in the UK.

Almost 100 of these recommendations focus on RD&D needed to meet short-term objectives (ie on a timescale of 0-10 years); the others focus on RD&D needed to meet objectives that are either medium-term (7-15 years) or long-term (10-20+ years). Most recommendations are categorised as “Medium Priority” and should begin as soon as possible; the “Highest Priority” recommendations concentrate, for example, on topics that could benefit from linkage to the first/early full-scale CCS projects. Recommendations are cross-referenced to recent/current projects relevant to planning further RD&D.

Complementing this list of RD&D recommendations, the strategy also sets out a range of additional recommendations that cover: knowledge exchange; skills development, capacity building and supply chain de-

velopment; international collaboration; and public outreach/education.

The UK Department of Energy & Climate Change’s (DECC’s) updated CCS Roadmap has emphasised the Government’s desire for a strong CCS industry with projects beyond the current Commercialisation Projects. Building industry confidence in a “trajectory” for CCS implementation in the UK and likely pay-back on investment will help overcome the challenges currently faced in planning and justifying RD&D.

The recommendations of this strategy, viewed in the context of the broad sentiment within industry at the end of 2013, present a major challenge to the APGTF, the UK Government and its agencies, to motivate industrial co-investment in R&D and maintain the embryonic CCS teams in those organisations not involved in the Commercialisation Projects. Momentum must be maintained across the industry to ensure that the best value is obtained from public investment to date in CCS.

The APGTF will now follow up the strategy by developing, with others as appropriate, pragmatic Action Plans. These, in conjunction with the targets, priorities and recommendations outlined in this document, will provide a framework enabling top-line objectives to be achieved, delivery milestones to be reached and investment to be encouraged – helping to turn CCS into a mainstream carbon-abatement technology and underpinning development of a strong, globally influential UK CCS industry in the years and decades ahead.



More information

The Advanced Power Generation Technology Forum (APGTF) was formed in 1999 to provide the focus for the Power Generation Sector in the UK for research, development and demonstration activities on near-to-zero and zero emission technologies from fossil fuel, biomass, and associated technologies. Recently its main focus has been on carbon abatement technologies including carbon capture and storage. The APGTF is an industry-led stakeholder group.

www.apgtf-uk.com

Book review "Introduction to Carbon Capture and Sequestration" - Berkeley

If you would like a comprehensive understanding of the latest with science and engineering behind carbon capture, a new book written by four Berkeley researchers (two from the University of Berkeley and two from Lawrence Berkeley National Laboratory) will get you there.

The book imparts two strong messages - that the fundamental technology aspects of CCS are well understood (with carbon capture with amines done since 1937 (to remove impurities from natural gas) and CO₂ has been stored for EOR since 1972 (Val Verde Gas Plants in the US). But there is still plenty of scope to improve the technology - such as using membranes for carbon separation - where research is in an early stage.

The book is 580 pages long - of which the first 140 cover the carbon cycles and climate modelling before even starting on carbon capture - but it all helps to create the context of how carbon capture could fit into a global plan to reduce emissions (one of the 12 'wedges' - or should that be 21 wedges).

In order to understand carbon capture science you also need to understand how carbon capture fits into the wider picture of options. If you work in the field you'll probably get asked plenty of questions about (for example) why it makes sense to carry on burning fossil fuels with carbon capture, rather than to completely into renewables.

When it comes to capture, there is comprehensive coverage of absorption into liquids (usually amines) as you would expect - but also coverage of 'adsorption' (which is roughly the same thing, but into solids) and membranes. The authors show that adsorption and membranes could work equally well or better, but the technology is much less mature.

The sequestration chapter goes into depth into the way CO₂ can be held in the subsurface and how to get it there.

It is a technical / academic book, which includes all the relevant equations, including how fluids mix and flow.

The authors draw freely on a wide range of academic research into aspects of carbon capture from around the world, including plenty of graphs and tables - also aiming to create something readable.

There are also plenty of movies and animations quoted in the book - although you have to go to the web to watch them (and you can see a list of links to the movies, without buying the book, here <http://bit.ly/lgWukA>)

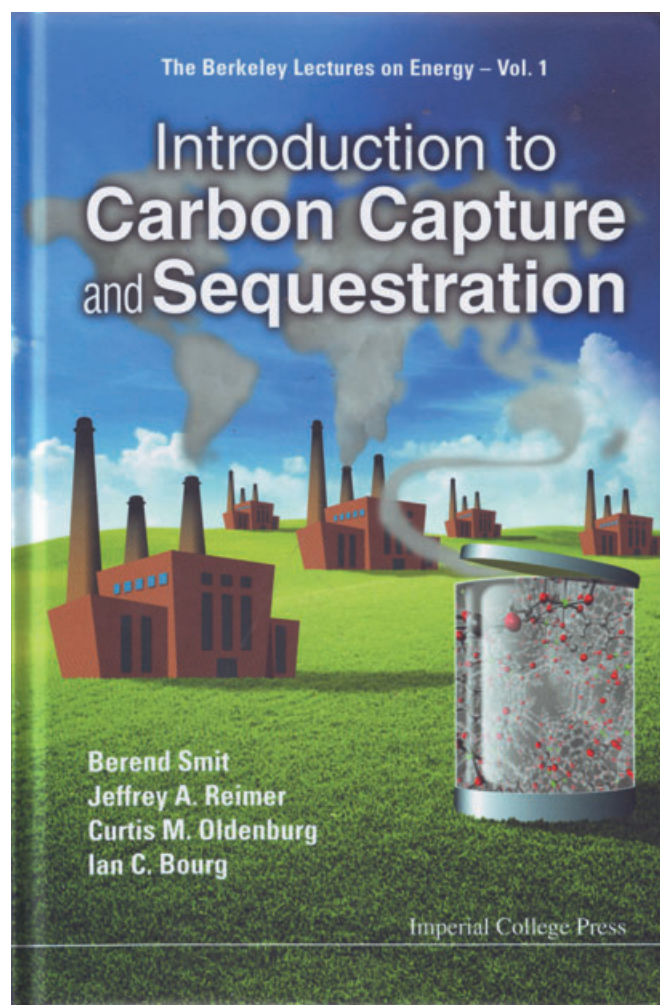
You can see different ways of working out storage capacity - from a basic volumetric calculation to one based on Monte Carlo probabilities, as used in the US to make an assessment of oil industry reserves.

The book makes it clear that nearly all of the relevant expertise to do carbon storage already resides in the oil and gas industry - and most of the expertise to do carbon capture, with the columns very similar to distillation columns you might find in an oil refinery.

The book does not include any business aspects of carbon capture - although the authors would be forgiven for believing that 580 pages was long enough - but the business aspects are surely equally important, if not more important, than the technical aspects, in terms of getting carbon capture financed.

There could have been a little more on vertical seismic profile monitoring using fibre optics - which could be a ground breaking technology in monitoring the subsurface and making sure the CO₂ stays where you think it is - although that could be in another book.

The authors are Berend Smit, in the Department of Chemical and Biomolecular Engineering and Department of Chemistry at UC Berkeley, where he is directing an Energy Frontier Research Center for the US Department of Energy (DOE) focused on Carbon Capture (and a Professor of Computational Chemistry at the University of Amsterdam); Jeffrey A Reimer, a Fellow of the American Association for the Advancement of Science and the American Physical Soci-



ety who "has won every teaching award given on the UC Berkeley campus";

Curtis M Oldenburg, Head of the Geologic Carbon Sequestration Program at Lawrence Berkeley National Laboratory and Editor in Chief of the Wiley journal, "Greenhouse Gases: Science and Technology"; and Ian C Bourg, who serves on the executive committee of Lawrence Berkeley National Laboratory Center for Nanoscale Control of Geologic CO₂.

More information

The book costs £51 (paperback), £83 (hardback) or £38 (pdf download). Available at www.worldscientific.com

UK moves ahead with Peterhead project

www.decc.gov.uk/ccs

The UK Government has awarded FEED study funding for Shell and SSE's Peterhead CCS Project, as part of its CCS Commercialisation Competition.

The FEED study will allow a detailed programme of engineering, planning and financial work to finalise and de-risk all aspects of the proposal ahead of taking the final investment decisions, which is expected to be taken in 2015. It will be the first commercial scale gas powered plant to capture and store CO₂ in a depleted gas reservoir.

The Peterhead power station is a Combined Cycle Gas Turbines (CCGT) station owned and operated by Scottish and Southern Energy near Peterhead in Aberdeenshire, Scotland. Peterhead is situated on the coast, and lies close to available pipelines that can safely transport CO₂. The Goldeneye depleted gas field is about 100km offshore in the North Sea.

The Project will investigate capturing more than 85% of CO₂ emissions that would otherwise be emitted to the air; this CO₂ will then be transported by pipeline to the Goldeneye platform in the North Sea for storage in a depleted gas reservoir about 2.5km below the sea bed.

Dr Luke Warren, Chief Executive of the CCSA, commented on the news. "It is wonderful news that the second project in the Government's CCS competition has successfully reached the next step. The Peterhead CCS project is an important part of the UK's CCS story, as it will showcase CCS on a gas-fired power station – and gas is set to become an increasingly important part of the UK's low-carbon energy mix going forward."

"We are also pleased to see that the Government has accepted all the recommendations in the Wood Review. In particular, the potential for CCS with Enhanced Oil Recovery can bring significant financial benefits to the CCS industry as well as helping to prolong the life of our valuable North Sea oil and gas assets."

"The White Rose and Peterhead projects will be the foundation for CCS clusters in the industrial heartlands of Scotland and North East England."

"Together with the projects outside of the current competition, these will deliver a significant boost to the UK economy. Indeed, the CCSA and the TUC have recently published new modelling, which shows that CCS can reduce household energy bills



Shell and SSE's Peterhead CCS Project in Scotland receives funding for FEED study (Image ©Shell)

by £82 per year by 2030, creating up to 30,000 jobs."

Professor Stuart Haszeldine, SCCS Director and Professor of CCS at the University of Edinburgh, said, "The Peterhead project is critical to reducing the cost of tackling the UK's carbon emissions by demonstrating that full-chain CCS offers a viable and safe route to doing so. CCS on gas will become even more important, due to the UK Government's emphasis on using more gas for electricity generation, and is inescapable if shale gas emerges as a fuel source for the UK."

"The flexible operation of this type of CCS linked to gas-fired power makes it an ideal complement to renewables, with the potential to infill electricity generation during variable wind output."

"The agreement of the FEED studies for both Peterhead and White Rose also helps give fresh momentum to CCS in Europe. The European Commission's recent proposals for climate and energy policy for 2030 reiterated that accelerated efforts are required during the next decade to develop infrastructure so that CCS can be deployed on industrial sources of CO₂ emissions as well as power generation."

"Although gas is frequently hailed as a low-carbon fuel, it is not a zero carbon fuel," he explained. "CCS will be required on gas power stations to sufficiently reduce CO₂ emissions, but the development of gas

CCS projects has, until recently, lagged behind those focused on the use of coal. Despite offering several advantages – such as operational flexibility, cost of electricity and reduced volumes of CO₂ for storage – the US Environmental Protection Agency ruled that CCS on gas is not yet ready for commercial deployment. The Peterhead project therefore carries wider international significance, opening the door to a step change reduction in CO₂ emissions from power generation."

TCM launches CO₂ capture for gas test programme

www.tcmda.com

CO₂ Technology Centre Mongstad (TCM) has launched the world's first large scale tests of the amine solvent MEA on a gas fired source.

The results will be openly shared with the global Carbon Capture & Storage (CCS) community, to increase knowledge and understanding and accelerate the implementation of CCS.

Monoethanolamine (MEA) is used as a baseline solvent, which is commonly used in post-combustion carbon capture studies to compare the performance of proprietary-developed amines and other CO₂ removal processes. TCM, in cooperation with Aker Solutions, has been operating the amine plant since August 2012. Now, for the first time, TCM has undertaken large

scale testing of the performance of the MEA solvent system on gas-fired emissions sources, which will be shared openly.

Speaking from the ARPA-E Energy innovation Summit, Washington DC, Olav Falk-Pedersen, Business Development Manager, CO₂ Technology Centre Mongstad, said:

“We are excited to have embarked on this exciting testing phase at TCM. MEA is a widely used solvent by companies for benchmarking and improving their technology. So by thoroughly testing the MEA solvent system in the Amine plant, and openly sharing that information, we stand to help technologists around the world maximise the performance of their technologies and advance the CCS industry on a major scale.”

MEA has been used for many decades in the process industry including for production of CO₂ for industrial purposes. Nowadays the MEA process acts as a baseline solvent, against which various technologies are benchmarked. The new tests will include measurement and evaluation of a number of important parameters, such as energy consumption, emissions and degradation, within an accuracy of 2 -3%.

The tests are expected to run until March, after which the findings will be published in several scientific papers. Ultimately, the testing will provide a valid MEA baseline for a variety of CCS applications, both in the process industry and in power production.

Howard J. Herzog, Senior Research Engineer, MIT, said:

“I applaud TCM for their efforts in advancing CCS technology. Not only are they breaking new ground by the size of their capture plant, the fact that they will make their test results public is extremely important in enabling future improvements.”

Olav Falk-Pedersen, Business Development Manager, CO₂ Technology Centre Mongstad, added:

“Any gas-fired CCS project will be very interested in the results of the MEA testing at TCM. The second dash for gas is locking unabated natural gas into the energy mix for the foreseeable future. Now the big question is how can the oil & gas industry adopt CCS, to maximise future gas profits, whilst simultaneously mitigating carbon emissions? Demonstration of CO₂ capture from natural gas-fired power plant exhaust, at a considerable scale, is absolutely vital to answering that question.”

TCM’s MEA tests are being performed with 30 and 40 wt.% aqueous MEA solutions and with exhaust gas from the

natural gas fired heat and power plant as an exhaust gas source. The MEA test will provide a new and important baseline from an industrial size facility.

TCM’s industrial-scale laboratory collects a vast amount of data from more than 4,000 measuring points connected to on-line instruments. The lab tests a large number of samples each day, providing vital information from the tests performed at TCM.

Instruments and sampling systems have been successfully verified and optimized, which is an important achievement for technology development and verification of CCS technologies.

EU adopts CO₂ reduction target

europa.eu

The EU has adopted a reduction target for greenhouse gas emissions of 40% below the 1990 level by 2030.

Other measures include an EU-wide binding target for renewable energy of at least 27% in 2030, reform of the Emissions Trading System (ETS), and a review of energy efficiency.

The ETS will be bolstered by a reserve fund which the European Commission says would, “both address the surplus of emission allowances that has built up in recent years and improve the system’s resilience to major shocks by automatically adjusting the supply of allowances to be auctioned.”

The Carbon Capture and Storage Association (CCSA) welcomed the new GHG reduction goal, but was critical of the renewables target.

“It is absolutely critical that Europe sets an ambitious target for emissions reductions for 2030,” commented Dr Luke Warren, Chief Executive of the CCSA. “This must remain the cornerstone of the EU’s response to climate change and will be vital in driving future investment in all low-carbon technologies, including CCS. We strongly support the UK’s position that anything less than a 40% target will not be sufficient.”

“We are extremely disappointed that the Commission has recommended a dedicated renewables target. We have seen from the existing 2020 package that a renewables target disproportionately drives investment into renewables and disadvantages other low carbon technologies such as CCS.”

“We strongly recommend that this renewables target is either dropped or expanded into a ‘sustainable energy’ target which includes CCS. This would provide Member States with the flexibility to meet

targets at the lowest cost to consumers.”

“If Europe is to decarbonise at least cost, Member States must have flexibility in how they meet targets. We cannot afford a dedicated renewables target; CCS must be an integral part of the mix.”

UK union urges Government to adopt CCS

www.unitetheunion.org

Unite, Britain’s biggest union, and the National Union of Mineworkers (NUM) have joined forces to call on the government to embrace Carbon Capture Storage to cut energy bills, create jobs and reduce CO₂ emissions.

At a conference on January 27 attended by politicians, industry experts and workers in the energy sector, the unions warned that jobs are being lost and the UK is facing a “make or break moment” if the country is to take advantage of its prime position to be a world leader in Carbon Capture technology.

Speakers at the conference included Tom Greatrix MP, Peter Emery, production director for Drax and Philip Garner, director general, Coal Pro.

Failure to embrace CCS would have devastating consequences for jobs, said the unions, because of the premature closure of coal fired power stations if CCS is not deployed. 800 jobs are due to be lost at Eggborough power station in North Yorkshire. Had CCS already been in use those jobs and the power produced by Eggborough would still be viable.

The same region also includes the Drax power station and encompasses the Kellingley deep mine and is the location of the proposed White Rose CCS project. If the White Rose CCS project goes ahead the immediate short term effect would be to create over 1,000 construction jobs during a four year period as well as securing the jobs within the local existing supply chain.

Unite national officer Kevin Coyne said: “Capture carbon or lose jobs, that is our message to the government. The UK is facing a make or break moment if the country is to take advantage of its prime position to be a world leader in carbon capture technology. If the government steps up and embraces carbon capture it will cut energy bills, create jobs and reduce CO₂ emissions.

“There needs to be a sense of urgency because jobs are already being lost, like those at Eggborough power station and our energy supplies are being put at risk. We hope our conference will focus minds and will be a step further towards keeping the lights on and creating jobs.”

Researchers find new material for CO₂ storage

www.unl.edu

Research led by University of Nebraska-Lincoln chemist Xiao Cheng Zeng has led to the discovery of a new material that could have applications to CO₂ storage.

At first glance, there wouldn't seem to be much of a connection between dry ice and quartz. But in scientific terms, they are actually quite close as they are oxides of the first two elements in a chemical group in the periodic table (Group IV) -- carbon for dry ice (frozen carbon dioxide) and silicon for quartz.

In 2011, European researchers announced the discovery of a new substance called silicon carbonate when they combined dry ice and silicon dioxide (quartz) under high pressure. They were unable to determine the material's crystal structure, however, and the question caught the attention of Zeng and his colleagues, who took up the challenge and spent almost a year in modeling possible structures on the University of Nebraska's Holland Computing Center supercomputer.

"We did an exhaustive search of possible solid structures for a given ratio of carbon dioxide and silicon dioxide," said Zeng, Ameritas University Professor of chemistry. "We did an extensive structure search of thousands of crystal structures before we identified one highly stable one."

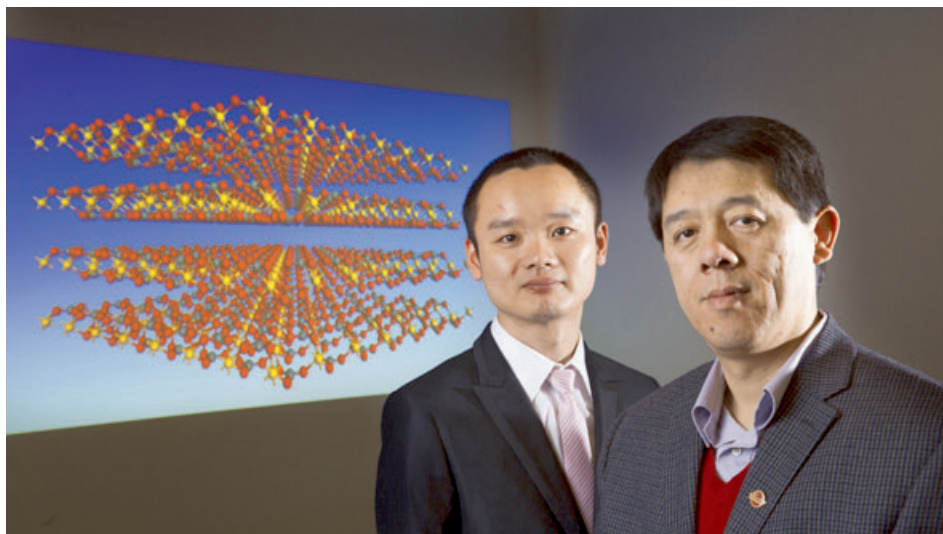
That highly stable form, Zeng said, consists of one silicon atom, two carbon atoms and six oxygen atoms, or SiC₂O₆.

The result was reported in the Feb. 27 issue of *Physical Review X*, the fully open-access journal of the American Physical Society. It is the first time UNL research has been published in the three-year-old journal.

"One of the potential applications is carbon dioxide storage," Zeng said. "We predict that under high pressure, about 200,000 atmospheres, carbon dioxide can combine with silicon dioxide to form a new crystal form that is a possible sequestration form."

"This solid is somewhere between dry ice and quartz, and in the past, people didn't imagine that there was something in between. Something in the middle is very hard for chemists to imagine, but we provide a candidate for something in the middle."

Zeng said the predicted crystal may also provide an important clue to the makeup of terrestrial planets and satellites since silicon dioxide and carbon dioxide in its gaseous and frozen forms are common components of those bodies. With a layered structure similar to graphite's, the silicon carbonate crys-



Xiao Cheng Zeng (right) and Jun Dai. In the background is a computer simulation of the new material, silicon carbonate, illustrating its three-layer structure. (Photo: Craig Chandler, University Communications)

tal also has potential as a solid lubricant.

"The structure we saw is a three-layered structure where the middle layer is silicon," he said. "The layers can slip and shear, making it a good solid lubricant."

Zeng's collaborators on the project were Rulong Zhou, a former postdoctoral researcher in Zeng's lab at UNL and now the chair of the physics department at the Hefei (China) University of Technology; Bingyan Qu at Hefei University of Technology; and Jun Dai, a current postdoctoral researcher with Zeng.

The research was supported with funding from the Army Research Office and UNL's Materials Research Science and Engineering Center and Nebraska Center for Energy Sciences Research.

Costain claims carbon capture 'breakthrough'

www.costain.com

Costain has developed an innovative way of separating carbon dioxide from natural gas which it says is cheaper than other methods.

Using in-house process design capability, Costain has filed a patent application at the UK patent office for a process to effectively separate very high levels of carbon dioxide from associated gas.

The developed process technology is particularly suitable for use in Enhanced Oil Recovery (EOR) says Costain, as it removes carbon dioxide with lower energy consumption and potentially smaller equipment than current competing technologies.

Not only are the processing costs much lower but the process also produces natural gas to conventional transmission specifications as well as natural gas liquids (NGL) for use as fuel and/or petrochemical feedstock.

"If carbon dioxide were stored in existing oil reservoirs rather than in spent oil or gas reservoirs, as is usually considered, then the carbon dioxide can significantly increase oil production from the reservoir to provide considerable revenues" said Adrian Finn, Costain's Process Technology Manager.

"As the carbon dioxide effectively drives out oil and associated gas from the reservoir it will eventually start to appear in the associated gas and will require removal and recycle to the reservoir. The process technology that has been developed separates the carbon dioxide from the associated gas to provide pure high pressure liquid carbon dioxide suitable for recycle," said Adrian.

Mitsubishi CO₂ capture pilot completes test phase

www.mhi.co.jp

A demonstration test for capturing CO₂ from a coal-fired power plant conducted jointly by Mitsubishi Heavy Industries and Southern Company has completed its initial demonstration phase.

With the initial demonstration phase complete, Southern Company Services (SCS) and Mitsubishi Heavy Industries (MHI) are currently in discussions concerning the performance of additional demonstration phases and activities using the plant.

The demonstration test got under way

in June 2011. After verifying the technology for recovering CO₂ from the coal-fired plant flue gas, as well as recovery performance, integrated capture and sequestration demonstration testing began in August 2012. High-performance continuous and stable operation of the large-scale CO₂ recovery plant was confirmed.

In this project, MHI provided basic planning and engineering, supply of the CO₂ compressors and other core machinery, and technical support during the demonstration test.

The CO₂ capture demonstration plant that supplied the CO₂ under this project was built jointly by MHI and SCS and is the world's largest in scale, handling some 500 mtpd. The plant consists primarily of a flue-gas scrubber, flue-gas CO₂ capture/re-generation system, CO₂ compression machinery, and electrical components. It has capacity to recover 150,000 metric tons of CO₂ per year with recovery efficiency above 90%.

For CO₂ recovery the facility adopts the KM CDR Process®, which uses a proprietary KS-1 high-performance solvent for CO₂ absorption and desorption that was jointly developed by MHI and the Kansai Electric Power Co. Compared with other CO₂ capture technologies, the KM CDR Process uses significantly less energy, says MHI.

CO₂CRC tests CO₂ filtering "spaghetti"

www.co2crc.com.au

Researchers from the Cooperative Research Centre for Greenhouse Gas Technologies (CO₂CRC) are testing the membrane tubes at a power plant in Australia.

CO₂CRC researchers at the University of New South Wales have installed a custom built rig at Delta Electricity's Carbon Capture Research Facility at Vales Point Power Station to trial new hollow fibre membranes for capturing CO₂ from power stations.

Hollow fibre membrane modules contain hundreds of tiny spaghetti-like tubes which maximise contact between the gas and the membrane surfaces. Flue gas passes across the outside of the tubes but only carbon dioxide passes through to the inside. A similar approach is used to purify water in some desalination plants.

"The trials are an important step in developing effective membranes for industrial scale use," says Professor Dianne Wiley, CO₂CRC Capture Program Manager.

"The new membranes are highly selective for carbon dioxide in the lab but until we trial them with real flue gas we won't see how well they stand up to industrial conditions".

The Vales Point rig is able to test three hollow fibre modules at a time, providing the flexibility to test a range of new membrane formulations.

Currently CO₂ is separated from flue gas using volatile liquid solvents, which are bulky and have a significant energy cost.

Hollow fibre membranes have the potential to substantially reduce the energy required to capture carbon dioxide, while having a smaller environmental and physical footprint than existing solvent systems.

The project is funded by Australian National Low Emissions Coal Research & Development (ANLEC R&D) and supported by Delta Electricity.

£2 Million available for UK CCS research

www.ukccsrc.ac.uk

The money is available for UKCCSRC (UK Carbon Capture and Storage Research Centre) led CCS research.

In this second call for proposals, the UKCCSRC is inviting applications for fundamental and multidisciplinary Carbon Capture and Storage research projects that address research needs identified by the Advanced Power Generation Technology Forum (APGTF) and the DECC CCS Roadmap for Innovation and R&D. Proposals are expected to be between £100k and £300k in size but no fixed limits have been set.

The deadline for the submission of applications is 5pm on Monday 31st March 2014. Interested parties will be able to submit proposals via the UKCCSRC website. Funding decisions will be announced in mid-May 2014.

Members of all organisations eligible to receive funding from the Engineering and Physical Sciences Research Council (EPSRC) can receive support but proposals must be led by UKCCSRC members, who have established experience in the CCS field.

As well as giving financial support, the UKCCSRC will also help facilitate linkages between the project teams and the wider CCS research community and users.

Newlight achieves commercial scale production of AirCarbon

www.newlight.com

Newlight Technologies has scaled up its AirCarbon production technology.

Newlight Technologies is a sustainable materials company that uses carbon capture technology to produce clean, high-performance materials that maintain performance, reduce cost, and displace oil with carbon that would otherwise be released.

With two facilities in California, Newlight is working to expand its carbon capture operations at other sites throughout the U.S., Europe, and Asia.

The company launched its first commercial product, AirCarbon-based chairs, in November with another company, KI.

Founded in 2003, Newlight has invented, patented, and commercialized AirCarbon™, a material made from air and captured carbon that can match the performance of oil-based plastics while out-competing on price, representing a market-driven solution to carbon capture. AirCarbon is currently being used to manufacture furniture, bags, caps, and a variety of other products, with partners including Fortune 500 companies and brand-name market leaders.

In recognition of the company's technological and commercialization achievements, Newlight was named "Most Innovative Company of the Year" in 2013, and AirCarbon was named "Biomaterial of the Year" and "Tech Innovation of the Year" in 2013.

University of Calgary receives \$500k grant

www.ucalgary.ca

A University of Calgary researcher, Nader Mahinpey, has received a grant from the Natural Sciences and Engineering Research Council (NSERC) of Canada to support CO₂ capture research.

Nader Mahinpey, associate professor and associate head (research) of chemical and petroleum engineering in the Schulich School of Engineering, is receiving a NSERC Strategic Project Grant of \$583,082 over three years, toward developing a novel integrated approach to energy production and gasification, the process which converts organic or fossil-based carbon material into carbon monoxide, carbon dioxide and hydrogen.

His approach combines gasification technology with newly created solid absorbent materials to provide cost-effective solutions for capturing the greenhouse gas carbon dioxide (CO₂). He will use pilot-plant studies to take laboratory-scale knowledge to what's required for commercialization.

"This proposed solution will address major challenges that hinder transformative innovation in the area of CO₂ capture, with benefits to Canada's economy, energy and environment," said Mahinpey, who leads the Energy and Environment Research Group at the University of Calgary.

A common method of capturing CO₂ in industrial processes involves wet scrubbing of flue gases with chemicals (amine solvents). However, this causes a serious loss in process thermodynamic efficiency, so is unlikely to be cost-effective on a large scale.

Mahinpey's approach uses a "dry process" to capture CO₂. The technology is expected to reduce greenhouse gas emissions and lead to sustainable production of hydrogen, and involve the training of highly qualified personnel for Canada's natural resources and energy sectors.

CO₂-EOR - the view from Texas

The US produces 318,000 barrels of oil per day with the help of carbon dioxide injection, and oil companies can't get enough carbon dioxide, according to an article in the February 2014 Journal of Petroleum Technology written by Stephen Rassenfoss.

The article says 3,443 bn ft³ of carbon dioxide is used to produce the oil - it does not provide the period, but if the period is yearly, it means that the CO₂ used is 480,000 tons per day - so each ton of oil is helping to produce 0.66 barrels of oil.

Using carbon dioxide to improve oil recovery is one type of 'enhanced oil recovery' (EOR). When CO₂ and oil mix, the oil's viscosity reduces (so it flows more easily), the oil swells (so it can be forced out of rock pores), and its surface tension reduces (so it does not cling so strongly to the rock).

There is particular interest in CO₂ enhanced oil recovery in Texas, because there is thought to be a large oil layer beneath the known aging oil reservoirs, called "Residual Oil Zone", the 'which is too low saturation (20 to 40 per cent) to produce conventionally, but might be possible to produce with the help of carbon dioxide. (Saturation is the ratio of hydrocarbons to water in the pores of the reservoir).

Oil company Hess is producing oil from the ROZ with the help of CO₂.

"The biggest problem with carbon dioxide is there is not enough of it, there are far more projects than carbon dioxide," geologist David Vance is quoted as saying.

There is an interesting development on the regulatory side. The US Environmental Protection Agency has developed a standard for long term CO₂ storage, to ensure that the CO₂ does not leak, which it calls "Class VI".

CO₂ used for EOR is subject to a less tough requirement - called "Class II".

Michael Moore, executive director of the North American Carbon Capture and Storage Association, is quoted as saying that companies fear extra costs and liabilities if they switch to Class VI.

If they stay with Class II, but the CO₂ stays in the ground, you have the situation (which will appeal to Ayn Rand fans) that companies are doing carbon capture and storage for purely commercial reasons, and nothing to do with carbon prices either.

CO₂ supplies from industrial plants are expected to rise between 5 and 7 times over the next 5 years.

However there seems to be a limit of how much oil and gas companies are prepared to pay for CO₂ - of \$40 a ton. So, without any other regulatory requirement to re-

duce carbon emissions, it will only work if coal power stations can provide a supply of clean CO₂ for under \$40 a ton - and the price of CO₂ from coal power stations is "commonly estimated at twice or more" of that, according to the article. A lot of the costs is in separating other impurities from the coal power station emission.

The CO₂ might come from petrochemical plants (which have rapidly sprung up around the Gulf Coast to take advantage of cheap gas prices) rather than coal power stations. Gas liquefaction plants can also supply CO₂.

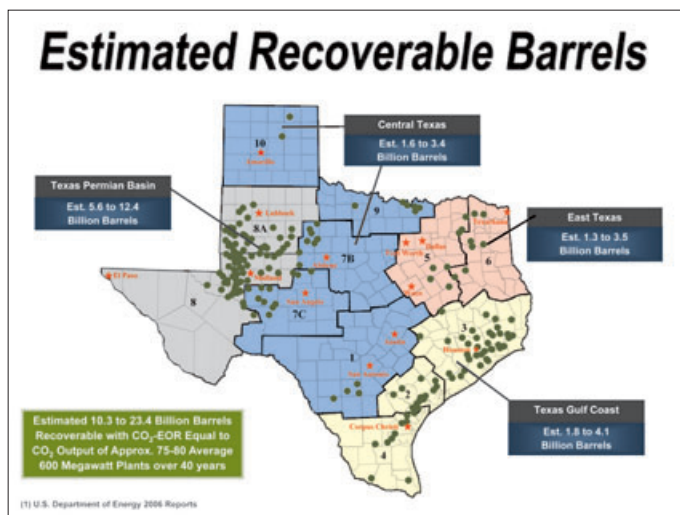
On the financial side, there is a bit of an argument between shale and CO₂/EOR on whether the money is best spent. Shale gas provides a quicker returns but CO₂/EOR projects should provide better returns over the longer term.

One company, Tabula Rasa Partners, has been founded to work on CO₂/EOR projects - and aims to have interests both in supply of CO₂ and using it for EOR.

Another company, Chaparral Energy, has a \$250m project to compress 45m ft³/day of carbon dioxide (2,300 tons / day), gathered from three fertiliser plants and an ethanol plant, and pipe it 380 miles to its oil field, where it expects production to grow from 4,000 b/d now to 35,000 b/d in 2020. "They (Chaparral) are the company that looks like other companies will look like over time," Michael Moore of the North American Carbon Capture and Storage Association is quoted as saying.

Kinder Morgan CO₂ is drilling CO₂ wells just to produce CO₂ - and sells 60 per cent of this, and uses the rest for its own EOR operations.

A coal fired power plant is being built in Kemper County, Mississippi, which will be able to capture nearly 66 per cent of its CO₂, to be used for EOR. It will produce ammonia and sulphuric acid to gain additional revenue. However the costs of this



plant, including a coal mine and pipeline to an oilfield, have recently increased by \$1bn, to \$4.45bn.

Another coal plant in Texas is the "Texas Clean Energy Project", which has not yet started construction, with deals for financing under discussion with Chinese backers, as of the end of 2013.

A Canadian company, Inventys Thermal Technologies, is developing a ceramic material which promises to capture CO₂ for \$15 a ton, so that the total costs of delivering CO₂ to an oilfield will be around \$40 to \$50. Michael Cu, former US Energy Secretary, sits on this company's board.

There are developments for portable enhanced oil recovery technology. Pioneer Energy has a system for burning natural gas in oxygen to form CO₂, also using the hydrogen to generate electricity and selling it to the grid.

Maersk has a technology to burn natural gas in pure oxygen, to provide CO₂, electricity, nitrogen and pure water, all of which could be sold. This technology can burn low quality field gas from oilfields, which is often flared. Pieter Kapteijn of Maersk says that the technology could provide CO₂ at under \$40/ton, provided there is a market for the electricity of \$0.07 to \$0.09 per Kwh.

More information

<http://www.spe.org/jpt/issue/2014-02>

Transport and storage news

Aberdeen researchers join Scottish CCS group

www.sccs.org.uk

Researchers from the University of Aberdeen have joined Scottish Carbon Capture & Storage, the UK's largest grouping of scientists engaged in the research and development of CCS technology.

The University of Aberdeen brings further expertise to the existing partnership of the British Geological Survey, Heriot-Watt University and the University of Edinburgh, strengthening the Scottish network of scientists engaged in research at every stage of the CCS chain.

Strategic research between the University and other SCCS partners is already under way. Economist Professor Alex Kemp is part of a team designing new fiscal incentives to encourage the use of CO₂ captured from power plants to produce up to three billion barrels of additional oil. Dr Dubravka Pokrajac is improving methods of CO₂ injection at storage sites, while Dr Clare Bond is studying reservoir seals, which prevent CO₂ movement after injection. The Aberdeen team also includes Professor Fred Glasser, who is developing cements that utilise CO₂. And Professor John Paterson is examining ways to improve storage legislation.

Professor Stuart Haszeldine, SCCS Director and Professor of CCS at the University of Edinburgh, said: "We welcome the University of Aberdeen to the SCCS partnership. They bring invaluable, proven expertise to the group and will expand the cutting-edge research already under way on all aspects of CCS, from capture engineering and geoscience to social perceptions, law and petro-

leum economics. It is an exciting time for CCS in the north east, particularly with news that the Peterhead CCS Project has secured design funding. The project will be a pathfinder for the development of a CCS industry, and will draw on the extensive research and engineering expertise that exists in Scotland."

The announcement comes during a week of renewed focus on CCS in the north east. The Peterhead CCS demonstration project at a gas-fired power station secured design funding from the UK Government. The interdependency of CCS with the north-east offshore industries was also highlighted in the Wood Review of future oil and gas activity on the UK Continental Shelf.

The co-operation of companies could create new ways of using industry knowledge to enable the geological storage of carbon dioxide (CO₂) – for example, using CO₂ for enhanced oil recovery could develop CCS infrastructure without the need for public subsidy.

Masdar and ADNOC proceed with CO₂-EOR project with Emirates Steel

www.masdar.ae

Masdar Carbon, one of the five integrated units of Masdar, and the Abu Dhabi National Oil Company (ADNOC) have reached agreement concerning the carbon capture use and storage facility adjacent to Emirates Steel complex at Mussafah allowing the project to proceed to tender.

The carbon capture facility is part of a collaboration between Masdar and ADNOC to explore feasibility of joint projects to reduce the carbon footprint of the emirate and make available CO₂ for potential enhanced

oil recovery (EOR) operations in the future.

A CO₂ injection pilot project on EOR at an onshore field completed two years ago and the wealth of data collected over the period has encouraged the two partners to go ahead with the Emirates Steel project.

In the next stage, Masdar intends to issue requests for proposal (RFP) for the carbon capture usage and storage facility that will capture nearly 800,000 tonnes per annum CO₂-rich stream, prior to emission from the Emirates Steel Phase 1 and Phase 2 lines.

The CO₂ feed stream from the Emirates Steel plant, containing 90% CO₂, will be transferred to a common compression and dehydration facility at the project site in Mus-safah. The feed stream will be compressed into dense phase; delivering a CO₂ stream of over 98% purity, through 50km of the pipeline network, to be injected in an onshore field, operated by Abu Dhabi Company for Onshore Oil Operations (ADCO).

Successful carbon capture projects are anticipated to have a positive long-term economic impact on Abu Dhabi including economic growth, job creation and the development and export of CCS-related technology know-how.

Mandated to drive clean fossil fuel energy and energy efficiency at an industrial level and monetize emission reductions, Masdar Carbon provides technical assistance, project management, carbon finance and emissions trading expertise to asset owners primarily in the oil and gas and power sectors in the Middle East, Africa and Asia. It also aims to remain a frontrunner in developing global advancements in technology, value chain applications, policy and deployment strategies for clean energy and CCS.

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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

Project Lifecycle Stage	Project Name	State / District	Country	Volume CO ₂ (mtpa)	Operation Date
Operate	Air Products Steam Methane Reformer EOR Project	Texas	UNITED STATES	1.0	2013
Operate	Century Plant	Texas	UNITED STATES	8.4	2010
Operate	Coffeyville Gasification Plant	Kansas	UNITED STATES	1.0	2013
Operate	Enid Fertilizer CO₂-EOR Project	Oklahoma	UNITED STATES	0.7	1982
Operate	Great Plains Synfuel Plant and Weyburn-Midale Project	Saskatchewan	CANADA	3.0	2000
Operate	In Salah CO₂ Storage	Wilaya de Ouargla	ALGERIA	0	2004
Operate	Lost Cabin Gas Plant	Wyoming	UNITED STATES	0.8-1.0	2013
Operate	Petrobras Lula Oil Field CCS Project	Santos Basin (off the coast of Rio de Janeiro)	BRAZIL	0.7	2013
Operate	Shute Creek Gas Processing Facility	Wyoming	UNITED STATES	7.0	1986
Operate	Sleipner CO₂ Injection	North Sea	NORWAY	0.9	1996
Operate	Snøhvit CO₂ Injection	Barents Sea	NORWAY	0.6-0.8	2008
Operate	Val Verde Natural Gas Plants	Texas	UNITED STATES	1.3	1972
Execute	Alberta Carbon Trunk Line ("ACTL") with Agrium CO₂ Stream	Alberta	CANADA	0.4-0.6	2015
Execute	Alberta Carbon Trunk Line ("ACTL") with North West Sturgeon Refinery CO₂ Stream	Alberta	CANADA	1.2-1.4	2016
Execute	Boundary Dam Integrated Carbon Capture and Sequestration Demonstration Project	Saskatchewan	CANADA	1.0	2014
Execute	Gorgon Carbon Dioxide Injection Project	Western Australia	AUSTRALIA	3.4-4.1	2015
Execute	Illinois Industrial Carbon Capture and Storage Project	Illinois	UNITED STATES	0.8-1.0	2015

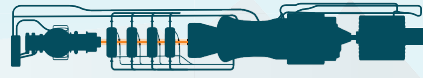
Facility Details	Capture Type	Transport Length (km)	Transport Type	Storage Type
Hydrogen Production	Pre-combustion capture (gasification)	101-150	Pipeline	Enhanced hydrocarbon recovery
Natural Gas Processing	Pre-combustion capture (natural gas processing)	69	Pipeline	Enhanced hydrocarbon recovery
Fertiliser Production	Industrial Separation	112	Pipeline	Enhanced hydrocarbon recovery
Fertiliser Production	Industrial Separation	225	Pipeline	Enhanced hydrocarbon recovery
Synthetic Natural Gas	Pre-combustion capture (gasification)	315	Pipeline	Enhanced hydrocarbon recovery
Natural Gas Processing	Pre-combustion capture (natural gas processing)	14	Pipeline	Dedicated Geological Storage
Natural Gas Processing	Pre-combustion capture (natural gas processing)	Not specified	Pipeline	Enhanced hydrocarbon recovery
Natural gas processing	Pre-combustion capture (natural gas processing)	Not specified	No transport required (i.e. direct injection)	Enhanced hydrocarbon recovery
Natural Gas Processing	Pre-combustion capture (natural gas processing)	403	Pipeline	Enhanced hydrocarbon recovery
Natural Gas Processing	Pre-combustion capture (natural gas processing)	0.11	No transport required (i.e. direct injection)	Dedicated Geological Storage
Natural Gas Processing	Pre-combustion capture (natural gas processing)	152	Pipeline	Dedicated Geological Storage
Natural Gas Processing	Pre-combustion capture (natural gas processing)	132	Pipeline	Enhanced hydrocarbon recovery
Fertiliser Production	Industrial Separation	240	Pipeline	Enhanced hydrocarbon recovery
Oil Refining	Pre-combustion capture (gasification)	240	Pipeline	Enhanced hydrocarbon recovery
Power Generation	Post-combustion capture	100	Pipeline	Enhanced hydrocarbon recovery
Natural Gas Processing	Pre-combustion capture (natural gas processing)	7	Pipeline	Dedicated Geological Storage
Chemical production	Industrial Separation	1.6	Pipeline	Dedicated Geological Storage

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