Carbon Capture Journal

CCS in review

Global CCS Institute Status CCS: 2016

IEA - 20 years of CCS: accelerating future deployment

Full-chain integrated CCS demo in Hokkaido, Japan

Jan / Feb 2017 Issue 55

CCS in India: report from our inaugural conference in Mumbai

- UK Parliamentary Advisory Group report: salvaging UK CCS
- MIT develops catalyst that can convert CO2 to gasoline
- Carbon dioxide injected into basalt converts to rock in two years
- Lessons from 10 years' post-injection monitoring at Nagaoka, Japan

First fully commercial CCSU plant launches capturing CO2 at $30/tonne

Carbon Clean Solutions has launched a project that will see more than 60,000 tonnes of CO2 captured from the 10 megawatt coal-fired power station based near Chennai, India. Post-start up, the power station is set to become a zero-emission plant.

The project, believed to be the first of its kind, is privately financed and will capture CO2 at just $30 per/tonne – much lower than the $60-90 per tonne capture costs typically observed in the global power sector.

The captured CO2 will then be used by Indian firm, Tuticorin Alkali Chemicals & Fertilizers (TACFL), for soda ash production.

Aniruddha Sharma, Chief Executive Officer at CCSL, said, "This project is a game-changer. By capturing and crucially, re-using, CO2 at just $30 per/tonne, we believe that there is an opportunity to dramatically accelerate uptake of CCU technology, with its many benefits, around the world. This is a project that doesn't rely on government funding or subsidies – it just makes great business sense. We are delighted to be partnering with TACFL to make this project a reality."

This is the first project following the successful completion of CCSL's pilot testing programme at Technology Centre Mongstad.

The pilot yielded results that showed that use of CCSL's solvent dramatically reduced emission levels and lowered corrosion, while improving system reliability.

The pilot, which ran from November 2015 until the end of March 2016, involved a drop-in solvent test using CCSL's patented 'APBS' chemical, and was designed to measure environmental emissions, corrosion and energy efficiency.

The test prompted highly successful results, with plant availability levels of 100% and no loss of run time due to solvent issues. Over the period, CCSL successfully captured more than 25,000 tons of carbon dioxide. Most significantly, it demonstrated parts per billion solvent emissions compared to parts per million for traditional solvents, and aerosol emissions were 80 times lower than the permissible HSE limit.

Carbon Clean Solutions' first commercial project captures CO2 from Tuticorin power plant in India – the CO2 is then used as a feedstock to produce baking soda

This represents a major breakthrough, as solvent emissions using CCSL's technology are essentially negligible. CCSL's solvent degradation was also negligible over the test campaign run, demonstrating a far superior solvent stability.

Corrosion testing confirmed that with APBS, it is possible to construct 50% of a plant using carbon steel rather than stainless steel. Traditional solvents require stainless steel, which is at least four times more expensive than carbon steel. This achievement can reduce the capex for commercial scale plants by over 25%.

More information

www.carboncleansolutions.com

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Front cover:
CCS in India: Group photo from Carbon Capture Journal's inaugural India conference in Mumbai

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Carbon Capture Journal review of 2016

The year saw several commercial projects and demos starting up, including CO2 capture from waste in Oslo, CO2 re-use from a power plant in India, a full-chain project in Japan, CO2 re-use in plastic production in Germany and CO2-EOR from steel in Abu Dhabi. Policy progress was dominated by the ratification of the Paris Climate Agreement.

January

The Norwegian Government tasks Statoil to conduct a feasibility study regarding CO2 storage on the Norwegian Continental Shelf

The UK Government is widely criticised for scrapping £1bn funding for a CCS demonstration - an analysis suggests a ten-year delay to deployment could add billions each year to the cost of decarbonising the UK economy

For the first time, researchers demonstrate that CO2 captured from the air can be directly converted into methanol (CH3OH) using a homogeneous catalyst

Oslo's main waste incinerator begins the world's first experiment to capture carbon dioxide from the fumes of burning rubbish

Carbon dioxide instead of crude oil: Covestro is now incorporating 20 percent CO2 into a foam component. The newly opened plant in Dormagen, Germany has capacity of 5,000 metric tons per year (photo: ©Covestro)

February

BHP Billiton and SaskPower establish carbon Capture and Storage Knowledge Centre

The Illinois Basin Decatur Project captures and stores 1 million metric tons of carbon dioxide in a saline formation

Multiple escape pathways exist due to chemical reactions between carbon dioxide, water, rocks and cement from abandoned wells, according to Penn State researchers

UK Parliament releases a critical report looking at the future of CCS in light of the Government's cancellation of CCS funding.

University of Texas at Arlington team shows that concentrated light, heat and high pressures can drive the one-step conversion of CO2 directly into liquid hydrocarbon fuels

Universities of Edinburgh and Regina collaborate on CCS research establishing an MSc scholarships for joint research

Japan pushes ahead with Hokkaido carbon capture test despite quake concerns

March

A Global CCS Institute report confirms the North Sea as an ideal area for CO2 storage

A new highly permeable carbon capture membrane is developed by the Lawrence Berkeley National Laboratory

The China Resources Power (CRP) Haifeng Testing Platform Engineering Study is launched in Guangzhou at the UK-China Low Carbon Week Event

The Global CCS Institute releases the first Global Storage Portfolio

April

Tomakomai integrated CCS project comes online in Japan capturing and storing CO2 from a hydrogen production unit in an oil refinery

University of California Los Angeles find a way to turn carbon dioxide emissions from power plants into a novel building material that could replace concrete

15,000 tonnes of CO2 are stored at Otway in another milestone for the Australian project

Representatives of more than 170 countries endorse Paris agreement to cut carbon emissions, with France's president saying: 'There is no turning back'

May

The Low Emissions Intensity Lime And Cement (LEILAC) consortium secures funding to test Calix's direct CO2 separation process

The Huazhong University of Science and Technology (HUST) Oxyfuel Plant in China goes into operation

ETI project confirms there are no major technical hurdles to storing industrial scale CO2 offshore in the UK with sites able to service mainland Europe

U.S. Energy Department suspends funding for Texas Clean Energy Project

Carbon Clean Solutions says the results of its pilot project show that its technology could halve the cost of carbon capture

June

Scientists in California test sponges made with the key ingredient of baking soda as a way of capturing carbon emissions

CarbFix publishes a paper in Science that demonstrates the possiblity to permanently store CO2 as minerals in basaltic rock

North China's Shanxi province establises a 10 billion yuan ($1.52 billion) investment fund for the clean utilization of coal

Progress by the Guangdong offshore CO2 project is highlighted in the latest strategic talks between the US and China

DOE announces $68.4m in funding to advance the safe and permanent storage of CO2

Covestro opens a production plant for a plastic foam component made with 20 percent CO2 at its Dormagen site near Cologne

July

U.S. technology developer ION Engineering signs a contract to test its solvent technology at Technology Centre Mongstad

The Global CCS Institute releases two new public information reports highlighting the long-term application of CCS technology in a variety of industrial sectors

A study published in Nature confirmes that the 2050 emission reduction target associated with the Paris Agreement requires massive deployment of CCS

CO2CRC and Canada's Petroleum Technology Research Centre collaborate

Gassnova in Norway releases feasibility study on full-scale CCS in Norway by 2022

Air Products hits major milestone after transporting its three millionth tonne of captured CO2 from Port Arthur, Texas

BASF and Linde successfully complete a joint pilot project to improve capture of CO2 from flue gas at a coal fired power plant

August

Researchers at the University of Illinois develop solar cell that converts atmospheric carbon dioxide directly into usable hydrocarbon fuel

A Cambridge University study of naturally occurring 100,000 year old CO2 reservoirs shows no significant corroding of cap rock, suggesting the gas hasn't leaked

The UK Parliamentary Advisory Group on CCS says urgent Government action could save £5 billion a year

September

US and China ratify Paris climate agreement

The Quest oil sands CCS project in Alberta Canada captures and stores its first tonne of CO2 ahead of schedule

CO2CRC and Federation University Australia open a new CCS laboratory at the University's Gippsland Campus

October

Norway continues support of Technology Center Mongstad operations, initially until 2020

SNC-Lavalin is to develop a "generic business case" for a gas fired power plant fitted with carbon capture and storage.

November

EnCO2re CO2 re-use programme seeks new industrial partners to turn CO2 emissions into a source of value for European industry

The Oil and Gas Climate Initiative (OGCI) will invest $1 billion over the next ten years to develop and accelerate the commercial deployment of technologies including CCS

A CCUS plant developed by joint venture between Abu Dhabi National Oil Company (ADNOC) and Masdar will sequester up to 800,000 metric tons of C02 annually

FuelCell Energy and ExxonMobil announce pilot plant at the James M. Barry Electric Generating Station in the U.S.

Scientists at King Abdullah University of Science & Technology (KAUST) develop new solid CO2 capture materials

A new catalyst developed at MIT provides design principles for producing fuels from carbon dioxide emissions

A report from the Energy Technologies Institute (ETI) highlights the importance of combining bioenergy with carbon capture and storage (BECCS) if the UK is to meet its emission reduction targets cost-effectively

Bacteria and archaea could be used to monitor stored carbon dioxide and convert it into useful products, such as ethanol and acetate

Carbon Capture still viable under Trump: Energy Department official says businesses may want the technology for their own purposes

Saudi Aramco to invest $100 million in climate-friendly technologies

December

The Netherlands Energy and Climate Plan recognises the importance of Carbon Capture and Storage to achieve Dutch climate change targets

U.S. states group outlines the growing opportunities for capturing carbon dioxide for use in enhanced oil recovery (CO2-EOR) with geologic storage

A working paper by Scottish Carbon Capture & Storage (SCCS) outlines a 'twin-track' path to developing CCS in Scotland

SaskPower's carbon capture and storage facility faces millions in additional costs thanks to contract penalties

The Canadian government and 10 provinces agree on a national carbon price of $7.60/ton

Technology developed by Carbon Clean Solutions is being used at a 10MW coal plant in India

Breakthrough Energy Ventures raises more than $1 billion to fight climate change

IEA: CCS Essential to Meeting Paris Targets

New analysis by the International Energy Agency (IEA) highlights the important role of carbon capture and storage technologies in achieving the ambitions of the Paris Agreement. The "20 Years of CCS: Accelerating Future Deployment" publication reflects on two decades of technology and project experience since the commencement of the Sleipner CCS Project in Norway.

By Juho Lipponen and Samantha McCulloch, IEA

The report explores in detail the role of CCS in limiting future temperature increases to 2°C and well below 2°C, considers the implications if CCS is not deployed, and proposes new approaches and priorities for accelerating deployment.

More than 20 years of technology and project experience has garnered considerable progress in CCS development and deployment, evidenced by the 15 large-scale projects that are now operating across diverse mix of power and industrial facilities. CCS technologies are now proven in many applications and there is high confidence in the availability, safety and integrity of CO2 storage. However much faster progress – and significantly more projects – will be required if Paris Agreement ambitions are to be achieved.

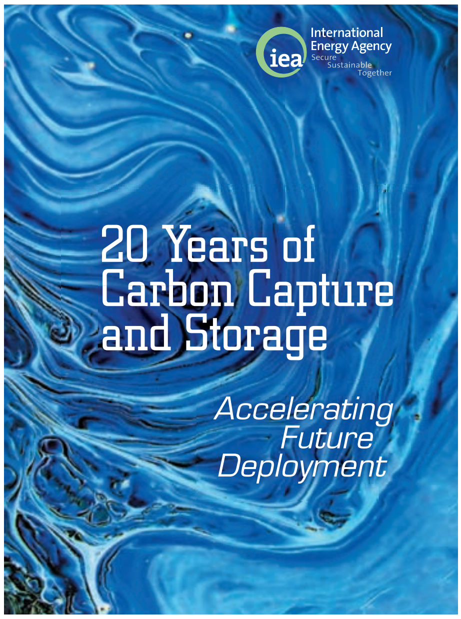
According to the IEA, CCS could account for 12% of the cumulative emissions reductions needed across the energy sector by 2050 in its 2°C scenario (2DS). CCS delivers 94 gigatones (Gt) of CO2 emissions reductions across power generation and industrial processes globally in the 2DS. Around 55% of the total CO2 captured is from the power sector, predominately coal-fired power generation, while in industry iron and steel, cement, and chemicals are the key sectors where CCS is deployed. CCS is particularly important in reducing emissions from cement production, with almost 50% of the emissions reductions achieved in the sector are from CCS.

Without CCS, the IEA finds that the cost of the energy transition will be higher and more ambitious climate targets may be out of reach. If CCS were not available in the power sector, around 1 900 GW of additional renewable capacity would be required in the period to 2050 to replace 850 GW of CCS-equipped plant – over and above the 10 000 GW of renewable capacity already deployed in the 2DS. This could create significant challenges for energy networks while adding at least USD 3.5 trillion in additional generation capacity costs alone (excluding costs associated with energy storage and network requirements).

Failing to implement CCS in power in the 2DS would also require a virtual phase-out of coal-fired power generation globally by 2050, as well as limited use of gas-fired power generation. This is a challenging prospect given today's reality of more than 2 200 GW of coal-fired power generation currently in operation or under construction. The average age of coal plants in developing countries is around 15 years, and most of this fleet would face early retirement. This could have enormous political, economic and social implications, as well as potential energy security impacts in some areas. While it will never be business as usual for coal-fired generation in a 2°C world, CCS offers an important and strategic alternative to these early retirements while supporting the transition to a low carbon economy.

The availability of CCS in industry is critically important for climate targets: by 2050, the industrial sector becomes the single largest source of emissions in the IEA 2DS. While renewables, energy efficiency and alternative processes can all play a part in reducing these emissions, they alone are unlikely to put the industrial sector on the path to 2°C. Around 29 Gt of CO2 is captured in industry in the 2DS and, without CCS, it is possible that much of the burden of this abatement could shift to other sectors which are already facing a challenging decarbonisation effort.

Realising this important role for CCS in practice will require a step-change increase in the current deployment effort. The IEA report notes that fluctuating policy and political support has hampered CCS deployment and calls for targeted financial incentives and government leadership in developing CO2 transport and storage infrastructure. It proposes that disaggregating the CCS project chain could enable new business models to emerge, particularly for CO2 storage, while moving from a focus on individual projects to plan for, and invest in, multi-user transport and storage infrastructure could support a much faster roll-out of CCS. Greater emphasis on the opportunities for CCS-retrofitting and modifying traditional enhanced oil recovery (EOR) practices to support permanent CO2 storage should also be considered.



The IEA's analysis confirms that CCS can contribute to a strengthened global climate response following the success of the Paris Agreement. There is a major gap between the ambitions contained in the Agreement and the level of action today: bridging this gap requires us to act faster and look further for deeper emissions reductions across a greater number of sectors. All technologies and all options will need to be embraced, and CCS must be central amongst these.

More information

The IEA's "20 years of CCS: Accelerating Future Deployment" report is available for free download at **iea.org/publications**

Global CCS Institute Status CCS: 2016

The pace of carbon capture and storage development must be accelerated if Paris climate change targets are to be met, says the Global CCS Institute in its flagship Status Report. It currently identifies 38 large-scale CCS projects around the world, either in operation, under construction or in various stages of development planning.

The report also emphasised that CCS must be afforded 'policy parity' in clean energy dialogues as reliance on renewables and energy efficiency alone cannot deliver climate outcomes consistent with the Paris Agreement.

Speaking at a press conference to launch its Global Status of CCS: 2016 Report at the twenty second conference of the parties (COP 22) in Marrakech, Global CCS Institute Chief Executive, Brad Page, said the scale of the challenge to deliver the 'well below' 2°C climate goal should not be underestimated.

"The current level of CO2 capture capacity is dwarfed by the amount of CCS deployment required over the next 25 years under the International Energy Agency's (IEA) 2°C scenario.

Under the 2° scenario (2DS), we need to capture and store almost 4,000 million tonnes per annum (Mtpa) of CO2 in 2040 – mostly from non-OECD countries. Current carbon capture capacity of facilities in operation or under construction sits at around 40 Mtpa. We need to make up a lot of ground to bridge that gap."

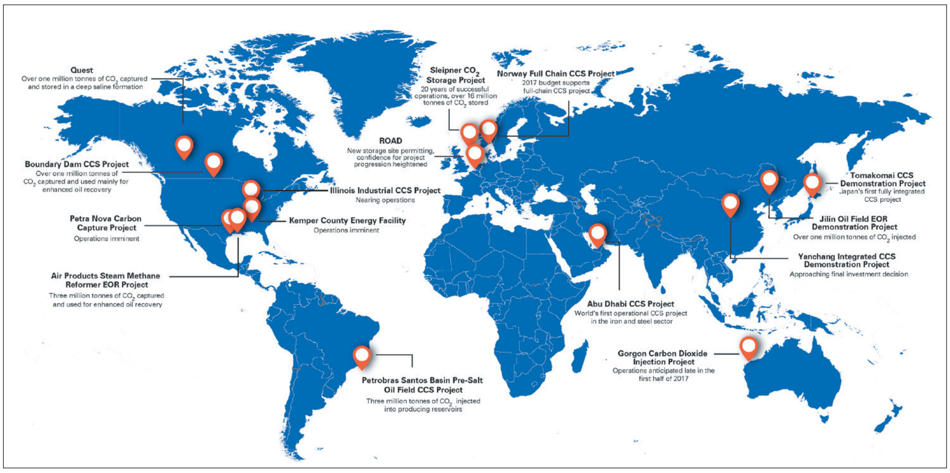
Mr Page said the past five years has heralded hugely positive developments for global CCS projects.

"We are close to having 18 large-scale CCS facilities operational globally with a number of key facilities in the United States completing construction and in the final phases of commissioning. This compares with less than 10 operational large-scale CCS facilities at the start of 2010.

This success has been driven by proactive government policy initiatives developed towards the end of the last decade."

The 2016 report reveals that continued proactive and multi-government support is intrinsic to the ongoing success of CCS and our shared ability to reach Paris climate targets.

"Widespread deployment of CCS must be based on 'policy parity', particularly the provision of equitable consideration, recognition and support for CCS alongside other low-carbon technologies," said Mr Page.



Key CCS project developments and milestones (from Global CCS Institute Status CCS: 2016)

"For CCS, this means the design and implementation of support measures tailored specifically to the technology and its lifecycle stage. Future efforts needs to focus on identifying incentive mechanisms that tackle the complexity of risks and act as economic multipliers to improve the conditions for CCS uptake."

Mr Page said the steady progression of CCS facilities in recent years and the many milestones reached in the past year were proof of CCS' success. He warned, however, that momentum needs to be maintained.

"The technology still depends on more widespread adoption. The vital role attached to CCS in global models in the transition to a low-carbon economy has not translated broadly enough into policy support at national levels.

"The timeline of forward activities is critical. The number of large-scale CCS facilities must rise substantially to help meet the climate targets and aspirations of the Paris Agreement. The danger is, if the right policy, legal and regulatory preconditions are not put in place over the next five years, Paris will be just a pipe dream."

International advisor to the Global CCS Institute and Chair of the Grantham Research Institute on Climate Change and the Environment at the London School of Economics and Political Science, Professor Lord Nicholas Stern, said the pace of deployment of carbon capture and storage is simply too slow and must be given much greater attention by countries around the world.

"If the world is to achieve the target set in the Paris Agreement of holding global warming to well below two Celsius degrees, we are likely to need negative emissions, including those from the use of bioenergy with carbon capture and storage.

"In addition, carbon capture and storage seems to be the only option for reducing emissions from many industrial activities. We cannot afford to neglect this technology, and we need better policies and more investment to accelerate its development."

Projects

At the time of launch of this Global Status of CCS: 2016 report, there were 15 large-scale CCS projects in operation around the world, with a CO2 capture capacity of close to 30 million tonnes per annum (Mtpa).

A further three large-scale projects, all in the US, are poised to become operational, bringing the number of operational projects to 18 by early 2017 (with a CO2 capture capacity of 35 Mtpa). As projects in Australia and Canada come on-line during 2017, the number of large-scale operational CCS projects is expected to increase to 21 by the end of 2017, with a CO2 capture capacity of approximately 40 Mtpa.

This compares with less than 10 operational large-scale CCS projects in 2010.

Two significant projects were launched in 2016 – one large-scale project and one demonstration-scale project. Both projects are in the industrial sector:

• A key large-scale CCS project development was the launch on 5 November of the Abu Dhabi CCS Project, Phase 1 being the Emirates Steel Industries (ESI) CCS Project. This project represents the world's first application of CCS to iron and steel production. It involves the capture of approximately 0.8 Mtpa of CO2 from the direct reduced iron (DRI) process used at the ESI plant in Abu Dhabi and its use for enhanced oil recovery (EOR).

• Japan has embarked on an active program of pilot and demonstration CCS projects. The most notable development in 2016 was the commencement of CO2 injection in April at the Tomakomai CCS Demonstration Project. The capture system (using emissions from a hydrogen production facility at Tomakomai port) is processing CO2 at a rate of at least 100,000 tonnes per annum; this CO2 is then injected into near-shore deep geologic formations.

Three large-scale CCS projects are considered very close to being operational, having achieved significant plant construction and commissioning milestones. All three projects are in the US; they include two key projects in (coal-fired) power generation and one in the industrial sector:

• The Kemper County Energy Facility in Mississippi (CO2 capture capacity of approximately 3 Mtpa) is expected to be operational by the end of 2016. This landmark project will be the first commercial-scale deployment of the TRIG™ coal gasification process developed jointly by Southern Company and KBR in partnership with the United States Department of Energy (US DOE).

• The Petra Nova Carbon Capture Project in Texas (CO2 capture capacity of approximately 1.4 Mtpa) is expected to be operational either by the end of 2016 or at the beginning of 2017. When fully operational, this project will be the world's largest post-combustion capture project at a power station.

• The Illinois Industrial Carbon Capture and Storage Project (CO2 capture capacity of approximately 1 Mtpa) is expected to begin operations early in 2017. This project will be the world's first large-scale BECCS project, as well as the first CCS project in the US to inject CO2 into a deep saline formation at a scale of 1 Mtpa.

Commissioning of the Gorgon Project, offshore Western Australia, is also progressing, with the first LNG delivery made in 2016. The Gorgon Carbon Dioxide Injection Project, which the Institute anticipates will begin operations late in the first half of 2017, is the largest in the world to inject CO2 into a deep saline formation (being capable of injecting up to 4 Mtpa of CO2).

This milestone would bring the number of large-scale operational CCS projects to 19 by the middle of 2017. Two additional large-scale CCS projects in Alberta, Canada, associated with the Alberta Carbon Trunk Line (ACTL) development, are expected to be operational by the end of 2017, bringing the number of operational large-scale CCS projects to 21 at that time.

Positive signals are emerging on key projects progressing through development planning:

• In China, there are strong indications that the Yanchang Integrated Carbon Capture and Storage Demonstration Project will progress into the Execute (or construction) stage in the near future (possibly before the end of 2016). Between 0.4 and 0.5 Mtpa of CO2 would be captured from gasification facilities at chemical plants in Shaanxi Province, with the CO2 used for EOR.

• In the Netherlands, the ROAD project (CO2 capture capacity of approximately 1 Mtpa) is proposing a new initial storage site. Revised storage and transport permitting is underway, suggesting a willingness on the part of the project proponents to move the project forward into construction in 2017.

• The Norwegian budget for 2017, released in early October 2016, contained grant monies of 360 million Norwegian Krone (approximately US$45 million) for the continued planning of a full-chain CCS project. While contracts for the financing of these advanced planning studies need to be completed, this is a very positive signal for CCS in Norway.

A number of large and demonstration-scale projects across the world have achieved significant milestones in the past year (see Figure):

• Twenty years of successful operation for the Sleipner CO2 Storage Project (located off the Norwegian coast), with over 16 million tonnes of CO2 injected since the project commenced operations in 1996.

• When added to the more than three million tonnes of CO2 injected by the Snøhvit CO2 Storage Project (also offshore Norway) since 2008, the combined CO2 injection volume into geological formations for these two pioneer projects is approximately 20 million tonnes.

• In Brazil, Petrobras announced that, as of December 2015, the Santos Basin Pre-Salt Oil Field CCS Project (located approximately 300 kilometres off the coast of Rio de Janeiro in ultra-deep water) had injected three million tonnes of CO2 into the producing reservoirs.

• The Air Products Steam Methane Reformer EOR Project in Texas had captured three million tonnes of CO2 from hydrogen production facilities as of end June 2016 (and used for EOR).

• The Boundary Dam Carbon Capture and Storage Project had captured one million tonnes of CO2 from its Unit 3 power generation facility as of July 2016 (and used mainly for EOR).

• The Quest project in Alberta, Canada, had successfully captured (from a hydrogen-processing plant) and stored more than one million tonnes of CO2 into a deep saline formation as of September 2016.

• In October 2016, the US DOE Office of Fossil Energy website highlighted that over 13 million tonnes of CO2 has been injected in the US as part of the DOE's Clean Coal Research, Development, and Demonstration Programs.

• The Jilin Oil Field EOR Demonstration Project in China began CO2-EOR injection testing ten years ago, and reached one million tonnes of CO2 injected in 2016.

More information

www.globalccsinstitute.com

Full Chain CCS Demonstration Project in Hokkaido, Japan

A large-scale CCS demonstration project is currently being undertaken by the Japanese government in the Tomakomai area, Hokkaido Prefecture, Japan to demonstrate the viability of a full chain CCS system, from CO2 capture to injection and storage.

One hundred thousand tonnes/year or more of will be injected and stored in offshore saline aquifers in the Tomakomai port area from JFY2016 thru JFY2018 (Note: JFY is from April to March of following year). The implementation of this project has been commissioned to Japan CCS Co., Ltd. Construction of the facilities was completed in October 2015, and after finishing a test-run in February, CO2 injection commenced in April 2016.

The main features of this project are as follows:

• First full chain CCS system deployed in Japan, a country prone to frequent earthquakes.

• Two-stage CO2 capture system providing for low energy consumption.

• Application of two highly deviated injection wells drilled from the onshore injection site targeting the most prospective segments of two separate reservoirs in the offshore subseabed.

• Extensive marine monitoring system for observation of CO2 behavior in the reservoirs, micro-seismicity and natural earthquakes.

• World's-first CCS project reflecting the London Protocol.

• CCS project being implemented near urban area, requiring extensive stakeholder engagement.

Figure 1 - Aerial photo of the CO2 capture and injection facilities

CO2 capture facilities

The CO2 source is a hydrogen production unit (HPU) of an adjacent oil refinery, which supplies off gas containing approximately 50% CO2 from a Pressure Swing Adsorption (PSA) hydrogen purification unit. The off gas is transported to the Tomakomai demonstration project CO2 capture facility via a 1.4km pipeline.

Figure 2 shows the gas flow from the CO2 source to the capture and injection facilities. At the capture facility, gaseous CO2 of 99% or higher purity is recovered from the PSA off-gas by an activated amine process at a rate of 100,000 tonnes per year or more.

A two-stage CO2 absorption tower (where CO2 lean amine and CO2 semi-lean amine are circulated to the upper and lower parts of the CO2 absorption tower respectively) connects with a low pressure flash tower, greatly reducing the energy consumption of the capture system, estimated to be approximately 1.22 GJ/tonne-CO2 or less. Following CO2 capture, the remaining gas which contains H2, CH4 and CO is utilized as fuel for a high-pressure boiler to supply steam to generate electric power for the capture and injection facilities, and a low-pressure boiler to supply steam to the amine reboiler.

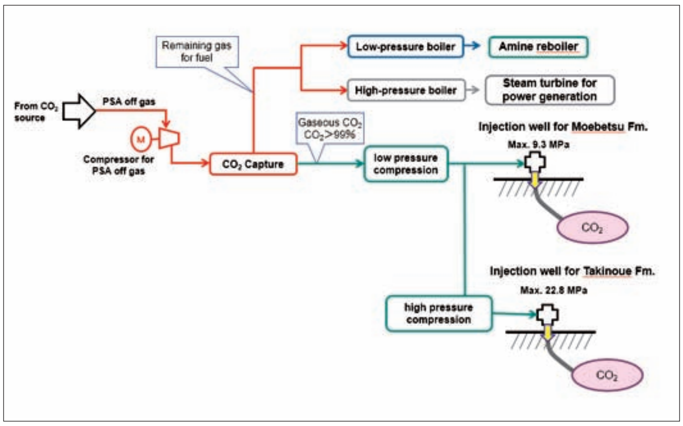


Figure 2 - Gas flow from CO2 source to capture and injection facilities

Reservoirs and the injection points

The CO_2 from the capture facility is compressed and injected into a shallow and deep reservoir by two dedicated deviated wells. The shallow reservoir is a sandstone layer of the Moebetsu Formation, located at a depth of approximately 1,000m to 1,200m below the seabed. This reservoir is a Lower Quaternary saline aquifer and is approximately 100m thick. The reservoir is overlain by a thick mudstone layer of the Moebetsu Formation (approximately 200m thick) which serves as a cap rock, as illustrated below. The Moebestu Formation has a gentle monocline structure with a NE dip of 1 to 3 degrees at the planned storage interval located 3km offshore.

The deep reservoir is the Takinoue Formation, located at a depth of approximately 2,400m to 3,000m below the seabed. This reservoir is a Miocene saline aquifer composed of volcanic and volcaniclastic rocks and is approximately 600m thick. The Takinoue Formation is overlain by Miocene mudstones (Fureoi Formation, Biratori-Karumai Formation and Nina Formation) which act as cap rocks with a total thickness of approximately 1,000m. The Takinoue Formation is an anticlinal structure with a NNW-SSE trending axis and the planned storage interval is located in the north-eastern wing of the anticline about 4km offshore.

Injection wells

Drilling of the two injection wells started in October 2014 and was completed in July 2015. Two highly deviated injection wells were drilled from an onshore site and targeted the most prospective segments of each reservoir determined from analyses of 3D seismic surveys conducted in 2009 and 2010.

The injection well for the Moebetsu Formation is an extended reach drilling (ERD) well with a maximum inclination of 83 degrees, a drilled depth of 3,650m, vertical depth of 1,188m and horizontal reach of 3,025m. The injection interval of 1,194m in length is completed by perforated liners covered by sand control screens, which help minimize sand flow back into the well. The brine injection test immediately following drilling and completion indicated that the injectivity of the Moebetsu Formation was very high (hundreds millidarcy order in permeability).

The injection well for the Takinoue Formation has a maximum inclination of 72 degrees with a drilled depth of 5,800m, vertical depth of 2,753m and horizontal reach of 4,346m. The injection interval is completed with perforated liners achieving a length of 1,134m.

The brine injection test conducted shortly after the drilling and completion of IW-1 indicated that the injectivity of the Takinoue Formation was very low (nano darcy order in permeability).

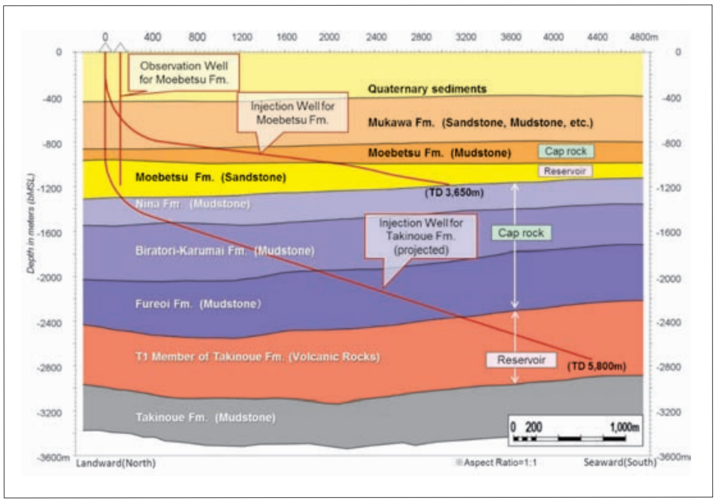


Figure 3 – Schematic geological cross section of the Tomakomai demonstration site

Test injection into the Moebetsu Formation was conducted between April 6th and May 24th, 2016, and a cumulative amount of 7,162.9 tonnes of CO_2 was injected. The maximum injection rate was 210,000 tonnes per year. Before proceeding with the test injection, the maximum value of the bottom hole pressure was set as the operational limit of the CO_2 injection. The value of 12.6MPaG is 90% of the leakoff pressure of the cap rock obtained from the XLOT (extended leakoff test) conducted shortly after completion of the injection well for the Moebetsu Formation.

The initial bottom hole pressure was 9.3MPaG and the maximum bottom hole pressure recorded during the test injection was 10.0MPaG, much lower than the operational limit pressure, meaning that the injectivity of the Moebetsu Formation is very high. Since the commencement of CO_2 injection in April 6th 2016, no micro-seismic events have been detected in the micro-seismicity monitoring area.

The forward plan is to implement CO_2 injection for 3 years until JFY2018, and continue monitoring of micro-seismicity, natural earthquakes and the marine environment for an additional 2 years until the end of JFY2020.

Monitoring systems

In order to confirm that CO_2 is injected and stored safely and stably, it is necessary to set up systems to monitor the behavior of CO_2 in the reservoirs and to detect CO_2 movement out of the reservoirs. As Japan is highly susceptible to earthquakes, it is also necessary to allocate systems to measure and verify any correlation (or dis-relation) between CO_2 storage and seismicity. The construction and deployment of the monitoring facilities were completed by January 2014 so that baseline observation could be started at least one year prior to the commencement of CO_2 injection. The figure below illustrates the layout of the monitoring facilities that have been established.

In the injection wells, CO_2 injection rates, bottom hole temperatures and pressures are continuously monitored as well as wellhead temperatures and pressures. Temperature and pressure sensors and downhole seismometers have been installed in three observation wells. A permanent ocean bottom cable (OBC) 3.6km long with 72 seismometers has been installed directly above the storage points of the reservoirs.

Four ocean bottom seismometers (OBSs) have been placed above and surrounding the storage points. One onshore seismic station was constructed in the northwestern part of Tomakomai City. Using the seismometers in the observation wells, the OBC, the OBSs and the onshore seismic station, the monitoring of micro-seismicity and natural earthquakes started on February 1st 2015, thirteen months before the start-up of CO_2 injection.

A 3D seismic survey of the working area (3.8km×4.1km) was first conducted in 2009. Time lapse 3D seismic surveys over the same area will be performed twice until the project ends in JFY 2020. 2D seismic surveys are also planned using temporal deployment type OBCs along with the permanently installed

OBC in the years when 3D seismic surveys are not scheduled. In total, four 2D seismic surveys will be conducted (including the baseline survey conducted in 2013). Since the sensor locations of the permanently installed OBC are fixed, it is expected that highly accurate data will be obtained in the repeated 2D seismic surveys.

In Japan, CO2 geological storage below the seabed is regulated by the Act on Prevention of Marine Pollution and Maritime Disaster, enacted and amended to reflect the London Protocol. Marine environmental surveys were conducted in JFY2013, JFY2014, and from JFY2016, seasonal surveys will be conducted each quarter.

Social Outreach Activities

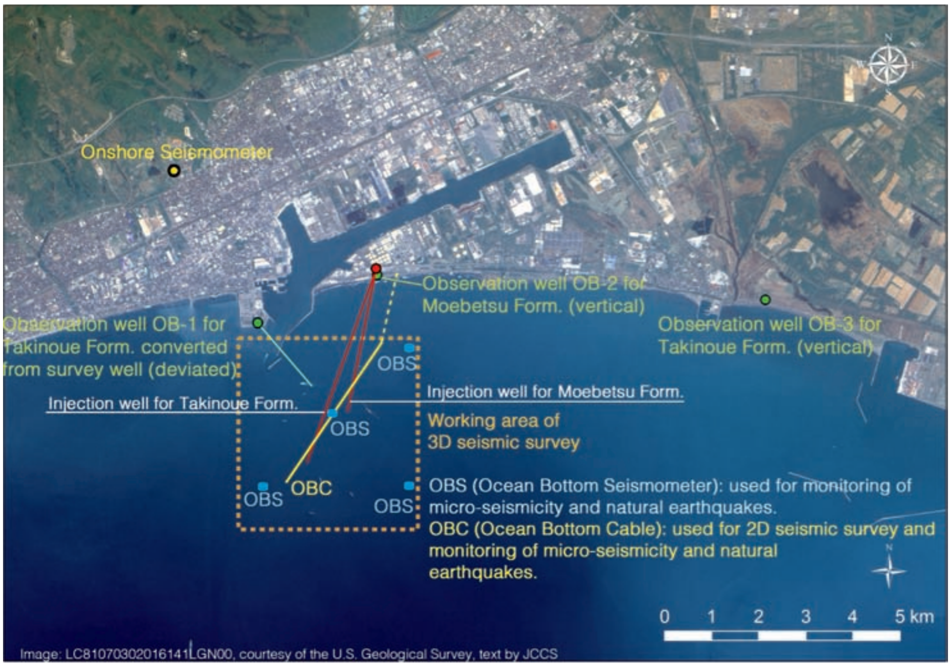
As the CCS demonstration project is being conducted in the offshore area of the Tomakomai Port, the understanding and support of the local government, industry, and community are a must. The City of Tomakomai has a legacy of a high awareness of environmental issues, having proclaimed itself as a "Human Environmental City" as early as in 1973.

When the city learned in 2009 that a geological survey was being conducted in offshore Tomakomai regarding its feasibility as a candidate site for CO2 storage, it saw early on that a CCS demonstration project at Tomakomai could become a basic model for CCS in Japan.

Garnering the support of major local companies, industrial associations and fishing unions, the city established the "Tomakomai CCS Promotion Association" in April 2010, in order to bring the demonstration project to Tomakomai, and to communicate information on CCS to its residents.

The local fishing cooperatives have also been very supportive of the demonstration project, and JCCS has maintained very close communications and consultations with the cooperatives ever since the preparatory stages of the project to ensure that the CCS project and fishing activities can coexist.

JCCS has also conducted extensive social outreach activities in Tomakomai and other areas since JFY2011. A wide range of activities; panel exhibitions, forums for the residents, science classes for schoolchildren, seminars for senior citizens, site visits, etc., is being implemented.



Layout of the monitoring facilities

In addition, in order to enhance the awareness and understanding of CCS by the general public, JCCS conducts seminars on CCS at Japanese universities and industrial associations and participates in large exhibitions on environmental and global warming issues in Japan and abroad.

Regarding the number of visitors (domestic and international) to the Tomakomai site, 1,600 people visited the site in JFY2015, a three-fold increase from the year before, reflecting the growing interest in the Tomakomai CCS demonstration project.

Conclusion

The Tomakomai CCS demonstration project, planned for the period JFY 2012 to 2020 aims to demonstrate and verify the technical viability of a full cycle CCS system from capture through injection and storage. Unique features of the project include an energy efficient CO2 capture facility, and onshore to offshore injection into two separate reservoirs by two dedicated deviated injection wells.

The demonstration facilities comprising the CO2 capture facility, CO2 injection facility, two injection wells, three observation wells and various onshore and offshore monitoring systems were completed during the first four-year period (JFY 2012 – 2015). The project will capture and store 100,000 tonnes per year or more of CO2 from JFY 2016 to 2018.

The CO2 injection into the shallow Moebetsu Formation started in April 2016, and the test injection results indicate that the injectivity of this reservoir is very high.

The project is being carried out in the port area of Tomakomai City, and a wide range of public outreach programs have been developed and are being run in parallel with the implementation of the project.

Authors

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Acknowledgments

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More information

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info@japanccs.com

Lessons from 10 years' post-injection monitoring at Nagaoka pilot site

Insights into trapping mechanisms and long term behaviour of saline aquifer CO2 storage. The Nagaoka CO2 Storage Project was the first pilot CO2 injection test in Japan and was conducted as part of an R&D project called "Research and Development of Underground Storage for Carbon Dioxide", funded by the Ministry of Trade, Industry and Energy of Japan.

The work was undertaken by the Research Institute of Innovative Technology for the Earth (RITE). The purpose of the project was to test the feasibility of CO2 geological storage in Japan and incorporated aspects of public acceptance and environmental assessment methodologies.

The field test site for CO2 injection was situated at the Minami-Nagaoka (onshore) gas and oil field where the Teikoku Oil Company produces natural gas from deep reservoirs (at 4,700 metres / 15,515 feet). The injection reservoir was a saline sandstone formation, the Pleistocene Haizume Formation, which lies in a stratigraphically shallower zone than the gas field.

The Haizume Formation is around 800-1,200 metres (2,624-3,937 feet) deep with a thickness of 60 metres / 197 feet overlain by a thick 130-150 metre (426-490 feet) mudstone caprock. The upper part of the Haizume Formation, with a thickness of 12 metres / 40 feet and referred to as Zone 2, was found to have the higher porosity and permeability and was considered the most suitable injection layer.

In 2000, an injection well was drilled to a depth of 1,230 metres / 4,035 feet to analyse the geophysical characteristics of the targeted aquifer and caprock. Based on drill results, a configuration of three observation wells was determined and these wells were drilled in 2001 and 2002 (Figure 1). CO2 injection carried out between July 2003 and January 2005. The injection rate for the first nine months was at 20 tonnes per day which was then increased to 40 tonnes per day. Overall, 10,400 tonnes of CO2 were injected into the reservoir.

During CO2 injection, a series of field surveys and measurements, including crosswell seismic tomography, well logging, reservoir formation pressure and temperature measurements, and microseismic monitoring were conducted, to improve understanding of CO2 behaviour in the storage reservoir.

One of the main objectives was to determine the arrival times of injected CO2 in observation wells from time-lapse well logging. The CO2 breakthrough times at the observation wells are necessary for modifying the computer-based reservoir simulation model and for describing fluid flow in the reservoir.

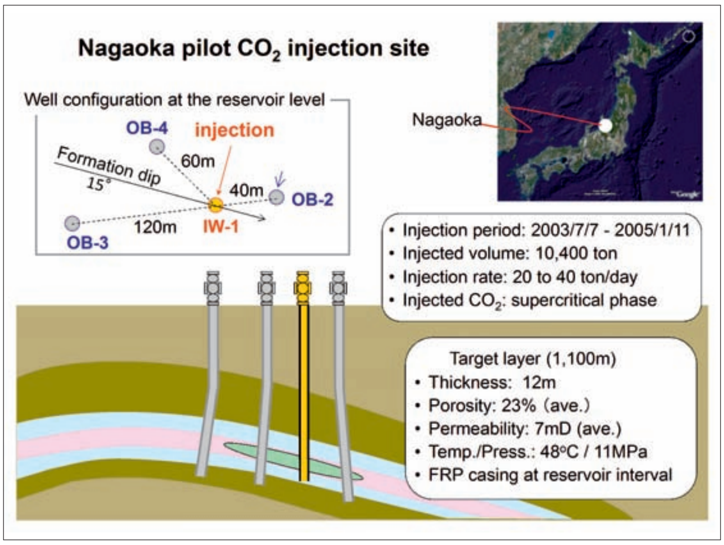


Figure 1 - Well configuration and information of target reservoir and CO2 injection at Nagaoka site

Figure 2 shows the results of sonic P-wave velocity, resistivity and CO2 saturation converted from neutron porosity change throughout injection and post-injection periods. Drastic decreases in P-wave velocity and CO2 saturation, and a moderate increase in resistivity suggested CO2 breakthrough at the observation well OB-2.

From the 10 years post-injection monitoring at Nagaoka, we learned that the drainage process continued in early stage of the post-injection phase. After nearly stabilizing pressure, imbibition process started. The results of time-lapse well logging provide the observational data for solubility trapping and residual trapping which is currently occurring in the reservoir progress and will be the ultimate solution for long-term safety of large scale CO2 geological storage.

Also, it is well known that injected CO2 reacts with formation water and minerals in a saline reservoir and, over time, is altered to

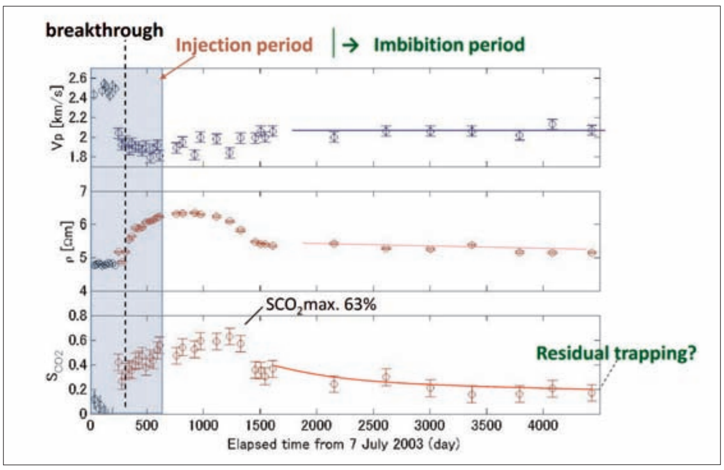


Figure 2 - Time-lapse changes of sonic P-wave velocity, resistivity and CO2 saturation obtained from the observation well OB-2 at Nagaoka site

dissolved CO_2 (e.g. $CO_2(aq)$ and HCO_3^-) and mineral CO_2 (e.g. $CaCO_3$). In-situ formation fluid sampling was performed twice aiming to improve understandings of geochemical reactions in reservoirs.

Results of the repeated fluid sampling suggested that at the early stage of CO_2 dissolution, pH change was buffered by a carbonate system in the formation water. Once this exceeded the capacity of the carbonate buffer, pH decreased and then minerals dissolved.

n further geochemical reactions, formation water was neutralised and a part of injected CO_2 was potentially stored in subsurface as a result of mineralization in the post-injection phase. The geochemical results from the fluid sampling of the reservoir and the preliminary geochemical simulation support that the notion that geochemical trapping contributes significantly to permanent CO_2 geological storage at the Nagaoka site.

On October 23, 2004, a huge earthquake with a magnitude of 6.8 in JMA (Japan Meteorological Agency) Magnitude hit the Mid-Niigata area. The earthquake epicentre depth was 14 km (JMA), and the CO_2 injection site is located about 20 km away from the earthquake epicentre. The ground motions during the earthquake recorded by the seismicity monitoring system installed at the Nagaoka site was 705 gal (maximum).

CO_2 injection stopped and crosswell seismic tomography and well logging survey were carried out to investigate the CO_2 distribution within the reservoir and integrity of well casing. There was no evidence of any CO_2 leakage from the reservoir according to the survey results. It is important to note that no seismicity was recorded at the Nagaoka site during CO_2 injection.

More information

Further information on the Nagaoka Project, please contact Ziqiu Xue (**xue@rite.or.jp**)

The Osaki CoolGen project

Osaki CoolGen is an Integrated Coal Gasification Fuel Cell Combined Cycle (IGFC) demonstration project planned for March 2017.

Japan's energy policy has changed responding to diverse needs of the times. The policy was reviewed using zero-based thinking, as a result of the Great East Japan Earthquake on March 11, 2011 and the subsequent accidents at the Fukushima Daiichi Nuclear Power Station. As a crucial perspective, the Basic Energy Plan, which was approved in the Japanese cabinet meeting held on April 11, 2014, focuses on 3E+S, where 3E stands for Energy security, Environmental compatibility and Economic efficiency, and S for safety was newly added.

Coal has achieved higher reliability because of its excellent supply stability, cost-effectiveness and safety performance over a number of years. Coal consistently ranks, therefore, as the critical fuel for base load power generation. There are, however, growing concerns about adverse impact on the environment caused by its higher CO_2 emission per power generated than other fossil fuels. In recent years, therefore, the importance of development of high-efficient and clean coal technologies is increasing. The Integrated Coal Gasification Combined Cycle (IGCC) is a promising technology for high-efficiency power generation. The Basic Energy Plan also describes the needs of development and practical application of innovative low-carbon coal-fired thermal power generation technologies using IGCC with CCS(carbon dioxide capture and storage).

Nuclear power generation had been considered to be a base load power source, but in the current situation its future outlook is opaque. This means that coal-fired thermal power generation will continue to be an important base load source into the future. It is envisioned that most of coal-fired thermal power plants will continue to be replaced with coal-fired facilities with higher efficiency, and a part of these will be of the IGCC type. It was under the foregoing circumstances, that the Osaki CoolGen Project began in April 2012, subsidized by the Ministry of Economy, Trade and Industry (until 2015FY) and New Energy and Industrial Technology Development Organization (from 2016 FY) that is national research and development agency.

Coal gasification technology

Japan's Integrated Coal Gasification Combined Cycle technology has developed in earnest since the 1970s with the aim of enhancing the efficiency of coal-fired thermal power generation. Oxygen-blown coal gasification technologies promise to further enhance efficiency through application to high-temperature Gas Turbines and expansion into IGFC. One such coal gasification technology that was the EAGLE (coal Energy Application for Gas, Liquid & Electricity) Gasifier, which in addition to enhancing efficiency has a capability of coal type expansion –that is, it is able to utilize a wide range of coal types.

Pilot testing of the EAGLE was conducted at Electric Power Development Co., Ltd. (J-POWER) Wakamatsu Research Institute, as a joint research project by J-POWER and NEDO. Using a pilot test plant that consumes 150 tons of coal per day, to date this project has confirmed the coal gasification performance, gas purification performance and a capability of coal type expansion, and has also verified CO_2 capture technologies employing chemical and physical absorption from coal gas in a coal gasification power generation system.

The Osaki CoolGen project is placed as a commercialization-oriented large-scale demonstration to make progress, step by step from the EAGLE pilot testing.

Osaki CoolGen project

A joint company was set up in July 2009 as the project implementer. The company is jointly funded by the Chugoku Electric Power Co., Inc. and J-POWER, which share the urgent issues of further enhancing the efficiency of coal-fired thermal power generation and of reducing its carbon dioxide through clean technologies. The company was named the Osaki CoolGen corporation from its object of realizing the "CoolGen Plan", which constitutes the Japanese government's clean coal policy.

The Osaki CoolGen project is an "Integrated Coal Gasification Fuel Cell Combined Cycle (IGFC) demonstration project" subsidized by

NEDO. This project aims to realize innovative low-carbon, coal-fired thermal power generation that combines IGFC, an extremely efficient coal-fired thermal power generation technology with CO2 capture technologies, thus drastically reducing the CO2 that is emitted from coal-fired thermal power generation.

The demonstration project is planned in three stages. The first stage will implement demonstration tests of oxygen-blown IGCC, which is the base technology for IGFC. An oxygen-blown IGCC demonstration test facility with an EAGLE Gasifier as its core is to be constructed on the premise of the Chugoku Electric's Osaki Power Station, and is scheduled to begin demonstration test operation in March 2017.

Fig. 1 shows the process flow of IGCC Demonstration System. The major system consists of Coal gasification unit, Gas clean up unit, Air separation unit, Gas turbine unit, and Wastewater treatment unit. In order to reduce the construction costs, the Osaki Power Station's existing equipment is utilized for the facility's Stack, for part of its Wastewater treatment unit, for its Coal berth, for its Cooling water intake/discharge, and for certain other aspects.

Demonstration will be carried out on a linked-up total system that scales up the individual processes demonstrated in the EAGLE pilot tests.

In our demonstrations, we aim to be in the top class for Generating efficiency, Environmental performance, Coal variety compatibility, Reliability and Operability.

The basic performance target of net thermal efficiency 40.5% (HHV) is the highest level in the world for the 170 MW scale facilities. When 40.5% net thermal efficiency could be achieved with the demonstration test scale plant, it will open up the prospect of realizing in a commercial plant that employs a 1,500°C class Gas turbine, the IGCC net thermal efficiency of 46% (HHV) that is put forward as a goal for high-efficiency coal-fired thermal power generation. As regards environmental performance, the testing will verify that the plant has environmental characteristics that are able to comply with Japan's stringent environmental regulations and are of comparable levels to those attained by the new pulverized coal thermal power generation.

In order to confirm that the system has characteristics similar to those in the EAGLE pilot tests regarding coal variety compatibility, we plan tests that will use coals for confirming a capability of type expansion in addition to coals for verifying the basic performance.

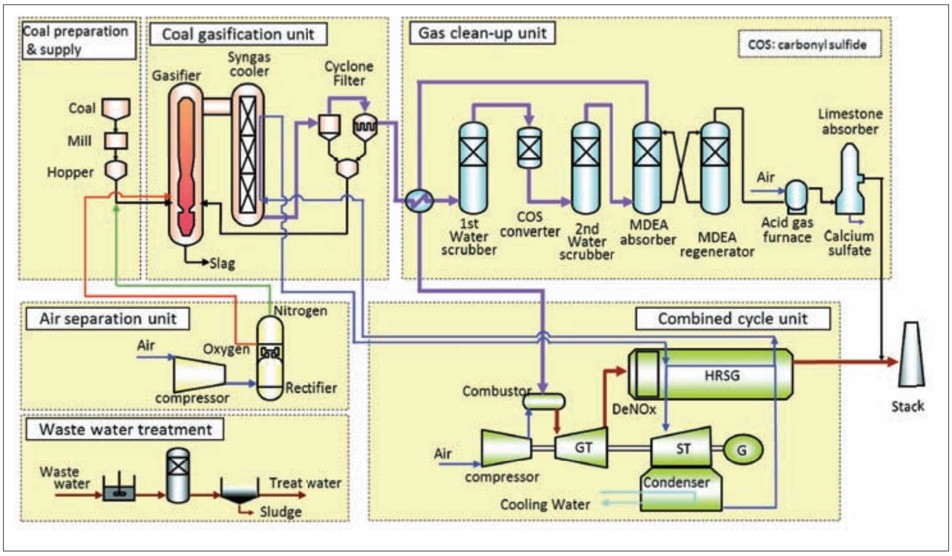


Figure 1 - process flow of IGCC Demonstration System

The civil engineering work started in March 2013, and equipment and electrical work was started in June 2014. Installation of the main equipment has been completed and commissioning began in earnest towards the start of demonstration testing in March 2017.

Demonstration of CO2 capture

In the second step, we plan to do demonstration testing of an IGCC system made up of the oxygen-blown IGCC of the first step with CO2 capture equipment added. The Chugoku Electric Power and J-POWER have conducted a comparison/evaluation of the IGCC system using the chemical absorption and physical absorption methods evaluated under the EAGLE project, and have decided to adopt the physical absorption method to be able to efficiency capture CO2 in case of IGCC. Also, due to the constraints of the Osaki Power Station space and ability for utility supply, we have determined 17% of the gas produced (CO2 capture rate being 90% with the CO2 capture equipment).

In the CO2 capture demonstration, the facility is to enable system demonstration equivalent to a commercial facility, and besides the performance of the CO2 capture equipment, the facility is also to verify the operability, economy and environmental performance of the system Fas a thermal power generation system and the effects on the generation efficiency, etc., with adding of the CO2 capture equipment. Further, although technology development for CO2 transport and storage is not part of the Osaki CoolGen Project, the possibility of cooperation with the CO2 storage demonstration testing, etc., that is being separately conducted is to be studied while observing its progress.

Conclusion

In this paper, we described an overview of the Osaki CoolGen project and state of progress. We will continue towards the start of the demonstration test of March 2017, and intends to proceed with commissioning in safety first.

We should mention that the project has come this far by reflecting the outcomes of the EAGLE pilot tests that was undertaken jointly with NEDO. We are deeply grateful to the Ministry of Economy, Trade and Industry and NEDO.

Reference

1. NEDO Final Report, Development of Multi-Purpose Coal Gasification Technology (EAGLE) and research on Zero-Emission Technology (FY2004-2009) Final Report.

2. NEDO Final Report, Development of Zero-emission Coal-Fired Power Generation /R&D of Coal Gasification Technology with Innovative CO2 Capture (FY2010-2014) Final Report.

More information

www.osaki-coolgen.jp/english

UK report 'doing the rounds'

The report from the UK's Parliamentary Advisory Group on carbon capture is currently 'doing the rounds' of government departments. It suggests setting up a government owned CCS delivery company.

By Karl Jeffery reporting from the Global CCS Institute 2016 Europe Middle East and Africa (EMEA) CCS Forum in Oslo in October 2016

The UK's Parliamentary Advisory Group on Carbon Capture and Storage published a report in September 2016 about how the UK could best proceed with carbon capture, suggesting that it set up a special 'delivery company', similar to the company established to deliver the London Olympic Games.

Lord Oxburgh, chairman of the group (and a former chairman of Shell Transport and Trading), said that at the time of the conference in October 2016, there had not yet been any formal response from the UK government about the proposal.

However the UK government energy department has been occupied with a big decision about nuclear power for most the time since the report was published, he said.

"The report is doing the rounds of government departments," he said. "I have a feeling the decision will largely depend on the Treasury [department]."

The plan has been structured so there should not be any much expenditure needed within the current parliamentary term, which should make the plan more acceptable to the current leaders, he said.

The Advisory Group was established following the decision by the UK Government to cancel its £1bn carbon capture funding competition in December 2015.

The group includes politicians of all parties and CCS experts. The experts were chosen on the basis of both their technical backgrounds and their track record of making things happen, he said.

Interestingly, not all members of the Parliamentary Advisory Group were convinced that CCS was important, before the discussions began, he said.

"Successful businesses are reluctant to go into areas they don't understand, and take risks" - Lord Oxburgh, chairman of the UK's Parliamentary Advisory Group on Carbon Capture and Storage

CCS Delivery Company

In its September 2015 report, the Advisory Group proposed that the UK government should set up a 'CCS delivery company' to take responsibility for delivering CCS.

It would initially be government owned, but eventually privatised. Government could look at the company as an investment, not a subsidy.

It would be given a budget by government and would place contracts for a range of activities. The company would own the carbon capture infrastructure it would build, including power generation, and it would sell the electricity.

The company could develop CCS hubs at coastal industrial centres, taking CO2 rich flue gas from a number of different industrial and power generation sources.

The company could be set up with two parts, a power company and a transport+storage company, with a trading relationship between the two parts.

These would eventually be privatised into their relevant sectors, for example an existing power company might buy the carbon capture power company. The transport+storage company could become like a utility or waste company, with low risk and low returns, offering to take CO2 off your hands.

Being government owned, the company could also borrow money at very low rates, he said. It could also help better manage risks, with the government taking on risks which are too complex for companies to take on, such as long term storage risk.

Currently, UK electricity buyers have an electricity surcharge on their bills which pays for low carbon electricity, with the money currently being spent on wind and solar, he said. Some of these funds could be diverted to pay for carbon capture.

As a supplier of low carbon electricity, "we think we can undercut everything except onshore wind," he said.

Getting started in the UK

We need carbon capture in the UK because the only other way to stop emitting CO2 is to stop using fossil fuel, and that transition will take decades, he said. "CCS and fossil fuels offers low carbon flexible power."

If the government does not follow a plan like this, "I don't see where they go to meeting Paris commitments," he said.

Also, if you think negative emissions will be important (ie actually removing CO2 from the atmosphere), this very probably can't be done without CCS. "All expert bodies say we can't see how it can be done without CCS," he said.

And there isn't really any other way to stop emitting CO2 from industrial activity, unless the CO2 is stored underground, he said.

The work needs to be started urgently, because "major infrastructure development takes a heck of a time."

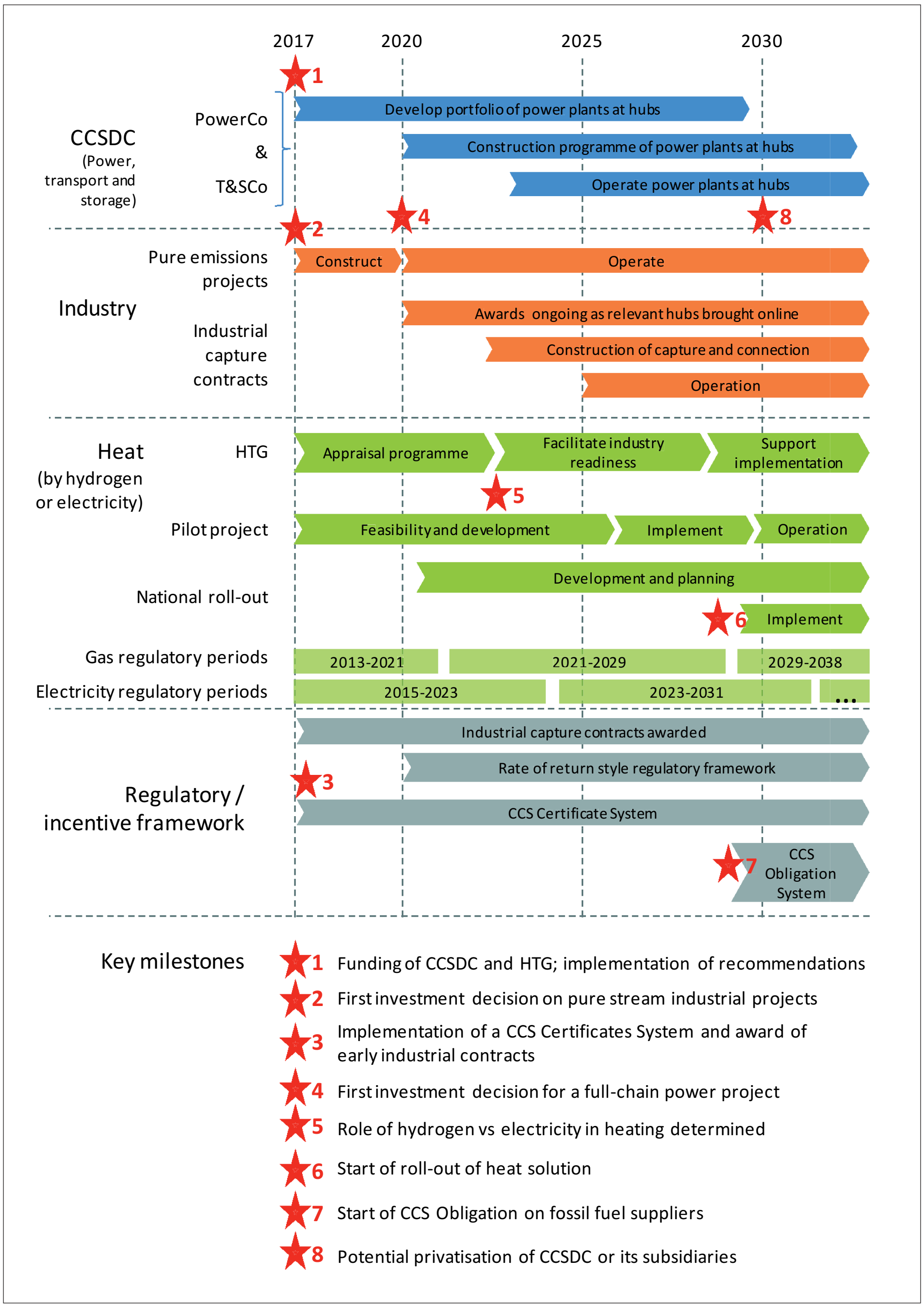
The reason CCS has not yet got started in the UK is not because of technical problems, but the difficulty "getting a sensible business model which would make the whole thing come together."

So far there's "no commercial enterprise in the world that has CCS as its main focus," he said. "It is still perceived as being risky and expensive."

"CCS combines a number of different activities which [individually] are pretty well understood but [usually] don't much overlap," he said.

"Successful businesses are reluctant to go into areas they don't understand, and take risks."

Some government people believed that it might be possible for the UK to let other countries take the risk and expense of developing CCS and then buy into it afterwards, he said.



Milestones for lowest cost decarbonisation using CCS (from UK Parliamentary Advisory Group on Carbon Capture and Storage report)

But a lot of CCS challenges can only be solved in your own country, in particular understanding your own reservoirs and infrastructure, he said.

The discussions within the Parliamentary Advisory Group looked at ways to break this complex 'logjam' of reasons preventing carbon capture being built.

Heating and transport

To find ways to reduce all carbon emissions for least cost, it is necessary to look at the whole system of CO2 emissions, covering industry, transport, heat and electricity, he said. Otherwise you might end up reducing emissions in one place only to create more emissions in another.

For industrial heat, CO_2 emitted from industrial heating systems could be sold to the transport and storage company, he said.

However, collecting emissions from domestic gas boilers, of which there are about 20m in the UK, would be very difficult.

Some people suggest that the answer is to electrify domestic heating. But this would mean a massive investment in electricity generation capacity, considering that demand for heating in winter is so much bigger than the summer. "You'd need to triple electricity generating capacity," he said.

A possible alternative, which his being considered in Leeds (UK), is to run domestic gas boilers on hydrogen, so the carbon is removed from the methane upstream.

The UK gas supply was run on 'town gas' until about 40 years ago, which is a mixture of hydrogen and methane, he said.

Hydrogen generated during the summer could be stored until the winter in salt caverns.

A country-wide hydrogen network could make hydrogen fuel cell cars possible, he said, which would be competition for electric vehicles as a zero emission form of transport.

Teeside Collective

Sarah Tennison, Low Carbon Manager, Tees Valley Combined Authority, talked about developments with the 'Teesside Collective', a project to develop a carbon capture and storage scheme in Teesside, an industrial area in North East England.

The Teesside Collective has commissioned bank Société Générale to look at how it might get CO_2 investment without any change in government policy.

Some ideas Société Générale identified were to do a 'soft start' by sending CO_2 by ship to Norway (rather than develop CO_2 storage in the UK); getting a financial return via the EU Emissions Trading Scheme; and to develop the 'transport and storage' business separately to the industrial CO_2 business, because some investors are interested in one and not the other.

It would like to get a project running for 'tens of millions' of pounds, rather than the hundreds of millions cited for other UK carbon capture projects.

It would like to sell the CO_2, for example to existing CO_2 companies like Praxair, or for CO_2 utilisation. It is also considering setting up a CO_2 utilisation demonstration centre. "We think the area is ideal for CO_2 utilisation scale up," she said.

Key recommendations from the Parliamentary report

1. Establish a CCS Delivery Company ("CCSDC")

A newly formed and initially state-owned company tasked with delivering full-chain CCS for power at strategic hubs around the UK at or below £85/MWh on a baseload CfD equivalent basis. Formed of two linked but separately regulated companies: "PowerCo" to deliver the power stations and "T&SCo" to deliver the transport and storage infrastructure, the CCSDC will need c.£200-300m of funding over the coming 4-5 years.

2. Establish a system of economic regulation for CCS in the UK

The government will establish a system of economic regulation for CCS in the UK which is based on a regulated return approach. This will draw heavily on existing regulatory structures in the energy system and hence include: a CCS Power Contract based on the existing CfD or capacity contract to incentivise CCS for power; the regulation of T&SCo as other energy network operators; the introduction of an Industrial Capture Contract (see below); and the continued regulation of the energy network industry.

3. Incentivise industrial CCS through Industrial Capture Contracts

The Industrial Capture Contract, will be funded by the UK government and will remunerate industry for capture and storage of their CO_2. It will be a regulated contract which will have a higher price in the early period in order to deliver capital repayment in a timescale consistent with industry horizons. Industry will have access to transport and storage through short-term contracts. Early projects will use existing infrastructure and pure streams of CO_2.

4. Establish a Heat Transformation Group ("HTG")

The Heat Transformation Group will assess the least cost route to the decarbonisation of heat in the UK (comparing electricity and hydrogen) and complete the work needed to assess the chosen approach in detail. The HTG has a likely funding need of £70-90m.

5. Establish a CCS Certificate System

Government will implement a CCS Certificate System for the certification of captured and stored CO_2.

6. Establish a CCS Obligation System

Government will also implement a CCS Obligation from the late 2020s as a means of giving a long-term trajectory to the fossil fuel and CCS industries. This will put an obligation on fossil fuel suppliers to the UK to sequester a growing percentage of the CO_2 associated with that supply. Proof of storage and hence fulfilment of the obligation being via presentation of CCS Certificates.

More information

The Global CCS Institute partnered with the Norwegian state-owned company Gassnova SF to host this year's Forum.

Presentations from the conference, and the GCCSI's own report, is online at

http://bit.ly/GCCSIOslo

Scotland's Energy Strategy: a 'twin-track' approach to carbon removal

A working paper by Scottish Carbon Capture & Storage (SCCS) outlines an alternative path to developing CCS in Scotland.

Scotland's new "whole system" energy strategy must include a clear ambition to achieve a "net zero carbon" economy before 2050, with a twin-track approach to reinvigorating the delivery of carbon removal technology, according to a briefing sent to the Scottish Government.

The authors suggest that, by starting small and capturing carbon dioxide (CO2) across the heat, power, transport and industry sectors, this can improve the effectiveness of overall efforts to tackle Scotland's carbon emissions. Capture technology can be applied to different types of low-carbon energy systems, from biomass and biogas to district heating and combined heat and power (CHP).

The Scottish Government is also urged to take immediate steps to secure national infrastructure that can be used for large-scale, permanent CO2 storage, which will be necessary to decarbonise heavy industry. This can start from moderate-scale projects, which can be taken forward by the Scottish Government.

Prof Stuart Haszeldine, SCCS Director, said, "Scotland can start capturing and storing CO2 now through actions at local and business scale while also taking immediate action on seed projects for national CO2 storage infrastructure. Taking this twin-track approach can maintain Scotland's international lead in affordable energy transition to a zero-carbon economy."

Recommendations to the Scottish Government

For Scotland to achieve its target to decarbonise the whole energy system in a cost-effective way will require CCS to be implemented, and this will bring opportunities at multiple scales and across many sectors. We believe Scotland should extend its ambition further to plan for an overall net zero carbon economy in line with climate change mitigation science, international policy and Scotland's environmental leadership.

SCCS recommends that Scottish Government pursue a "twin-track" approach to CCS. It should promote near-term, small-scale CCS developments to maximise low-carbon actions, including utilisation opportunities. In parallel, it should take immediate action to retain existing large-scale infrastructure, which can provide a cost-efficient solution for future large-scale industrial CCS applications.

Specifically, we recommend that Scottish Government should

- Retain the National Transmission System No.10 Feeder onshore pipeline, and appropriate North Sea pipelines including the Goldeneye pipeline and borehole infrastructure and the Atlantic pipeline, avoiding their decommissioning and maintaining them in suitable condition to enable conversion for CO2 re-use;
- Assess opportunities for small-scale CO2 capture of emissions from biomass, biogas, fermentation, waste and small combined heat and power (CHP) energy processes to give a low-carbon impact multiplier, together with appropriately scaled options for transport and use or permanent storage;
- Assess opportunities for pilot trials of low-carbon heating using hydrogen for conversion of district-scale gas networks, with hydrogen produced by steam methane reforming coupled with CCS;
- Support investigation and development of seed projects for medium-scale CO2 storage opportunities.
- Support actions leading towards development and commercialisation of larger-scale CO2 storage operations, including projects involving cooperation with other states around the North Sea.

The prize – economic opportunity while achieving net zero carbon

Scotland needs to decarbonise its energy system, its economy and its society overall. To achieve the ambition of net zero carbon before 2050 it needs to deploy all practical means, methods and technologies: CCS is essential to meeting this target. Its basic action of removing CO2 from emissions or from the atmosphere (by direct air capture or bio-energy plus CCS) is fundamental to achieving net zero carbon. But CCS is more than just one of several technologies to deploy – it can enhance the effect of other low-carbon actions and it can open new opportunities for decarbonisation, such as the use of hydrogen. By complementing other actions CCS helps achieve affordable and socially acceptable decarbonisation of the energy system.

Scotland holds 35% of European geological storage resources suitable for CO2. This provides a new area of economic opportunity for industry in the North Sea. Scotland can develop new solutions and services in CO2 management, creating new jobs while making use of existing skills, capabilities and resources.

More information

www.sccs.org.uk

Projects and policy news

U.S. 14 state work group recommendations on carbon capture

www.betterenergy.org/EORpolicy

The U.S. states group outlies the growing opportunities for capturing carbon dioxide for use in enhanced oil recovery (CO2-EOR) with geologic storage.

The report, "Putting the Puzzle Together: State & Federal Policy Drivers for Growing America's Carbon Capture & CO2-EOR Industry" includes detailed analyses and federal and state recommendations of the State CO2-EOR Deployment Work Group, which consists of representatives from 14 states, leading private sector stakeholders and CO2-EOR experts.

Wyoming Governor Matt Mead and Montana Governor Steve Bullock launched the Work Group in 2015. The Great Plains Institute staffs and facilitates the Work Group.

The report notes that market forces and federal and state policy are driving the energy industry to reduce carbon emissions and that carbon capture with CO2-EOR compares cost-effectively with other emissions reduction options.

The Work Group recommends a targeted package of federal incentives for CO2-EOR:

• Improving and expanding an existing tax credit for storage of captured CO2;

• Deploying a revenue neutral mechanism to stabilize the price paid for CO2—and carbon capture project revenue—by removing volatility and investment risk associated with CO2 prices linked to oil prices; and

• Offering tax-exempt private activity bonds and master limited partnership tax status to provide project financing on better terms.

States can also assist by optimizing existing taxes commonly levied by states to complement federal incentives in helping carbon capture projects achieve commercial viability, the Work Group says. Analysis undertaken for the Work Group shows that an optimized approach to state taxes can add the equivalent of roughly $8 per barrel of oil to the economics of a carbon capture project.

"The Work Group endorsed a targeted package of federal and state incentives for CO2-EOR that will help ensure that CO2-EOR becomes an integral part of our future energy system," said Brad Crabtree, Great Plains Institute Vice President for Fossil Energy.

Crabtree noted that based on modeling results and qualitative criteria, the Work Group identified the extension, reform and expansion of the Section 45Q tax credit as its top federal priority for stimulating commercial deployment of carbon capture projects at power plants and industrial facilities.

"The Work Group report is timely. Congress has a narrow window right now to pass Section 45Q tax credit reforms before year's end," Crabtree said, noting that the Carbon Capture, Utilization and Storage Act (S. 3179) introduced by Senator Heidi Heitkamp (D-ND) has been co-sponsored by one-fifth of the U.S. Senate.

Bipartisan companion legislation in the U.S. House, the Carbon Capture Act (H.R. 4622) introduced by Representative Mike Conaway (R-TX), has attracted 47 co-sponsors. Governor Mead and Governor Bullock have endorsed these bills in letters to Congress.

"Complementary federal and state incentives will narrow the gap between the cost of carbon capture and revenue received from the sale of CO2 for EOR, spur commercial deployment by enticing private investment in projects, and bring down the cost of carbon capture technology as incentives have accomplished for other energy technologies," concluded Crabtree.

EU funds CCS development in China

ec.europa.eu/dgs/fpi/

The European Commission has approved eight new projects totalling more than €32 million under the Partnership Instrument (PI) to boost cooperation with partner countries in priority areas.

One of these projects, receiving €1 million, seeks to further Carbon Capture & Storage technology in China as a means to reduce CO2 emissions from coal fired power plants. The EU said the projects will contribute to the implementation of the Paris Climate Change agreement.

The Partnership Instrument will also boost the European Union's cooperation with China through €3 million for new initiatives designed to promote greener environmental policies and legislation based on the EU's best practice.

CMC Research Institutes partner with NRG Cosia XPrize

www.cmcghg.com

The partnership will support teams competing in the $20M global competition to develop technologies that convert carbon dioxide emissions into high-value products.

Under the terms of the partnership, teams have the option of using facilities and experts at CMC Research Institute's (CMC) technology commercialization centre as they develop and test their innovations. The Canadian centre is operated by CMC's Carbon Capture and Conversion Institute (CCCI) and aims to accelerate the development and scale-up to commercial use of technologies that capture and convert carbon dioxide (CO2) from industrial sources.

The Institute provides state-of-the-art facilities and access to a global network of industry and academic researchers as well as partners who can provide engineering and fabrication support. Playing a key role in the CCCI is industry partner BC Research Inc.

The Carbon Capture and Conversion Institute team will work with semi-finalists participating in Round 2 to design, build and test their technology at pilot scale (about 100 kg/day), using either real or simulated flue gas. Teams who move to Round 3, the Finals, will demonstrate their technologies at a commercial scale at one of the two Carbon XPRIZE test sites of the competition finals. Teams will be scored on how much CO2 they convert and the net value of their products.

Goran Vlajnic, Executive Director of the Vancouver-based Carbon Capture and Conversion Institute, said the new partnership will contribute to the thriving clean tech sector in B.C.'s Lower Mainland and will strengthen Canada's position as a global leader in the development of low carbon technologies.

"We collaborate with government and academic researchers at both the provincial and federal levels and also draw on a global pool of experts.

Carbon XPRIZE competitors will benefit by being able to use this diverse network of researchers who are at the forefront of low carbon technology development," said Vlajnic.

ETI: UK CCS Strategy should include bio CCS demo

www.eti.co.uk

A report from the Energy Technologies Institute (ETI) has highlighted the importance of combining bioenergy with carbon capture and storage (BECCS) if the UK is to meet its 2050 greenhouse gas emission reduction targets cost-effectively.

"The Evidence for Deploying Bioenergy with CCS (BECCS) in the UK" report states that BECCS can deliver negative emissions (the net removal of CO2 from the atmosphere) whilst also producing energy in the form of electricity, heat, gas and liquid fuels.

The ETI believes that BECCS deployment is achievable by 2030 because all the major components of a BECCS system have now been demonstrated or 'proven' individually. A successful implementation could lead to up to 55m tonnes of CO2 emissions a year in the 2050s being removed from the atmosphere. This is equivalent to half the UK emissions target in 2050.

To become effective significant support is needed over the next five to 10 years to demonstrate a commercial deployment of BECCS technology and the wider biomass and CO2 storage supply chain in the UK. The ETI believes the government should ensure that their UK CCS Strategy encompasses the demonstration of BECCS technology to deliver negative emissions within the next decade.

Geraldine Newton-Cross, ETI Strategy Manager for Bioenergy and the report's author said:

"The UK is well-placed to exploit the benefits of BECCS because it has vast storage opportunities offshore, experience in bioenergy deployment, and academic and industrial strength in both bioenergy and CCS.

"There are no "show-stopping" technical barriers to BECCS. The individual technologies, sectors and value chains have been substantially de-risked over the last 10 years so the next steps are to demonstrate all the components together in combination at a UK plant. This will prove the technology, feedstock supply and logistics, and overall commercial viability.

"For this to happen UK government support for BECCS is vital as the final decision on its implementation will be a political and financial one, not a technical one."

The ETI report highlights advances in the understanding of the costs, efficiencies and challenges of biomass-fed combustion systems with carbon capture together with evidence that numerous bioenergy value chains can deliver significant carbon savings, and sizeable negative emissions when including BECCS, based on certain feedstocks.

It also shows the potential availability and sustainability of feedstocks relevant to the UK and the identification and assessment of high capacity, low cost, low-risk stores for CO2 around the UK and the infrastructure required to connect to them.

"This progress in the technical, environmental and financial evidence and understanding, together with the commercial demonstration steps being taken by others globally, should give the UK government confidence to commit to, and support the demonstration of this vital technology in the UK," said Geraldine Newton-Cross.

"With the evidence and progress highlighted in this report, we would urge the government to ensure that the UK's CCS Strategy encompasses the demonstration of BECCS technology to deliver negative emissions within the next decade.

"All the BECCS jigsaw pieces are now clear and on the table. Others have started to put them in place internationally, and the UK should do the same."

$1.3 Million awarded to evaluate CCS in MIssissippi river area

www.enrg.lsu.edu

The U.S. Department of Energy (DOE) has awarded a $1.3 million research grant to study the feasibility of a CCS plant in Louisiana's industrial corridor between Baton Rouge and New Orleans.

The research grant was awarded to an interdisciplinary team of scholars headed up by the LSU Center for Energy Studies. The multi-year project will examine the technical and economic feasibility of developing a commercial-scale carbon capture and storage project in Louisiana's industrial corridor between Baton Rouge and New Orleans.

CES Professor and Executive Director, Dr. David E. Dismukes, will lead a diverse and highly qualified research team investigating this timely and important environmental and economic development opportunity for Louisiana and the Gulf Coast.

Dismukes notes that this a unique opportunity for LSU that underscores its strengths in working with a wide range of stakeholder groups to solve applied energy and environmental challenges for our state.

The project will include active private sector participation in order to identify large-scale industrial candidate emission sources, such as natural gas processing or petrochemical plants, and then transporting those industrial emissions to either permanent underground storage facilities, or using them in higher-valued energy applications such as enhanced oil recovery (EOR).

The goals of the project are to "define a business case model" in which industrial carbon emissions can be safely and profitably stored, Dismukes notes. There is also a large public awareness and acceptance component to the project.

From a technical perspective, LSU will be conducting a number of high-level, supercomputer-based technical evaluations of the sub-basin and its geological potential to safely store large levels of carbon in a single location as well as exploring a myriad number of technical issues associated with the effective monitoring and verification of these permanent CO2 storage sites.

The award is part of the DOE National Energy Technology Laboratory's (NETL) Carbon Storage Assurance Enterprise, or CarbonSAFE, program, which seeks to develop an integrated CCS storage complex constructed and permitted for operation in the 2025 timeframe in several phases.

Carbon capture in India – potential for coal bed methane?

There could be a potential business in India with carbon capture together with enhanced coal bed methane recovery, we learned at our first Mumbai conference we organised together with Indian Institute of Technology Bombay.

By Karl Jeffery

There could be an exciting business opportunity in India doing carbon capture together with enhanced coal bed methane recovery, we learned at our first Carbon Capture India conference we organised in Mumbai on September 30, 2016.

The conference was organised jointly with Indian Institute of Technology (IIT) Bombay Department of Earth Sciences.

There is a region in the North and East of India (around Singrauli Coal Field in Madhya Pradesh and Uttar Pradesh) which many coal power plants (to generate the CO_2) and many coal mines containing methane (where the CO_2 could be injected). There is a great deal of coal seam which is too deep to mine (deeper than 600 metres), so there would not be any loss to future coal extraction if it was used for CO_2 storage.

The deeper coalfields have not yet been extensively explored, so the amount of coal is unknown.

Delegates at the inaugural Carbon Capture Journal India conference in Mumbai

Studies have shown that there could be 2.63 trillion cubic feet of coal bed methane which could be produced in India, and that would use up to 800m tonnes of CO_2. (As an illustration, annual UK gas consumption is 2.73 trillion cubic feet of gas).

Researchers at IITB are trying to understand how the mechanism works injecting CO_2 into coal seams, and how much methane might actually be produced.

The coal seam contains both free methane and methane adsorbed onto the coal surface. The free methane can be released by drilling into the coal seam, and the methane adsorbed onto the coal can be released by flooding the coal seam with CO_2.

The mechanics of what actually happens is not yet very well understood, but research has shown that it is possible to inject three volumes more CO_2 into the reservoir than methane which is recovered. This is good if storing large volumes of CO_2 is one of the main objectives. Further, the injected CO_2 enhances the recovery of coalbed methane during secondary recovery.

There may also be a business opportunity with CO_2 + Enhanced Oil Recovery – although we learned that ONGC explored a CO_2 EOR project in 2003, in Gujarat, Western India, and did not decide it was feasible. One reason is that fields are thought to need to be depleted by a certain amount for CO_2 EOR to be viable, and not many fields are this depleted.

Standalone carbon capture and storage seems unlikely to work in India. The government's position could be generally summarised as "we won't finance carbon capture, but we won't obstruct it either," and unless there is a real cost to CO_2 emission, standalone carbon capture and storage needs government funding.

Very possibly, there could be funding arranged through the UN from developed countries to developing countries such as India, to cover the cost of climate change mitigation, as agreed through the climate discussions, which could pay for carbon capture. Most people in India take a 'believe it when I see it' approach to this.

India is the third largest producer of coal in world, after China and the US, with 677m tons of coal produced in 2015. It also imports coal.

The conference was jointly organised by Vikram Vishal, Assistant Professor at the

Department of Earth Sciences, at Indian Institute of Technology who has a PhD on carbon storage and enhanced coal bed methane recovery, to try to understand the mechanics of what happens in the subsurface.

Professor Garg - living with coal

One of the key arguments about why India should have carbon capture and storage is that the country is so dependent on coal, and the dependence is likely to increase as electricity demand increases, said Professor Amit Garg, from the Indian Institute of Management in Ahmedabad, India, in his opening address.

Professor Garg was a member of the UN body Intergovernmental Panel on Climate Change that was awarded the Nobel Peace Prize in 2007.

By using carbon capture and storage, India can continue with its domestic coal as the mainstay of India's energy system, he said.

Coal employs about two million people in India, and adding their families, means that 7 to 8 million people are dependent on the coal industry.

Meanwhile Indian CO2 emissions are growing at 5 to 6 per cent a year, and power generation is the biggest source of those, also industrial.

Some people in India think that it can wait for other countries to do carbon capture first. "But if emissions are going down around the world, the pressure will be on India," he said.

India should not close options down. "Everything is on the table, there is no silver bullet," he said.

"We say to the government, 'please don't shy away from saying India is dependent on coal. Coal has to continue.'"

Carbon capture will strengthen India as a nation, and give the country the ability to counter arguments that it is not doing anything about emissions.

"We can't say, 'very primitive country, we are not ready'", he said.

"We are leaders in many places in the world. We should take our place.

"Everything is on the table, there is no silver bullet" - Professor Amit Garg, from the Indian Institute of Management in Ahmedabad, India

We should not shy away."

Also India has some advantages over other countries, including being able to innovate at low cost.

And if India doesn't invest in carbon capture, with its enormous coal power production, perhaps no-one else will, he said.

As far as a regulatory regime to force or encourage carbon capture, in India "we have not even thought about these things. We are very primitive. But "I think the perspective is changing."

In terms of the current attitude of the Indian government and industry, Professor Garg said, "Different ministries are responding in different forms. I was in a [carbon capture] forum where Oil India, NTPC was there.

The government's attitude to enhanced oil recovery and ECBM does not include "anything negative," he said. So if the business case works, companies should 'please go ahead'. "I don't think there's anything stopping you," he said.

Oil and gas production in India is declining, so there might be interest in using CO2 to try to get it on the increase again.

And if industry gets more engaged in carbon capture, the scenario could change very quickly.

"When we proposed that one of these big corporations should go for big demonstration projects, they were sort of neutral to this. "But the corporates are not saying 'don't do it'".

But whether or not there is a high carbon price, the cost of emitting CO2 will continue. And India "may start a carbon market very soon," he said. The Indian market could also connect with some of the other carbon markets around the world, creating an enormous business opportunity, if it can store CO2 cheaper than anywhere else in the world.

But not enough is known about the CO2 storage potential in India so far, Professor Garg said.

Professor Garg's team has been working on a major project to connect sources and sinks across the whole of the country.

One audience member noted that there is 3.14km2 of land in India, of which 1km2 has not been explored at all, and there is no knowledge about whether there might be oil and gas. As the government opens up its policy to oil and gas licensing, it may help encourage more exploration.

Dr Ajay K Singh – how to store carbon

Coal bed methane specialist Dr Ajay Kumar Singh explained the different ways CO2 can be stored in India – including in oil fields, unmineable coal seams, saline aquifers and basalt formations – and also how the enhanced coal bed methane recovery works.

Dr Ajay Kumar Singh, a specialist in coal bed methane, explained the various options for storing CO2 in India, including in oil fields, unmineable coal seams, saline aquifers and basalt.

Dr Singh is a specialist in coal bed methane. He is a senior scientist with The Central Institute of Mine and Fuel Research (CIMFR), which is part of the Council of Scientific & Industrial Research (CSIR), based in Dhanbad, a city in Jharkhand State in eastern India.

CSIR is an autonomous body under the Government of India Ministry of Science and Technology.

Dhanbad is known as the coal mining capital of India, according to its Wikipedia page.

Dr Singh was also one of the lead authors of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories. IPCC was awarded Nobel Peace Prize in 2007.

Dr Ajay Kumar Singh, senior scientist with The Central Institute of Mine and Fuel Research

Oil reservoirs

For oil reservoirs, sometimes the CO2 mixes with the oil, sometimes it doesn't, depending on the gas injection pressure, he said.

If it mixes, it is known as miscible CO2-EOR (enhanced oil recovery). The CO2 mixes with crude oil, causing oil to swell, reducing the viscosity of oil, while also maintaining reservoir pressure. Alternatively, CO2 may not mix with crude oil, resulting in immiscible CO2-EOR.

Looking at oilfields in India, the key ones are Assam in North East India; Cauvery Basin in South East India; and Rajasthan and offshore Mumbai in North West India.

There is a need for enhanced oil recovery in India, because currently recovery rates from reservoirs are only about 27 per cent, he said.

And Indian oil production has declined from 38.2 million metric tons in 2011 to 37.5m metric tons in 2014.

Gas production is also declining much faster, with 53 BCM produced in 2010 and 34 BCM in 2014.

There are no examples of CO2 being used for EOR or EGR (enhanced gas recovery) in India. There have been projects with thermal recovery of oil, where oil is combusted in the subsurface, heating the oil around it and reducing the viscosity, so it flows more easily. "This is a similar phenomenon," he said. It is being done in the Balol heavy-oil field in the North Cambay Basin, North West India.

Indian state owned oil company ONGC did propose a CO2-EOR project in the city of Ankleshwar, in the state of Gujarat, North West India, with CO2 to be injected from a gas processing complex in Hazira, Gujarat, planning 600,000 m3/d.

The project has the potential to sequester 5-10m tonnes of CO2 in one location, and lead to an increase in oil recovery of around 5 per cent, he said.

Cairn Energy also has plans for a C02-EOR project, supplying CO2 to one of the company's oilfields in Rajasthan, he said.

Coal fields

Another option is storing the CO2 in coal fields – where the CO2 can be used to enhance recovery of coalbed methane, providing a revenue stream. This is known as CO2-Enhanced Coal Bed Methane recovery of CO2-ECBM.

Possible sites for doing this include the Eastern part of Raniganj, Jharia and North Karanpura Coalfields in eastern India, and the Western part of Ib Valley Coalfield and Talcher Coalfield, in Odisha state, North East India. Cambay Basin and Barmer-Sanchor Basin in western India can also be prospective sites for CO2 sequestration.

Indian coal reserves are estimated at 307 billion tons, up to a depth of 1200m, and there are huge reserves of coal deeper than this, perhaps a further 200bn tons, he said. It is not practical to mine deep coal, but it might be possible to produce the gas from the coal seams.

The deepest coal mine in India is currently 630m, in West Bengal, he said. It is very difficult to mine deeper than this, because it gets very hard to manage the rock stresses and ensure mine safety.

Technology may advance but it seems probable that mining beyond 1000m will always be "next to impossible," he said.

Most of the coal reserves are concentrated in the Eastern of India, although there is some in the North West.

Coal has a very large surface area within its structure – scientists have calculated that every gram of coal has 200m2 of surface. Either methane or CO2 can attach to this surface.

Dr Singh has been involved in research to try to better understand what happens when CO2 is injected into a coal seam through a vertical well.

First of all, there is usually water production from the coal seam. After the water has flowed to the well, the pressure in the coal seam is lower, and then gas gets released from the coal and it flows to the well. "This is the primary method of coal bed methane recovery process," he said. About 40 to 50 per cent of methane can be recovered via primary recovery (not using CO2). Then CO2 can be injected, to enable more gas to be produced. If the coal seam is flooded with CO2, the CO2 will fill the pores on the coal.

Saline aquifers and basalt formations

Another possibility is storing CO2 in saline aquifers. The CO2 is stored in water permeable rocks which are saturated by salt water, called brine.

Government funded studies have looked at the Ganga basin (North East India) where there are aquifers 300m below ground level, Vindhyan basin (central North India) and Rajasthan basin (North West India), he said.

A further option is basalt storage. There is an area in West Central India called the Deccan Plateau, covering 500,000 km2. The basalt varies in thickness from a few hundred metres to 1.5km. The basalt provides a solid caprock (above the CO2 storage).

The basalt can slowly react with the CO2 to convert into mineral carbonates, so the CO2 is locked away forever.

Government attitude

Dr Ajay K Singh noted that "the government of India is always open to research and commercial scale projects on CCS.

India has been involved in the Carbon Sequestration Leadership Forum, and the government is supporting about 30 research projects.

But there is a big need for more detailed knowledge about Indian geology and suitable CO2 storage sites, he said.

Jupiter Oxygen oxy-combustion capture + enhanced coal bed methane recovery

The cost of carbon capture can be reduced if the fuel is burned in oxygen with a high flame temperature rather than air firing, according to the Jupiter Oxygen Corporation.

Jupiter Oxygen Corporation (JOC, Chicago, IL, USA) believes that the cost of carbon capture can be substantially reduced if coal is burned in oxygen with a high flame temperature rather than air firing.

In India, the costs of carbon capture can be recouped by using the CO2 for enhanced coal bed methane (ECBM) recovery from un-minable coal seams, the company believes.

India has a mature industrial structure for coal bed methane recovery, and a high potential to apply ECBM technology and significantly increase coal bed methane recovery.

India therefore provides an attractive business opportunity for the development of carbon capture, utilization, and storage technology.

This process enabling cost effective carbon capture is known as "high flame temperature oxy-combustion", resulting in high concentration CO2 in the flue gas and a fuel savings.

Thomas Weber, president of JOC presented this carbon capture, CO2 utilization and storage (CCUS) strategy at the Carbon Capture Journal Mumbai conference.

JOC has been applying oxy-combustion in the US since 1997 at an aluminium re-melting and coil-producing facility.

As a result of introducing high flame temperature oxy-combustion, the aluminium manufacturer reduced net energy consumption significantly, based on JOC's patented process.

Since 2001, Jupiter Oxygen has been developing high flame temperature oxy-combustion applications for coal and natural gas fired boilers. The technology is now ready for commercial-scale demonstration in coal-fired power plants, as well as natural gas fired units.

JOC intends to showcase the economic advantages of high flame temperature oxy-combustion for coal power plants with carbon capture at commercial-scale demonstrations in both China and India in the near term.

Between 2006 and 2012, the Jupiter Oxygen Corporation operated a test facility for high flame-temperature oxy-combustion as part of an extensive joint research and development program established with the US Department of Energy's National Energy Technology Laboratory (NETL).

JOC and NETL developed an application of the JOC's high flame temperature oxy-combustion technology at this test facility that was integrated with air pollutant removal and carbon capture.

"The test facility has produced a lot of good data coming out of this unique oxy-combustion process in combination with integrated air pollutant control, carbon capture and water recovery," he said.

JOC is now in the process of setting up a demonstration project in India that will include use of the produced CO2 for enhanced coalbed methane recovery.

For non-chemist readers, air is made up of about 20 per cent oxygen and 80 per cent nitrogen.

When coal (mainly carbon) is burned in air, the flue gas that results is mainly composed of nitrogen oxides (NOx). Separating out the carbon dioxide from the nitrogen post-combustion is an energy-intensive and expensive process.

By contrast, if the coal is burned with high flame temperature oxy-combustion, then the flue gas is mainly carbon dioxide and water vapour. Separation of the carbon dioxide is more cost-effective.

The oxygen needed for combustion is provided through a cryogenic air separation unit, which separates the incoming ambient air into oxygen, nitrogen and argon. This is a well-established process in the industry.

A principal advantage of using high flame-temperature oxy-combustion is that coal burns more efficiently. Fuel efficiency gains in the boiler close to 5% or greater have been demonstrated using JOC's unique approach.

Another advantage of oxy-combustion technology is that it results in ultra-low concentration of NOx in the flue gas, largely because the nitrogen has been removed from incoming air before sending pure oxygen to the burner.

Overall the upfront air separation process combined with carbon capture at the back end of system creates a net energy penalty of about 20 per cent.

In the JOC patented technologies, carbon dioxide is effectively separated from the much-reduced flue gas volume through steps of compression and condensation.

The final products are highly concentrated, pipeline quality CO2 and process water collected for treatment and re-use. Key local air pollutants (NOx, SOx, particulate matter, and mercury) are substantially reduced.

To convert an existing coal power plant to high flame temperature oxy-combustion with carbon capture using the JOC technology requires only moderate changes to the coal-fired boiler. Thus, it can be put to work more quickly than a new-build carbon capture plant, Mr Weber said.

Nitrogen and enhanced coal bed methane recovery

The nitrogen from the air separation unit provides an additional synergy in applications of the JOC technology. Nitrogen can be injected together with the CO2 into coal bed methane seams, enhancing CBM production, according to Mr Weber.

How much production is increased depends on the coal rank of the affected seams and the specific ratio of CO2 to N2 that is injected. Whether applied to low-, medium-, or high-rank coal seams, the additional injection volumes made up from adding nitrogen improves the level of coal bed methane recovery and the resulting economic feasibility of the application.

According to the experts from Advanced Resources International (ARI), a further advantage of injecting nitrogen with CO2 is the resulting reduction in swelling of the coal seam, which otherwise would lower permeability in the seam and reduce methane production.

Making CO2 utilization via ECBM work

To get a CO2 capture – ECBM project running requires an alliance of carbon capture technology providers, coal bed methane experts and local energy companies, according to Weber. Mr The oil and gas industry also needs to be involved in providing infrastructure that can take the methane to market.

Mr Weber suggested that CCS trust funds (including those held by the World Bank and the Asian Development Bank) could be useful in financing a feasibility study that would explore the technical and economic viability of a project in India, ultimately demonstrating whether the increased methane production would give the investors an adequate financial return.

"If investors see this as an attractive project, they will engage in a second step which would be a more detailed engineering study," he said.

JOC has already started a similar project in Western China. In China, the main driver pursuing this CCUS – ECBM project is to increase profitability of CBM operations from extracting more coal bed methane.

Welcome co-benefits of such a project are carbon capture, air pollutant control and water recovery from coal fired power plants, as well as permanent and safe storage of large amounts of CO2 underground via ECBM.

"Right now we're doing a feasibility study. Hopefully, in a couple of months we'll have interesting results to share. It is quite an interesting parallel to what we'd like to do in India," he said.

In India, Jupiter is preparing a consortium of US based and Indian companies, to establish a carbon capture, utilization and storage demonstration project, in the near future. The commercial scale demonstration will include retrofit of a local coal-fired boiler with JOC oxy-combustion technology, and CO2 utilization with enhanced coal bed methane recovery.

Mr Weber is confident that the costs of the carbon capture plant will be "more than offset" by revenues from CO2 / N2 sales for enhanced coal bed methane recovery. But a carbon tax or other incentives for unconventional domestic gas production would also help.

Jupiter Oxygen Corporation is a leading innovator in oxy-combustion technology applications, providing consultancy and know-how, based on patents in many countries of the world, and can be a critical part of strategic alliances for the financing and management of successful carbon capture and utilization projects, he said.

More information

Video presentations from the conference are online at:

www.carboncapturejournal.com

Status of carbon capture in India

India has had many carbon capture in the past – although perhaps the peak of its enthusiasm was in 2011, as Amit Verma explained

India has been involved in many carbon capture projects over the past 10 years, with interest perhaps peaking in 2011.

Amit Verma, assistant professor at the Indian School of Mines, Dhanbad, presented some of the findings of a study he had done as part of previous employment with TERI (The Indian Energy and Resources Institute).

The Department of Science and Technology (DST) of the Indian Ministry of Science and Technology would be responsible for research and development in CCS in India. It has floated a lot of research projects, he said.

It set up a "National Program on Carbon Sequestration Research" in 2007.

There was an "Agreement of Co-operation in Science and Technology" agreed with the government of India and the government of Norway, whereby DST and the Research Council of Norway started a program for joint funding of Indian-Norwegian joint research projects in climate research, including CCS.

ONGC has talked about plans (2003) to set up a pilot experimental EOR project in Gujarat, with CO2 from a gas processing plant in Hazira to be supplied to a depleted onshore reservoir in Ankleshwar, where it would be recompressed and injected for enhanced recovery of crude oil. "Somehow it has become not feasible," he said.

The National Aluminium Company (NALCO) announced (March 2011) plans to set up a carbon capture unit at its coal fired plant at Angul, Orissa state for bio sequestration.

NTPC, as part of the Carbon Sequestration Leadership Forum (CSLF), has partnered with the National Geophysical Research Laboratory, India (NGRI)

And the Battelle Pacific North West National Laboratory, USA, to evaluate the Deccan basalt formation in India as a potential long term CO2 storage option.

NTPC also organized a national workshop on CCS in collaboration with the Ministry of Power in September 2011.

Bharat Heavy Electrical Ltd. (BHEL) and APGENCO, the power generating company of Andhra Pradesh, are talking (April 2013) about setting up a 125 MW demonstration IGCC plant in Andhra Pradesh, India's first IGCC plant. BHEL is also coordinating with Indira Gandhi Centre for Atomic Research (IGCAR) and NTPC to design, develop and build ultra-super critical boilers.

BHEL has also collaborated with TREC STEP (Tiruchi Regional Engineering College Science and Technology Entrepreneurs Park) to implement a set of initiatives in CCT and CCS, as part of a three year EU funded project.

TREC STEP, in collaboration with Ernst and Young, organized an EU funded 2 day training programme on 'Introduction to CCS and CCT' in December 2011, and a 3 day 'Skill Leverage Programme on CCT - CCS Technologies' in January 2012.

Indian Institute of Petroleum (IIP) has been working on developing new adsorbents for post combustion CO2 capture.

IIT Bombay is one of the players developing technologies for storage of CO2.

The Global Carbon Capture and Storage Institute has rated countries for their carbon capture interest and policy developments so far. It ranks India in the "lower mid-tier" for policy interest, but in the "upper tier" for inherent CCS interest, along with the USA, Canada, Germany, China, Indonesia and Russia.

GCCSI has also classified countries for their legal frameworks for carbon capture, where Band A is where the country has a full legal framework for CCS (either with special CCS laws or its existing laws cover CCS) – with just 5 countries – Australia, Canada, UK, US and Denmark, and band C with very few specific laws.

There are complicated laws related to regulatory approval and storage challenges, which is stopping private players coming into play, he said.

India's largest power company, NPTC (previously known as National Thermal Power Corporation Limited) does not have a particularly positive view on carbon capture implementation in India, he said.

"A degree of confidence will be gained in the technology only after the conversion of demonstration phase to commercial scale projects worldwide," he predicted.

More information about geological storage sites would be very helpful, he said.

The Indian Ministry of Science and Technology has expressed concerns that carbon capture would increase the cost of electricity in India, he said.

Concerns continue about CO2 leakage. "The ministry will shoot a question, if CO2 comes out in 100 years, what will you do. Nobody has an answer," he says.

There are complex legal issues including around acquiring land and possible CO2 leakage, which would need to be addressed before any large scale transport and storage of CO2 could be permitted, he said.

The Ministry is very positive about enhanced oil recovery, which could offset the costs.

But the business opportunities for EOR might not be so great. "Some people in ONGC found that very few reservoirs are suitable for EOR," he said.

Not many oil people are actually looking for enhanced oil recovery. "It has been stated by stakeholders in the petroleum sector that there are few oil fields which are sufficiently depleted for EOR to be required at present," he said.

If the CO2 is used for enhanced coal bed methane recovery, it makes the coal impossible to mine (because it is full of sequestered CO2). There is always a risk that future technology developments might mean that people want to mine the coal, he said.

"There is widespread belief that the IGCC and CCS technologies have not been extensively tested and customized for Indian conditions. Since

India has not been involved with any of the current projects, the understanding of the technology and its adaptation in India is low," he said.

Adding this all together, you could say that the government is at best dis-interested, and at worst, actually opposed to carbon capture, for all these reasons, and also a belief that the current accumulation of greenhouse gases is not India's responsibility, he said.

India is involved in the Carbon Sequestration Leadership Forum, a meeting of senior government officials with a role which might include carbon capture. But this does not lead to involvement of state governments and industry, he said.

Altogether, "CCS is not expected to be applied in India before 2030 in current global and regional modelling studies."

However India does have a range of legislation which could be adapted for carbon capture, including Indian Petroleum Act of 1934, which covers transportation of petroleum products (which could be used for transporting CO_2); the Oilfields Regulation and Development Act of 1948, which could cover EOR; the Petroleum Mineral Pipelines Act of 1962, covering acquisition of land for pipelines; the Oil Industry Development Act of 1974, which covers taxes on oil and gas production, which could be used to make a tax on crude oil and natural gas produced in EOR.

There will probably need to be a Liability Bill, perhaps based on the Nuclear Liability Bill, to show how the responsibility for any spill would be managed.

There may be regulation on power generating companies, telling them they have to reduce the CO_2 in their emissions, as well as carbon prices, he said.

There will probably need to be rules about cross border movement of CO_2.

Combining CCS and flue gas desulphurisation

CO_2 and SO_2 can both be removed from flue gases using the same materials - amines, ammonia and sodium hydroxide. Flue gas desulphurisation is going to be introduced in India soon. So would it make sense to introduce carbon capture at the same time?

The technologies to remove CO_2 from flue gas have some commonalities with technologies to remove SO_2. As flue gas desulphurisation (FGD) is going to be introduced in India, may be it would make sense to introduce both systems at once, said Professor Amitava Bandyopadhyay of Department of Chemical Engineering at the University of Calcutta.

India has newly promulgated emission standards for SO_2, NO_x and mercury in addition to existing standard for particulate matter (PM) for thermal power plants to clean up the flue gas, but not for CO_2, said Professor Bandyopadhyay.

Flue gas desulphurisation technology has been around for some time, with the first research in 1850, and the first full scale plant deployed at Battersea Park Power Station, London, in the 1930s, using water from the River Thames. The sulphur dioxide was removed with a lime based process.

The sulphur dioxide can also be removed with ammonia, reacting it to make aqueous ammonium sulphate. Ammonia as a solvent can also be used for CO_2 capture.

There is a demonstration project for a multi-pollutant capture system, operated by National Energy Technology Laboratory of Department of Energy in the US, where the flue gas is treated with ammonia to generate ammonium nitrate and ammonium sulphate along with compressed CO_2.

Another multipollutant capture process is the one that is able to remove CO_2, SO_2, NO_x, mercury and other heavy metals, and acid gases (such as HCl, HF, H_2S) from the flue gas.

The process eliminates the limitations of lime/limestone and sodium based processes and is being commercialized in China by Airborne China Ltd. Such process could be the fourth generation FGD. There is a considerable potential for deployment of similar process under Indian perspective he added.

Amines, which are used in carbon capture plants, have also been used for removing H_2S from gas streams, he said.

Amine based systems can be dangerous considering possible emissions of amines into the ambient air leading to the formation of nitrosamines which are expected to be carcinogenic and have a safety limit of 0.1 parts per trillion (e.g., in Norway). Thus, ammonia may be relatively better than amines.

Cansolv Technologies Inc., a Canadian company, has a patented technology for removing both SO_2 and CO_2 from the flue gas, he said.

Another option for removing CO_2 is mineral carbonation, basically absorbing CO_2 into rock. Further, you can use sodium hydroxide, reacting with CO_2 to form sodium carbonate (Na_2CO_3) and sodium bicarbonate ($NaHCO_3$). Sodium hydroxide can also react with SO_2 (to make sodium sulphate: Na_2SO_4) and NO_2 (to make sodium nitrate: $NaNO_3$.

Is CCS relevant for India?

In order to cover all sides of the argument, Anand B. Rao, associate professor, with the Centre for Technology Alternatives for Rural Areas (CTARA), Indian Institute of Technology - Bombay (IITB), gave a talk on why carbon capture should not be a high priority for India.

As a developing country, perhaps India might be better off spending its limited resources on adapting to a high CO2 environment, rather than trying to stop the CO2 emissions, Mr Rao said.

India could argue that the responsibility for solving the CO2 problem should go to the countries that are responsible for putting most of the CO2 into the atmosphere, he said.

India is the third biggest CO2 emitter today after the US and China, but the US and Chinese emissions are much greater, he said.

"It is a tendency to address India and China together as though we are siblings and have the same realities, but we are in 2 different worlds. There is no comparison in terms of where India is, and where it is going in terms of energy production and consumption, compared to where China is," he said.

If the responsibility for managing emissions was linked to the country's level of development, and its emissions per person, then again India has an argument that it does not need to act, he said.

India is not short of other priorities. Much of India, particularly in rural areas, does not have basic minimal comforts, such as electricity.

Government data can be misleading. For example the government claims that 98 per cent of villages are now electrified, but counts a village as 'electrified' if only 10 per cent of households have a supply. The data also does not include distant hamlets. Mr Rao estimates that there are 50-60 million households in India with no electric connection.

If they were to use 1 unit (kWh) per day, that would need about 2.5 gigawatts of power generation, or about 4 or 5 typical coal power plants.

"Dealing with this is one of our biggest challenges," he said.

"I'm hopeful we don't have to use this [carbon capture] technology at all" - Anand B. Rao, associate professor with the Centre for Technology Alternatives for Rural Areas at the Indian Institute of Technology Bombay

Sometimes households have an electricity supply available, but it is unreliable, or the voltage is too low, or it is unaffordable, he said.

CCS will not contribute to improving any of these challenges, and could make it worse, if it pushes up the price of electricity.

There is still a lot of scepticism about big industrial projects in India, he said. "Bhopal is still fresh in the minds of people." The legal and regulatory issues regarding CCS need to be resolved.

Another question is the reliability of the technology – if a CCS plant has much higher downtime than a standard coal power plant, that will change the equation of electricity supply to the grid, he said.

There are questions of whether the public will accept it as an eco-friendly technology.

Perhaps it would be better for India to wait for the developed world to fully test and demonstrate the technology first, he said.

Meanwhile India can go a long way with improving efficiency or using renewables to reduce its emissions.

"I'm hopeful we don't have to use this [carbon capture] technology at all," he said. "I don't think CCS will come to India any time in the near future - or the next 2-3 decades at least.

I'm not denying that we should not have research on CCS, keeping it open as a future policy option. We should understand the potential of the technology. That does not mean we have to deploy it. We can keep CCS as an insurance policy."

However if the 'Green Climate Fund', where developed countries provide financing for developing countries to spend on climate change, should ever materialise, "CCS may get implemented," he said.

In the question session, one audience member commented that the talk had been mainly on conventional carbon capture and storage, but if there are other revenue models (such as with EOR) the discussion is different.

Mr Rao was asked what would happen if a big business opportunity was developed with CO2 utilisation, and India would miss out, by not having a CO2 supply.

"I understand this possibility, but this is a big 'IF," he replied. "There have been discussion about utilisation of CO2 – but it is maybe half a percent or 1 percent [of total CO2 volumes]. So to have all the CO2 we produce for power generation can be utilised, is going to take a lot of time."

Munish K. Chandel, assistant professor, Centre for Environmental Science and Engineering, Indian Institute of Technology Bombay

Munish Chandel – analysing the options

Munish K. Chandel, assistant professor, Centre for Environmental Science and Engineering, Indian Institute of Technology Bombay, talked about the work he has been doing to evaluate the different carbon capture options.

Dr Chandel's team used 'Integrated Environmental Control Model' developed by Carnegie Mellon University (CMU), a software tool which can simulate different coal power plants with carbon capture with different designs and cost factors, to see what the energy penalty would be.

It looks at a range of technologies, including membranes and oxy combustion, and amine / ammonia solvents.

The standard chemical absorption solvent processes have been used in the oil and gas industry for many years.

The capture cost is estimated at around $42 per ton for amine solvents and $75 per ton for ammonia, he said, and higher for membranes.

It probably makes more sense to retrofit carbon capture technology on a larger, newer, more efficient plant, he said. Since much of the cost of carbon capture is in the energy requirement, the more efficiently the energy can be generated the lower the cost of the carbon capture.

There are questions about whether it might be better to scrap all the old coal power plants and build new ones, perhaps with an IGCC design, or a new "ultra-supercritical" plant, which would generate less CO2 for each unit of electricity generated. But these are very expensive to build.

"One big issue which probably will come up with retrofitting is physical space availability," he said

Carbon Clean Solutions – reducing CCS costs by 50 per cent

UK-headquartered Carbon Clean Solutions Limited (CCSL) is finding ways to reduce the cost of carbon capture by 50 per cent with advances in solvents and process.

Carbon Clean Solutions (CCSL), a company headquartered in the UK, but with offices in India and the USA (Cumming, Georgia), has developed a solvent for carbon capture which promises to reduce the operating cost of carbon capture by 50 per cent and capital cost by 30 per cent.

The company was presented by Ramesh Kumar, team lead with CCSL.

The company was founded in 2009, with UK private equity funding. It has 20 employees and has demonstrated the technology at more than 10 sites around the world.

The solvent is the critical component of carbon capture technology. It is brought into contact with a flue gas containing CO2, it selectively absorbs only the CO2, taking the CO2 out of the flue gas stream. The solvent then exchanges heat with the solvent coming from regenerator and is further heated in the stripper, which causes the CO2 to strip off from the solvent. Then the solvent gives its heat to the solvent from absorber and is further cooled down before being fed to the absorber and goes through the cycle again.

The biggest problem with the earlier generation solvents is the very high levels of energy required to regenerate the solvent. If that energy can be reduced, there is a big cost saving. Instead of carbon capture needing perhaps a third of the total energy produced by the coal power plant, it can run on just 15 per cent of it, Mr Kumar said.

The solvent the company has developed solvent chemistry that aims to combine the strengths of amine liquids and salts. New molecule is quick to absorb CO2 due to high reaction kinetic properties of amines and requires less energy due to salt like properties

The research work, which involved testing 30 different solvents and 100 components, was done at the company's own laboratory in India, and Imperial College in London.

Solvents normally degrade over time with continuous heating and cooling, as well as reacting with oxygen. CCS solvent was found to have almost zero degradation rates and has a longer life expectancy than conventional solvents, lasting for 5-6 years, rather than a year for traditional solvents. This means lower solvent disposal costs.

A further advantage of CCSL's solvent is that it is much less hazardous than normal amine solvents. This means it is safe to use in much higher concentrations. Because of this, the same amount of CO2 can be captured in a smaller volume of solvent – and so the size of the plant can be smaller, reducing the capital costs and the amount of pumping which is required.

Compared to standard amine (MEA), the CCSL solvent also resulted in 15 times less corrosion to the piping, said Mr Kumar.

Typical loading capability, in mol CO2 per litre of solvent, is 1.2 for a typical solvent like MEA, and 2.5 for the CCSL solvent, Mr Kumar said.

Pilot testing

The solvent was pilot tested at a facility operated by research organisation TNO in the Netherlands, capturing 6 tons of CO2 a day, to get a better understanding of energy requirements and degradation rates. The pilot plant used flue gas from a real coal power plant, including the usual contaminants. It has also been tested in a 10 ton/ day scrubbing plant in the US.

In late 2015, it was tested at Technology Centre Mongstad, Norway, at a bigger scale, of 240 tons of CO2 a day. The test studied rates of degradation, corrosion, emissions and product CO2 concentration. Norway has much tougher emissions requirements, which CCSL's technology met and faired outstanding versus other competitors.

Ramesh Kumar, team lead with CCSL

The company proposed a modified process configuration with patented heat integration in order to best utilize the benefits of its solvent chemistry.

Commercial plant

The company has built a greenfield commercial plant in India, commissioned in October 2016 (the month after the conference), using CO2 from a coal fired boiler plant, and supplying it to a soda ash manufacturing facility.

The customer will be able to capture CO2 with 30 per cent less CAPEX, 50 per cent less energy and operating costs, and nearly zero solvent emissions, Mr Kumar said. It will capture 60,000 tonnes of CO2 a year.

The technology has also been used on biogas production (gas which is formed from the breakdown of organic waste). Biogas is typically 60 per cent methane and 40 per cent C02 and by removing more than 95% CO2 from the biogas, a more valuable/usable biomethane (>98% Methane) is produced.

More information

www.carboncleansolutions.com

MIT catalyst turns CO2 to gasoline

A new catalyst developed at MIT provides design principles for producing fuels from carbon dioxide emissions.

A new catalyst material developed by chemists at MIT provides a key insight into the design requirements for producing liquid fuels from carbon dioxide. The findings suggest a route toward using the world's existing infrastructure for fuel storage and distribution, without adding net greenhouse emissions to the atmosphere.

The new catalyst takes the process only through its first stage - converting carbon dioxide (CO2) to carbon monoxide (CO), explains assistant professor of chemistry Yogesh Surendranath, the senior researcher on a new study describing the advance. But that's a key initial step toward converting CO2 to other chemicals including fuels, he says; there are already established methods for converting CO and hydrogen to a variety of liquid fuels and other products.

"The problem in CO2 conversion is how to selectively convert it," Surendranath says.

While this basic molecule can form the basis of virtually any carbon-based chemistry, the tricky part is to create a system in which CO2 consistently converts to a single end-product that can then be further processed into the desired material. The new system, he says, provides just that kind of selective, specific conversion pathway — and, in fact, a whole range of such pathways. And if the hydrogen and CO are produced using solar or wind-generated power, the entire process could be carbon neutral.

Tunable conversion

"What you want is a tunable catalyst," he says, and that's just what this team developed, in the form of a highly porous silver electrode material. Depending on the exact formulation of this material, he says, it's possible to design variations of this catalyst where "each one may be designed for a different application."

The researchers learned that by tuning the dimensions of the material's pores they could get the system to produce the desired proportion of CO in the end-product.

Most efforts to "tune" the selectivity of silver catalysts for CO production have focused on varying the surface active site chemistry. However, with this formulation, a material called a silver inverse opal, it is the pore structure of the material that determines the effect. "What we found was very simple," Surendranath says. "You can tune the pore dimensions to tune the selectivity and activity of the catalyst, without modifying the surface active site chemistry."

Honeycomb structure

The porous material can be made by depositing tiny polystyrene beads on a conductive electrode substrate, then electrodepositing silver on the surface, then dissolving away the beads, leaving pores whose size is determined by that of the original beads. Because of the way spheres naturally organize themselves when packed together, this method produces a honeycomb-like structure of hexagonal cells, Surendranath explains.

It turns out that varying the thickness of this porous catalyst produces a double effect: As the porous inverse opal get thicker, the catalyst more strongly promotes the production of CO from CO2 by up to three times, while also suppressing an alternative reaction, the production of H2 (hydrogen gas), by as much as tenfold. Using this combined effect, production of CO can be easily varied to make up anywhere from 5 to 85 percent of the reaction's output. The study's results provide fundamental insights that may be applicable to designing other catalyst materials for fuel production from CO2.

This advance represents just one step in the conversion of carbon dioxide into usable fuels, and the initial demonstration is just at a small laboratory scale. So, much work still remains for this to become a practical approach to manufacturing transportation fuels. But because the selectivity and efficiency of this initial conversion step places an upper limit on the overall efficiency of fuel production from CO2, in technical terms, Surendranath says, the work provides key fundamental insight into how to engineer carbon-neutral technologies for replacing existing fossil-fuel systems — while still being able to use all of the existing infrastructure of gas stations, delivery vehicles, and storage tanks.

Ultimately, conversion plants could be connected directly to the emissions flow from fossil-fuel power plants, for example, to turn the CO2 into fuel instead of releasing it into the atmosphere at all. "We're very optimistic" that the process can be successfully developed, Surendranath says. If so, that could represent "the closing of the anthropogenic carbon cycle," through the use of renewably generated electricity to turn greenhouse gas emissions into fuel.

In essence, he says, the net process would be doing the same thing that plants and cyanobacteria did on Earth millions of years ago to produce fossil fuels in the first place: taking carbon dioxide out of the air and converting it into more complex molecules. But in this case, instead of taking place over millennia, the process needs to be replicated very quickly in a lab or factory. "It's the same thing that got us these fuels in the first place," he says, "but we need to do it faster and more efficiently than natural photosynthesis."

This paper could have "huge impacts on the basic science of important reactions to produce fuels," says Ken Sakaushi, a researcher at the National Institute for Materials Science in Tsukuba, Japan, who was not involved in this research. "Recently, many works just focus on the application side and thus make less of a contribution on basic science. However, this work seems to try to contribute to this important issue on science from the basics." Because of that, this research has "high value," he says.

The research was supported by the Air Force Office of Scientific Research and the MIT Department of Chemistry, and is part of the research taking place through the MIT Energy Initiative's Low-Carbon Energy Centers, established as part of the Institute's Plan for Action on Climate Change.

More information

chemistry.mit.edu

Capture and utilisation news

UNIST researchers turn CO2 into diesel fuel

www.unist.ac.kr

A new study, led by Professor Jae Sung Lee of Energy and Chemical Engineering at UNIST uncovers new ways to make biofuel from carbon dioxide.

In a paper published in the journal Applied Catalysis B: Environmental, the team presented direct CO2 conversion to liquid transportation fuels by reacting with renewable hydrogen (H2) generated by solar water splitting.

The currently existing catalysts, used for the reactions of H2 with CO2 are limited mostly to low molecular weight substances, such as methane or methanol. Besides, due to the low value of these catalysts, the reduction effects of CO2 is generally low. However, the new delafossite-based catalyst, presented by UNIST research team converts CO2 into liquid hydrocarbon-based fuels (e.g., diesel fuel) in one single step. These fuel samples can be, then, used by existing diesel vehicles, like trucks and buses.

This new delafossite-based catalyst, composed of inexpensive, earth-abundant copper and steel is used in a reaction between CO2 emissions of industrial plants and H2generated from solar hydrogen plant to produce diesel.

"Diesel fuels have longer chain of carbon and hydrogen atoms, compared to mathanol and methane," says Yo Han Choi, the first author of the research. "Using delafossite-CuFeO2 as the catalyst precursor, we can create longer carbon chains and this would allow for the production of diesel."

This direct CO2-FT synthesis is different from the German car maker Audi's CO2-to-dielsel conversion process, which actually involves two steps – reverse water gas shift (RWGS) reaction to CO followed by CO Fisher-Tropsch (FT) synthesis.

The benefits are two-fold: The process removes harmful CO2 from the atmosphere, and the diesel can be used as an alternative fuel to gasoline. The research team expects that this breakthrough holds a potential to revolutionize the automobile industry, thereby bringing us a step closer to eliminating greenhouse gas.

"We believe the new catalyst breaks through the limitation of CO2-based FT synthesis and will open the avenue for new opportunity for recycling CO2 into valuable fuels and chemicals," says Professor Lee.

This study has been supported by both the Climate Change-Response Tech Development Project and Mid-Career Researcher Program by Ministry of Science, ICT and Future Planning (MSIP), South Korea.

CO2 Solutions rotating packed bed pilot results

www.co2solutions.com

The test program has demonstrated the potential to significantly reduce carbon capture capital costs.

CO2 Solutions has completed a performance assessment of rotating packed bed (RPB) equipment in the context of the further reduction of carbon capture costs, utilizing the Corporation's proprietary enzymatic technology.

The programme, funded in part by a grant from the Natural Resources Canada ecoENERGY Innovation Initiative, consisted of an extended testing session at relevant scale at the University of North Dakota Energy & Environmental Research Center (EERC), as well as an analysis of equipment construction materials. The programme allowed for testing of both the CO2 absorption and stripping performance of RPB units from two suppliers.

The Corporation is pleased with the testing results and can confirm that a significant potential capital cost reduction for carbon capture plants is achievable.

This reduction is possible due to a combination of factors that enable CO2 Solutions' enzyme-accelerated carbonate solvent, including choice of equipment, use of less costly materials, design of the high intensity contacting units, and simpler process configurations.

Wyoming ITC looking for research teams

www.wyomingitc.org

The Wyoming Integrated Test Center (ITC) at Basin Electric Power Cooperatives' Dry Fork Station is looking for researchers to use its facilities.

Its goal is to advance Carbon Capture, Utilization and Storage (CCUS) technologies.

The Wyoming ITC issued a Request for Proposal (RFP) to identify candidates and select initial users of test bays. Applicants will need to go through a secure login process, creating a username and password to obtain and upload the RFP.

The RFP gives interested parties the opportunity to "lease," at no cost, a test bay with flue gas slipstream from a coal-fired power plant in a competitive process. The ITC provides developers of advanced post-combustion CO2 capture technologies a place to test equipment and processes in a real-world commercial facility.

Individuals and groups in private industry, government agencies, government laboratories, university faculty and staff may submit proposals.

"Every day, scientists, researchers and entrepreneurs around the world are making advancements in carbon utilization and storage technologies," said Governor Mead. "There is no better place to bring the best and brightest to test these cutting edge technologies than in Wyoming. The Wyoming ITC will be an incubator for game-changing technology and energy evolution."

The ITC will provide space for researchers to test CCUS technologies using 20 MW of actual coal based flue gas to be split among one large test bay and five smaller test bays. The large test bay will have access to flue gas equivalent of 5 MW to 18 MW. Today's RFP is for large test bay applicants.

RFPs will be reviewed and a selection made by a technical advisory committee made up of Wyoming ITC partners including the State of Wyoming, Basin Electric Power Cooperative, Tri-State Generation and Transmission Association and the National Rural Electric Cooperative Association. Proposals are due to the Wyoming Infrastructure Authority by December 12, 2016. The ITC is expected to be available in late 2017.

The NRG COSIA Carbon XPRIZE was previously announced as the first tenant of the Wyoming ITC. The Carbon XPRIZE is a global competition designed to spur breakthrough technologies that convert the most CO2 into one or more products with the highest net value.

Carbon dioxide injected into basalt rapidly converts to rock

Lab studies on basalt have shown that the rock, which formed from lava millions of years ago and is found throughout the world, can rapidly convert CO2 into stable carbonate minerals. A pilot project in Washington State has now shown the process works in a real world scenario.

The study is reported in the American Chemical Society journal Environmental Science & Technology Letters.

This evidence suggests that if CO2 could be locked into this solid form, it would be stowed away for good, unable to escape into the atmosphere. But what happens in the lab doesn't always reflect what happens in the field. One field project in Iceland injected CO2 pre-dissolved in water into a basalt formation, where it was successfully stored.

And starting in 2009, researchers with Pacific Northwest National Laboratory and the Montana-based Big Sky Carbon Sequestration Partnership undertook a pilot project in eastern Washington to inject 1,000 tons of pressurized liquid CO2 into a basalt formation.

The white areas within the dark basalt rock core sample show where the CO_2 has reacted with minerals in the basalt and converted into a carbonate mineral similar to limestone

Technicians make adjustments to the CO_2 piping during field study. The injection well itself is in the foreground, left. Image Courtesy of Boise Inc.

After drilling a well in the Columbia River Basalt formation and testing its properties, the team injected CO2 into it in 2013.

Core samples were extracted from the well two years later, and Pete McGrail and colleagues confirmed that the CO2 had indeed converted into the carbonate mineral ankerite, as the lab experiments had predicted.

And because basalts are widely found in North America and throughout the world, the researchers suggest that the formations could help permanently sequester carbon on a large scale.

The authors acknowledge funding from the U.S. Department of Energy; the National Energy Technology Laboratory; the Big Sky Carbon Sequestration Partnership; Shell Exploration & Production Company; Portland General Electric; and Schlumberger Inc.

More information

www.acs.org

www.pnnl.gov

Transport and storage news

DNV GL and EPCRC awarded NOK 40m for pipeline study

www.dnvgl.com

The Norwegian CLIMIT Programme and Australian Department of Industry, Innovation and Science have awarded DNV GL and Energy Pipelines CRC (EPCRC) just over NOK 40 million for a test programme for CO2 pipelines.

This will involve large scale testing at DNV GL's Spadeadam test site in the UK.

Pipelines are the most common way of transporting large quantities of CO2 in CCS projects, but the cost can be significant due to the quantity of material. In the absence of accurate fracture models, CO2 pipelines must be either designed and constructed conservatively or subjected to full-scale propagating tests.

Accurate modelling of CO2 dispersion to identify the hazards posed by small releases or a major leakage contributes to safe designs as well as better permitting processes and community consultation activities.

In order to reduce the future cost of CO2 pipelines while ensuring the required safety level, DNV GL and EPCRC are cooperating to advance optimal pipeline design through new simulation models and full-scale fracture tests. The Norwegian CLIMIT Programme and Australian Department of Industry, Innovation and Science are each providing funding of NOK 20.8 million for this test programme running from 3Q 2016 to 1Q 2019.

The test programme 'Improving the safety and efficiency of CO2 pipelines by developing and validating predictive models for CO2 pipeline design' is unique as it connects the Norwegian and Australian support schemes for funding R&D in the CCS value chain in a joint effort to address an issue that is important for the efficient and safe transportation of CO2.

DNV GL and EPCRC will make the results available to the wider CCS market by updating the standards 'DNV-RP-J202 Design and Operation of CO2 Pipelines' and 'DNV-OS-F101 Submarine Pipeline Systems' as well as by improving software.

The test programme will address the existing knowledge gaps in the fracture control of high pressure pipelines by conducting large-scale fracture-propagation testing of dense-phase CO2 pipelines at DNV GL's Spadeadam test site in the UK.

Results released from Australian CO2 monitoring project

www.ga.gov.au

Geocience Australia and CO2CRC have released new data from three sub-surface release experiments undertaken at the Ginninderra Controlled Release Facility in Canberra, Australia.

The research has enabled scientists to simulate release of carbon dioxide from the soil into the atmosphere under controlled experiment conditions, and to assess the performance of different monitoring technologies.

Over 10 different organisations participated in the trials led by Geoscience Australia and CO2CRC Limited at the CSIRO Ginninderra Experiment Station in Canberra, Australia from 2012-2013.

The project included development of monitoring techniques, including using mobile sensor and remote sensing technology to detect CO2 emissions and impacts. Monitoring results were found to depend on climatic conditions, groundwater levels and the extent of the soil zone above the water table.

A controlled release experiment involves safely releasing a known amount of CO2 into the soil, then monitoring how the CO2 moves through the soil and into the atmosphere.

The results found significant horizontal movement in the near surface, fundamentally changing perceptions of how CO2 migrates and expresses itself at the near surface. Surface leakage was found to be patchy, a result similar to that observed in other controlled release facilities internationally.

There were also clear shifts in crop responses to high CO2 levels and in the soil microbial community. This is important for understanding the potential impact of CO2 leakage on surrounding agricultural crops. Effects observed during the trial were found to be very localised, and no lasting impact on crop productivity was observed for soils following release of high CO2 during the trials.

A highlight of the work was improved quantification techniques to accurately measure emission rates. Results from a comprehensive assessment of soil flux techniques will be presented at the 13th International Conference on Greenhouse Gas Technologies in Lausanne, Switzerland from 14-18 November. Over 20 monitoring techniques were trialled, with the datasets now available for free download via Geoscience Australia's website.

The intention of this data release is to make the data available for comparison with measurements taken at other controlled release experiments, CO2 storage projects and natural analogues.

This will hopefully facilitate the further development of greenhouse gas monitoring technologies, methods and monitoring strategies and increase our understanding of the migration behaviour and impact of near surface CO2 leakage.

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