Carbon Capture Journal

CCS in the EU

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CO2 recycling: coordinating research and policy

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Bełchatów - lessons learned from PGE's CCS project in Poland

The potential for biochar to contribute to carbon capture

Bellona report: investments in CO2 storage must begin before 2020

CO2 EOR – understanding the opportunity for CO2 storage

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Front cover: HTC has demonstrated that it's Delta Reclaimer can recover 98% of used amine solvent and return it to virtually as clean a state as the original with minimum energy consumption.

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Leaders - CCS review of the year

Special section on CCS in the European Union

Projects and policy

Capture and utilisation

Transport and storage

Carbon Capture Journal review of 2014

The highlight of the year was the opening of SaskPower's Boundary Dam project in Canada, the first large-scale CCS project in the power sector, while a cooperation agreement between the U.S. and China shows promise for the future worldwide adoption of CCS.

January

The EU adopts a reduction target for greenhouse gas emissions of 40% below the 1990 level by 2030, along with a target for renewable energy of at least 27%.

The U.S. Environmental Protection Agency (EPA) publishes a final rule meant to remove potential obstacles in the implementation of CCS, exemptions for carbon streams pumped underground from the EPA's hazardous waste regulations.

Bloomberg predicts that EU carbon allowances will rise by 50% on 2013 levels to €7.5 as health of the global scheme improves. The 2014 price closed at €7.09.

The DOE provides around $1 billion of cost-shared funding to the FutureGen Industrial Alliance for the FutureGen 2.0 Project.

The U.S. DOE issues final approval for Lake Charles CCS project under which it will provide cost-shared funding to Leucadia Energy for the project in Louisiana.

A demonstration test for capturing CO2 from a coal-fired power plant conducted jointly by Mitsubishi Heavy Industries and Southern Company in the U.S. completes its initial demonstration phase.

CO2 Technology Centre Mongstad completed the first large scale tests of the amine solvent MEA on a gas-fired source. Shell Cansolv also started testing its CO2 capture technology at the site

February

CO2 Technology Centre Mongstad launches the world's first large scale tests of the amine solvent MEA on a gas fired source.

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

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

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

Australia's CO2CRC says the country should keep open the option to deploy carbon capture and storage, in readiness for global calls for deep cuts to greenhouse gas emissions.

The Global CCS Institute's Status of CCS: report finds Europe is lagging behind progress in North America and China.

March

A new analysis of a Natural Resources Defense Council proposal on how to cut carbon pollution from America's power plants concludes that greater reductions can be achieved than previously thought, and at less cost.

Researchers from the CO2CRC test CO2 filtering membrane tubes at a power plant in Australia.

Maersk and Masdar agree to collaborate on carbon capture using Maersk's TriGen technology that generates water and power in addition to CO2 for injection into oil reservoirs.

Emirates Steel in the UAE initiates a project whose aim is to capture, reuse and store 800,000 tonnes of carbon dioxide from its steel plant annually.

Global CCS Institute launches Decarboni.se, a new platform that makes it easier to share information on solutions to climate change

April

CCS and bio-CCS technologies are recognised by the IPCC as essential in the mix of climate mitigation technologies necessary to avoid the effects of climate change.

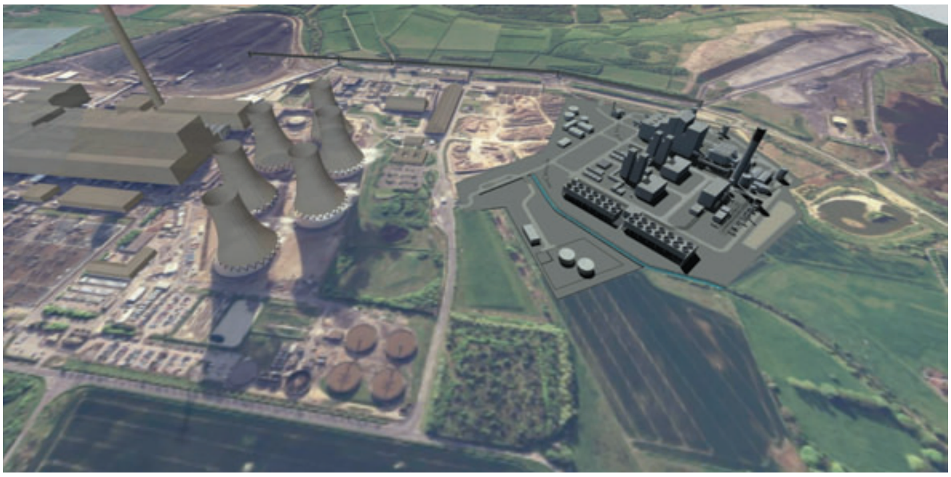
The Climate Change and Emissions Management Corporation (CCEMC) makes $65

million available for projects that will help Alberta reduce greenhouse gas emissions.

The EU OCTAVIUS project concludes that emissions from solvent and degradation products should not be a barrier for the majority of post-combustion CO2 capture processes implemented in industrial facilities.

CO2 Solutions will operate a pilot plant to test its enzymatic carbon capture technology at Husky Energy's heavy oil operations.

SaskPower and Vattenfall sign an agreement to explore opportunities for collaboration.



The White Rose CCS Project received €300 million funding through the EU NER300 programme

May

The International Energy Agency publishes the fourth volume of its Energy Technology Perspectives report which confirms that CCS is critical but too slow.

The Australian Government cuts funding to its CCS Flagships project in the Budget.

The UK Energy Technologies Institute starts developing a monitoring system using marine robotics to provide assurance that carbon dioxide stored below the seabed is secure.

UK MPs urge the Government to fast-track final funding decisions on two pilot Carbon capture and storage projects at Peterhead and Drax by early 2015.

Vattenfall ends coal power CCS research amid 'challenging market conditions'.

The UK Government releases a report into CO2 capture in the UK cement, chemicals, iron, steel and oil refining sectors.

June

Polk Power starts up a CO2 capture demonstration which involves testing RTI International's amine CO2 capture technology in a coal gasification unit in Florida.

A U.S. DOE study finds that a geological feature in Wyoming could store up to 300 years of the region's CO2 emissions.

The UK and China sign a cooperation agreement on climate change which includes supporting two CCS Centres in China.

A group of CO2CRC researchers at the University of Melbourne form UNO Technology to commercialise a range of Australian-developed carbon capture technologies.

The White Rose project in the UK receives €300 million funding through the EU NER300 programme.

July

Process Systems Enterprise launches its gCCS systems modelling environment for full-chain carbon capture and storage applications.

2Co Energy enters negotiations to sell the Don Valley CCS project in the UK to Norwegian CCS technology company Sargas

The UK Carbon Capture and Storage Research Centre and Australia's Cooperative Research Centre for Greenhouse Gas Technologies sign collaboration agreement.

A megawatt-scale carbon capture pilot unit located at Kentucky Utilities Company's E.W. Brown Generating Station in the U.S. begins construction.

China and the U.S. sign deals on climate change, half of which are related to CCS.

Australia repeals its carbon tax, leaving the nation with no legislated policy to achieve greenhouse gas reductions.

The UK Government makes over £200 million a year available for renewable energy projects including CCS.

August

The U.S. DOE announces the selection of 13 projects to develop technologies and methodologies for geologic storage of CO2.

Progress continues at Mississippi Power's Kemper County IGCC energy facility with the start of commercial operations of the combined cycle unit

The UK Government publishes a scoping document that seeks views on a possible Phase 2 of CCS deployment.

Solidia Technologies signs a partnership

agreement with The Linde Group to industrialize technology that could reduce the environmental footprint of pre-cast concrete.

Brown Coal Innovation Australia awards funding to a post combustion coal research and development project at Loy Yang Power plant in Victoria, Australia.

Scientists at Brown University's Center for the Capture and Conversion of CO2 develop copper foams that could convert CO2 into useful industrial chemicals.

Researchers from the Korea Institute of Science and Technology develop a technology to produce a material used to make plastics from CO2-grown microalgal biomass.

SaskPower's Boundary Dam project is officially opened in Estevan, Canada. It is the world's first commercial-scale coal power CCS plant in operation

September

NRG Energy begins retrofitting one unit of its WA Parish power plant in Texas to capture its carbon emissions.

The U.S. Environmental Protection Agency approves permits for CO2 storage at the FutureGen clean coal project.

An $18 million CO2CRC–University of Melbourne collaboration on new laboratories, plant and equipment will be used in a range of CCS activities over the next five years.

The CarbonKids book created by Western Australian primary school students helps children better understand greenhouse gases and the process of CCS.

An additional $5 million for research in CO2 storage at the Otway site in Australia is awarded by Victoria's Ministry for Energy and Resources.

EDF invests half a billion dollars in a new Paris R&D facility.

Researchers at Aalto University open a pilot plant that converts CO2 and slag, the by-product of steel manufacturing, into a valuable mineral product.

October

The world's first commercial-scale carbon capture and storage process on a coal-fired power plant officially opens at Boundary Dam Power Station in Saskatchewan.

Technology Centre Mongstad completes the world's first open-source, large-scale CO2 capture tests of amine solvent MEA on flue gas from a gas-fired power plant.

DNV GL makes new data available which will help make CO2 pipelines safer and more efficient through the CO2PIPETRANS joint industry project.

Scientists combine carbon capturing solids and liquids to develop a "slurry" that offers the best of both worlds.

Net Power proceeds with a 50MWt demonstration plant to validate a natural gas power generation system that produces no air emissions and includes full CO2 capture.

The EU pushes back deadlines on final investment decisions on CCS demonstration projects for 2 years.

November

U.S.-China climate deal includes building a coal plant with CCS in China that produces fresh water.

The EU agrees to increase funding for CCS demonstration projects after 2020.

Skyonic opens Capitol SkyMine CO2 recycling facility at Capitol Aggregates existing cement plant in San Antonia.

A Bellona report into the CO2 storage industry finds that annual investments in the range of €500 million need to begin by 2020 if the required capacity is to be developed.

CO2 Solutions develops a new high-performance carbonic anhydrase enzyme with a longer lifespan in the CO2 capture process.

Taiwan's Industrial Technology Research Institute receives an award for its HECLOT calcium looping carbon capture technology.

G20 leaders give Japan the task of fast-tracking new clean coal technology which would be used by developing countries to burn Australian coal more efficiently.

Masdar and Adnoc to develop commercial-scale projects for CCUS in Abu Dhabi.

December

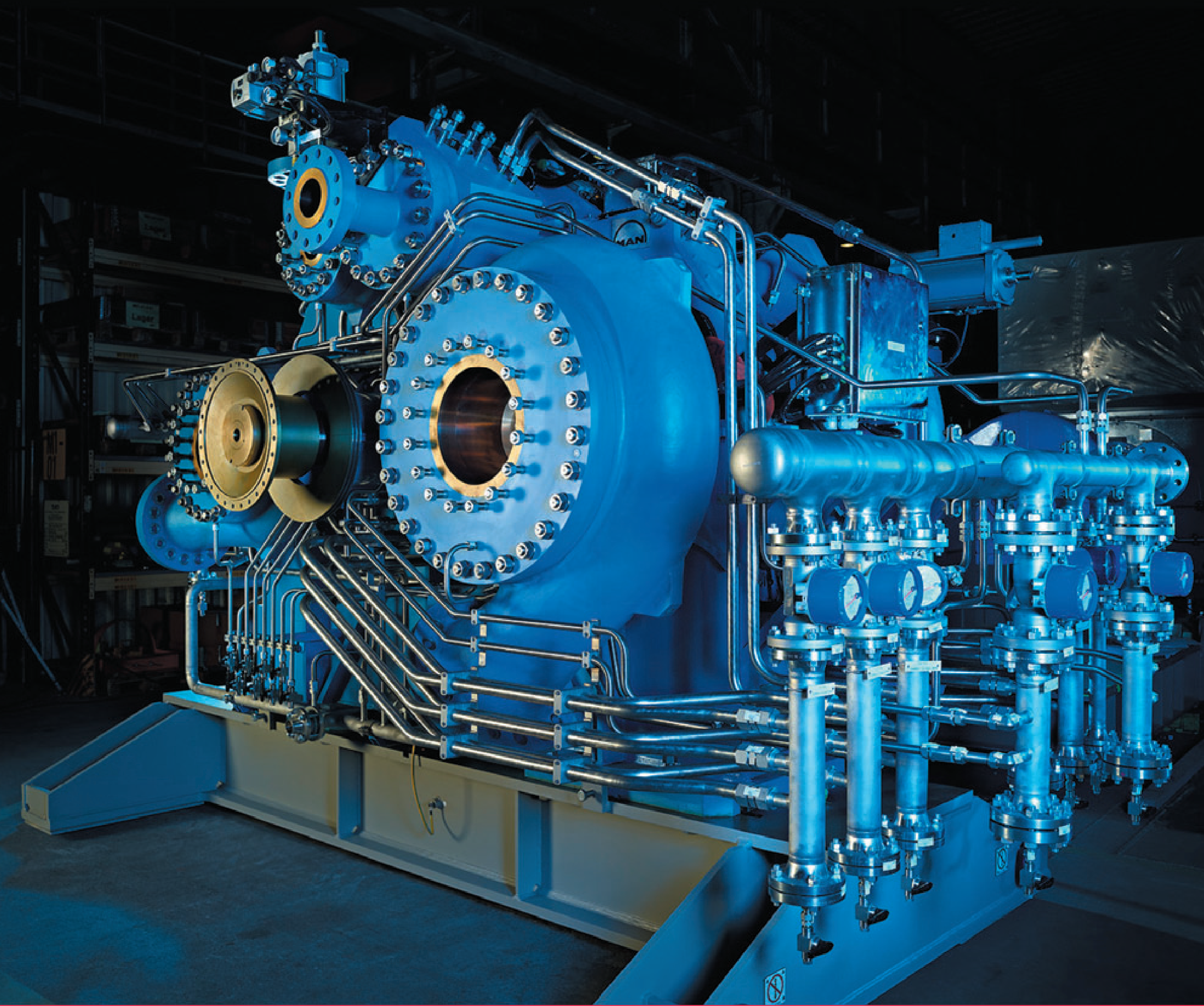
Research by the University of Liverpool identifies for the first time how global warming is related to the amount of carbon emitted.

Shell Cansolv begins testing its amine CO2 capture process at Norway's CO2 Technology Centre Mongstad

Petronas will invest up to US$1 billion to develop carbon capture solutions to recover natural gas from high CO2 concentration fields.

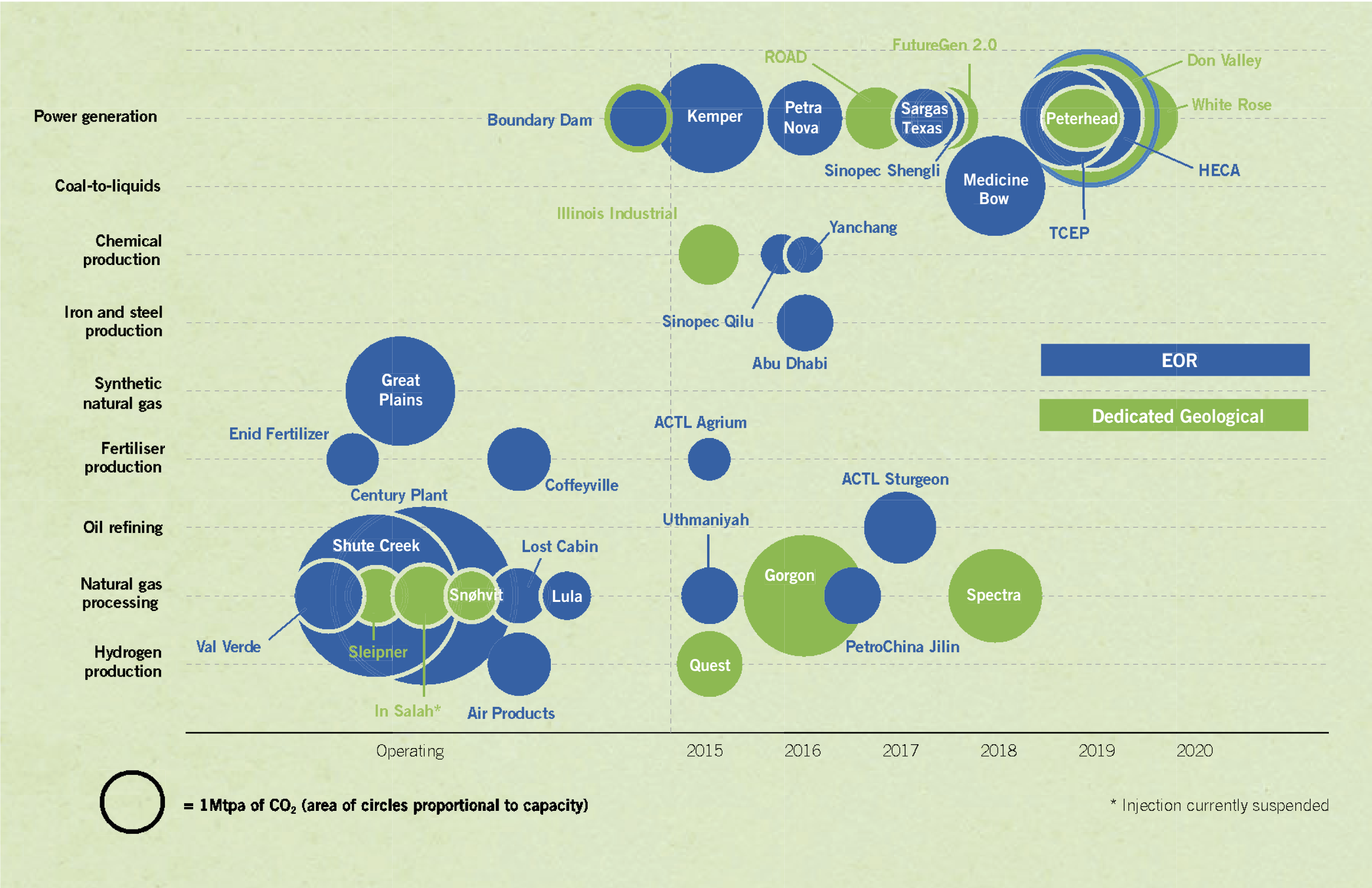
The UK Government makes £2.5m available to encourage development of CO2 storage in the North Sea.

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



The Global Status of CCS 2014

With large-scale CCS power projects now a reality, an important milestone in deployment of the technology has been achieved.This means that it is time to move discussion onto how CCS can best be deployed as part of a least-cost approach to climate change mitigation, says the Global CCS Institute's flagship CCS report.



Actual and expected operation dates for large-scale CCS projects in the Operate, Execute and Define stages by industry and storage type (©GCCSI)

The Global CCS Institute's Global Status of CCS 2014 report finds that the only low-carbon technology option for industrial and many power applications, carbon capture and storage (CCS), is now on the cusp of widespread deployment.

Brad Page, CEO of the Global CCS Institute, said, "CCS in the power sector is now a reality with the world's first large-scale CCS project operating at Boundary Dam, Canada. With eight major CCS projects anticipated to go live in a range of industries worldwide by 2016, this low-carbon technology is reaching the critical mass necessary for widespread deployment."

There are now 22 projects in construction or operation worldwide, a 50% increase since 2011. The report details progress on CCS over the past year, providing a raft of recommendations for decision makers.

It found the industry is poised to move through its most active construction period to date, extending across a diverse range of sectors such as iron and steel, natural gas and power. The report details nine CCS projects under construction with investments totalling billions of dollars. Eight of these are expected to become operational by 2016.

Mr Page called for "a year of action" on policy and deployment for CCS, saying, "Now is the time for decision makers to take stock of what has been achieved and build on these solid foundations so that CCS can make major contributions to reductions in greenhouse gas emissions."

2014-2015 - Watershed Years for CCS

The world's first large-scale carbon capture and storage project in the power sector commenced operation in October 2014 at the Boundary Dam power station in Saskatchewan, Canada. Two additional large-scale CCS projects in the power sector - at the Kemper County Energy Facility in Mississippi and the Petra Nova Carbon Capture Project in Texas - are planned to come into operation in 2015 and 2016 respectively. Con-

struction is also underway on the world's first large-scale CCS project in the iron and steel sector, the Abu Dhabi CCS Project in the United Arab Emirates (UAE). These four projects are among the 22 large-scale CCS projects in operation or construction around the world - double the number at the beginning of the decade.

There are a further 14 large-scale CCS projects in advanced planning, including nine in the power sector, many of which are anticipated to be in a position to make a final investment decision during 2015. Not only does this further reinforce the growing confidence in the (increasing) technical maturity of CCS, it offers the prospect of a 'potential portfolio' of operational large-scale CCS projects around the 2020 timeframe across a range of industries, storage types, fuels and technology suppliers.

Now is the time for actions to help realise the potential of these advanced projects (and for those projects in earlier stages of planning). Furthermore, the data on large-scale CCS projects highlights two other areas requiring increased attention by policymakers - the lack of projects in non-OECD economies (outside of China) and the lack of progress in CCS technology development in high carbon intensive industries such as cement, iron and steel and chemicals.

Numerous international studies continue to show that CCS is essential in meeting global climate targets. We need to realise the potential of CCS projects in the development pipeline and incentivise the development of CCS across a wider range of industries and regions to provide the basis for a rapid expansion in the number and diversity of next generation projects.

CCS is essential

Global consumption of fossil fuels continues to increase, driving growth in CO_2 emissions. Even when it is assumed that current policy commitments and pledges by governments around the world to tackle climate change are all implemented, it is expected that fossil fuels will still account for 75% of global energy demand in 2035.

CCS is a cost-effective technology for achieving large emission reductions from fossil fuel use, and it must play a signifcant role alongside renewables, energy efficiency, nuclear and other mitigation options in global action on climate change. CCS has a key role in curbing CO_2 emissions from fossil fuel-based power generation. Without investment in CCS in the power sector, total mitigation costs in the sector would increase by US$2 trillion by 2050 (IEA, 2012. Energy Technology Perspectives). Further, CCS is the only option available to significantly reduce direct emissions from many industrial processes at the large scale needed in the longer term.

Recommendations for Decision Makers

• Financial and policy support structures must be provided in the near term to enable transitioning the 'potential portfolio' of planned projects into an 'actual portfolio' of projects operating by 2020.

• Strong, sustainable emission reduction policies that encourage CCS are urgently needed for longer-term deployment and to give investors the policy predictability they need to invest in CCS. These policies must ensure that CCS is not disadvantaged in relation to other low-carbon technologies.

• There is an urgent need for policies and funded programs which encourage the exploration and appraisal of significant carbon dioxide (CO_2) storage capacity, so that broader deployment is not delayed by uncertainty over available storage.

• Substantial effort must be devoted to knowledge sharing, capacity development and the implementation of other policies and legal frameworks during the course of this decade to enable the increasing numbers of large-scale CCS projects needed in non-OECD economies by 2025-30 and beyond.

• CCS is the only technology that can achieve large reductions in CO_2 emissions from industries such as iron and steel and cement. Urgent attention must be given to the development of policies that incentivise the widespread deployment of CCS in such industries.

'After many years of research, development, and valuable but rather limited practical experience, we now need to shift to a higher gear in developing CCS into a true energy option, to be deployed in large scale. It is not enough to only see CCS in long-term energy scenarios as a solution that happens some time in a distant future. Instead, we must get to its true development right here and now.' - Maria van der Hoeven, Executive Director, IEA Foreword to the Technology Roadmap: Carbon Capture and Storage, 2013.

Further policy support is vital

Within the next year there is the potential for ten or more projects to be in a position to make a final investment decision. Current policy settings and any new initiatives taken in the next 12-18 months will therefore largely shape the CCS projects portfolio out to 2020. It is important that financial and policy structures in the near term support the transitioning of this 'potential portfolio' of planned projects into an 'actual portfolio' of operating projects by 2020.

In addition to near-term actions needed to bring planned projects into operation, the future pipeline of projects must be greatly expanded. Important lessons will be learnt from the projects in operation this decade that will help to reduce costs, increase confidence and expand the applications of second- and third-generation CCS technologies in the 2020s and 2030s. But the total absence of any proj-

ects in the earliest stage of project planning, except in China, is of concern. This situation must be rectified if CCS is to play its full part as a mitigation option, commensurate with IEA scenarios. As a result, strong sustainable emissions reduction policies that encourage CCS are urgently needed for longer-term deployment and to give investors the longer-term predictability they need to invest in CCS.

Immediate and longer-term policy support is vital. However, a majority of respondents to the Institute's 2014 Perceptions Survey reported that they had not noticed a material change to their CCS policy environment over the last year. More than three-quarters of respondents cited policy uncertainty as a major risk to their project's viability, and a similar proportion stated that their project's viability depends on new government policy settings.

Existing policy support alone over the past five years has not been enough to 'launch' the number of large-scale CCS projects anticipated at the start of the decade. In fact, more than 40% of respondents to the Perceptions Survey indicated that the incentives currently in place are inadequate for ensuring projects are not commercially stranded.

The need for supportive policies has been recognised in a number of countries and regions. The UK policy environment continues to promote progress of large-scale projects. The US policy, legal and regulatory environment for CCS/carbon capture, utilisation and storage (CCUS) continues to advance, and projects are also progressing there, particularly when supported by EOR opportunities. The European Commission (EC) is reviewing European Union (EU) CCS policy, against a backdrop of only one project (ROAD) in development planning in mainland Europe. Several developing countries are also progressing policy reviews or including CCS in broader climate change policy considerations. Governments are also supporting efforts through the International Organization for Standardization (ISO) to develop essential supporting technical infrastructure for future CCS development.

Progress must be accelerated in developing countries

It is not surprising that to date, most large-scale CCS projects are in the developed world. This is where key project enablers such as public support programs, marketable opportunities for CO2, storage assessments and regulatory frameworks are most advanced. However, non-OECD economies will account for the vast majority of growth in energy demand in coming decades. Meeting longer-term climate goals will involve significant capture and storage of CO2 from facilities in these economies. In its 2012 Energy Technology Perspectives, the IEA estimated that 70% of CCS deployment will need to happen in non-OECD countries by 2050 to achieve the 2°C global emission scenario.

Important progress is being made in a number of non-OECD and developing countries in CCS project and policy development. These efforts must continue, and substantial effort devoted to the implementation of policies and frameworks (including knowledge sharing and capacity development programs) during the course of this decade to support the increasing numbers of large-scale CCS projects required in non-OECD economies by 2025-30 and beyond.

International collaboration is vital to accelerate CCS

While some large-scale CCS projects have been operating for decades, the overall industry is still in its infancy. As with all industries at this stage of development, great benefits can be obtained from knowledge sharing and collaboration along the entire development chain, from early laboratory concept to scalable pilot testing and large-scale projects. Project case studies and comments from leading voices in the CCS and climate change community highlight the value of collaborating with others.

The transfer of large-scale project experience from successfully operating projects to new projects will help to reduce costs and risks, as well as build confidence about CCS among the general public, governments and the finance community. In particular, transferring experience from developed to developing economies will be vital given the future scale of the mitigation task and the role of CCS in helping to achieve mitigation goals in those countries at least cost.

Public engagement is an important part of the picture in all countries

The most advanced CCS projects have shown they are fully committed to public engagement and long-term outreach activity, not just with their local stakeholders, but also on the international stage. This engagement and outreach is critical for increasing understanding and ensuring acceptance of CCS generally, and with regard to specific projects. The engagement methods ranked most effective by projects are generally direct in nature, such as face-to-face meetings, site visits, formal consultation events and education programs.

The three large-scale power sector CCS projects that have taken a positive final investment decision (and those that will follow) will be vital in establishing a positive perception of CCS as an important part of an effective and efficient CO2 emission reduction portfolio. Leveraging these milestones in CCS deployment is critical to creating awareness and building enthusiasm to empower communication efforts, not just around CCS technology, but also on climate change and low-carbon energy more generally.

The first-mover projects that have progressed to the most advanced stages of the project lifecycle since the beginning of this decade lie almost exclusively in the Americas and Europe, Middle East and Africa (EMEA) regions. By contrast, most of the large-scale CCS projects in the early stages of project development are in the Asia Pacific region. While the Institute's 2014 Perceptions Survey indicated that around one-third of the projects in the Asia Pacific region are either actively engaged with stakeholders or developing a public engagement strategy, a substantial number are yet to develop such a strategy. This makes those projects that are adopting best practice approaches important and instructive case studies for others in the region.

The majority of CCS social research carried out to date has focused on the developed world, shedding very little light on the role of CCS within developing countries. This is not surprising given the areas of the world where CCS is most developed. However, these results underline the urgent need to improve access to the learnings and experiences of CCS projects and researchers in the developed world. This will help to understand differences in needs in developed and developing regions and allow projects in the latter to benefit from lessons learnt.

More information

The full report, summary report and other related materials are available free from:

www.globalccsinstitute.com

Why CCS needs to be newly discussed in Germany

A recent study by IZ Klima examines the infrastructural prerequisites for the transport of CO2 to potential offshore storage sites in Germany.

By Heinz Bergmann and Diana Voll

With its 2010 Energy Concept, the Federal Government clearly defined the climate protection targets for Germany. By 2020, greenhouse gas emissions are to be reduced by 40 % compared to 1990, and by at least 80 % by 2050. However, the latest prognoses indicate that meeting the climate protection targets is becoming more and more improbable.

In addition to developing renewable energies and enhancing energy efficiency, it makes sense to put the application of technologies to reduce CO2 emissions back on the political agenda. Here, two CO2 technologies are available in principle: capture and use of CO2 (CCU) and capture and storage of CO2 (CCS).

In April this year, Working Group III on the "Mitigation of Climate Change" of the Intergovernmental Panel on Climate Change (IPCC) published the third part of its 5th Assessment Report, dealing with the economic, technological and political measures to mitigate climate change. [1] The scientists unequivocally demand that action has to be taken now if the 2 degree goal is to be achieved. "If we wait until 2030, as the window of opportunity closes faster and faster, everything will become considerably more difficult, risky and expensive," warned Ottmar Edenhofer, Co-Chair of the Working Group [2].

Transport demand of 60 million tonnes of CO2 in 2050

The prognoses are also borne out by a recent study commissioned by IZ Klima (Informationszentrum für CO2-Technologien e.V.). The study takes the Federal Government's 2010 Energy Concept as a baseline to determine the amounts that need to be transported in order to develop a German transport infrastructure. The Energy Concept stipulates a reduction in levels of greenhouse gas emissions of 40 % by 2020 and 80 % by 2050. The share of renewable energies in gross energy consumption is to rise to 35 % by 2030 and to 80% by 2050.

Difference between targets and actual CO2 emissions in Germany up to 2050

	Unit	2030	2040	2050
CO2 residual emissions – electricity sector	m t/a	185	124	67
CO2 residual emissions – industry	m t/a	129	92	60
Overall residual emissions (electricity sector and industry)	m t/a	315	216	127
Emission target for electricity sector	m t/a	176	99	21
Emissions target for industry	m t/a	110	79	47
Overall emissions target (electricity sector and industry)	m t/a	286	177	68
Targeted CO2 transport volumes	m t/a	30	40	60

The study sets out from an assessment of how CO2 emissions are going to develop up to 2050, taking the framework conditions of the Energy Concept into account. The analysis concentrates on the major emission sources of emissions in electricity generation and industry comprising at least 0.5 million tonnes of CO2 emissions a year. Taking all targets regarding emissions reduction and the use of renewable energies into consideration, the gap between the targeted and the actual CO2 emissions in 2030 will already be at 30 million tonnes in 2030, and at 60 million tonnes in 2050 (see Table above).

The results of the analysis show that, with a view to the implementation of the climate protection targets, CCS technology can play a crucial role not only in the energy industry but in industry as a whole. In spite of this, hardly any consideration is being given to the application of CCS technology in Germany as an important element in achieving the climate protection targets. This is also due to the discussions on the landside storage of CO2 being partly prejudiced, above all with onshore storage of CO2 being questioned.

The study therefore focuses on the potentials of offshore storage under the German North Sea, which offers sufficient storage potential. In its saline aquifers, a total of three to six billion tonnes of CO2, or 60 million tonnes over a period of at least 50 to 100 years, can be stored [3].

Infrastructural requirements for CO2 transport to offshore storage

Against the background of the offshore storage potential, the study focuses on developing a CO2 transport infrastructure which is the

necessary condition for the establishment of CCS technology in Germany but has as yet only been marginally considered. Here, the study centres on the technical, legal and economic demands of a CO2 transport infrastructure. Since the development of an intelligent CO2 transport infrastructure strongly depends on the composition of the CO2 emitted, three abstract clusters were defined in the study to illustrate the diversity of CO2 sources in Germany and their emission profiles at the interface with the infrastructure of CO2 transport.

• The first cluster represents a highly industrialised area with a large energy demand. Several large-scale power stations as well as a number of industrial sources are located here in relatively close proximity of one another.

• The second cluster represents a less industrialised region with central electricity supply. Here, there are some large coal-fired power stations but no industrial point sources.

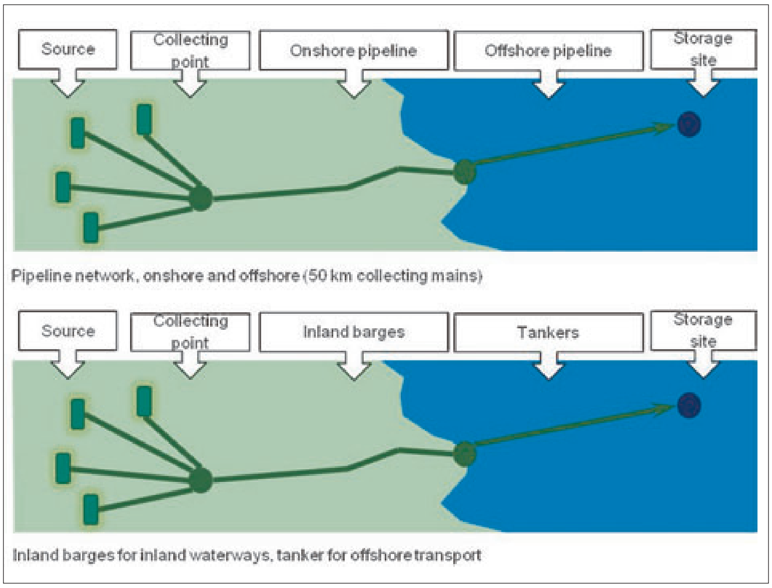
• The third cluster contains scattered industrial plants and power stations at relatively large distances from one another. Most of the power stations are coal-fired.

Utilisation of the transport infrastructure follows fluctuating feeding in of renewable energies

The influence of fluctuation on the dimensioning of a CO2 transport infrastructure has been examined on the basis of cluster formation: Fluctuations in throughput and in concentration result from the effects of combined CO2 throughputs from a diversity of sources, the influence of the operating mode and the minimum capacity level of power stations and industrial plant, the effects of the intermitting character of renewable energies and the share in regenerative energy generation.

A comparison of the different CO2 flow rates and the composition profiles with the cluster approach shows that a cluster with different CO2 sources ensures that CO2 is fed in more evenly and with less fluctuation in the flow rate, allowing a greater utilisation of the infrastructure. At the same time, the utilisation rate of the CO2 transport infrastructure is influenced by electricity generation with renewable energies. Since the electricity from Renewables is only fed in in fluctuating amounts and irregularly, in the foreseeable future, these fluctuations will have to be compensated by fossil fuel-fired power stations that will at least partly have to be equipped with CCS.

However, if the CCS transport system is designed for maximum amounts of CO2 to be fed in, it will be operated below maximum capacity for most of the time owing to a strongly fluctuating input. The calculations show that the utilisation rates of CO2 infrastructure would lie between 60 and 80 %.



A shipping system using inland barges and offshore tankers would enable greater flexibility in terms of capacity

Transport by pipeline: a proven technology with cost advantages

Not every transport option is equally suited to the task of large-scale CO2 transport. The choice of the right transport system depends on transport capacity, the distance between source and storage site, the availability of a suitable waterway or pipeline, and the location of the storage site. Thus, the large CO2 volume assumed in the study excludes road or rail transport because both would prove too costly. Gas phase transport is also unsuitable due to the limited mass flow rates it offers. However, transport by pipeline and transport of liquefied CO2 by barge and tanker were identified by the study as suitable transport systems.

Many of the technical requirements of a CO2 transport infrastructure are comparable to those set for transport infrastructures for natural gas. This means we are able to draw on existing know-how, experience, standards and practices. So when considering the main system components of a pipeline infrastructure (collecting network, compressors, main line, booster, transfer station, offshore pipeline), engineers can fall back on a mature technology for the design and construction of the transport infrastructure. Moreover, with pipelines, every aspect of the operation side is familiar.

Compared to pipeline transport, a shipping system using inland barges and offshore tankers would enable greater flexibility in terms of the capacity of the CO2 transport, since we can ramp up the quantities being transported simply by increasing the number of vessel journeys (see figure above). The logistics of such a transport system are, however, far more complex. Indeed, some of the important components of the transport chain still have to be worked out at the research and development stage.

Based on a calculation of the necessary CO2 volumes to be captured and transported, the study determined the size and capacity of the transport infrastructure in Germany. Setting the CO2 volume at 60 million tonnes for the year 2050, we find that a pipeline network would require an average capacity of 1,900 kg/s. Fluctuations in flow demand much higher peak-time capacities of around 3,000 kg/s. Depending on capacity demands, the pipe diameter would have to vary between 24" and 32". The shipping of these quantities would require around 110 barges with a holding capacity of 8,000 tonnes each along with 16 tankers capable of carrying 30,000 tonnes each.

For the shipping option (and possibly also for pipeline transport as part of its optimisation, but this would not necessarily be the case), there must be intermediate storage in order to keep up with CO2 production at the source. The capacity required for an intermediate storage facility is determined by the fluctuations in CO2 production, the maxi-

mum production rate at the source and the storage capacity of the barges. The study estimates the size of an intermediate storage facility to cope for three days with an average feed from a cluster delivering 22 million tonnes of CO2/a at 200,000 m^3.

In terms of the carbon feed, a particular challenge for the infrastructure is posed by the composition of the captured CO2, which will contain various secondary constituents. Almost all of them impair effective use of the transport and storage infrastructure. Among the potential consequences are capacity restrictions or corrosion damage. To curb such negative impacts, it is possible to purify captured CO2 after its separation. The aim is to reduce as far as possible the proportion of secondary constituents in the transport system, but the costs of purification must be kept down since they would only add to the cost of the CCS process chain.

To determine overall capital expenditure, the study made an indicative estimate of the capital expenditure required up to 2050, both on pipeline infrastructure and on shipping infrastructure. The investment required for the pipeline infrastructure and for the shipping system is calculated at around € 4 billion for each mode up to 2050. This estimate assumes a pipeline infrastructure consisting of collecting pipelines that are each 50 km long, as well as onshore pipelines with a length of 350 km and offshore pipelines with a length of 100 km. As for a shipping infrastructure, the study assumes there would be 50 km-long connecting pipelines, liquefaction terminals, inland barges and offshore tankers.

Setting the agenda now

Whatever transport option is chosen, the implementation of the necessary transport infrastructure demands a lead-in time of at least five years. This is shown by comparable projects. For instance, the expansion of the natural gas transport network in The Netherlands and Germany by Gasunie took six years, while there was a period of five years between investigating the design process for the Nord Stream pipeline and its operational launch. Moreover, the full-scale implementation of CO2 transport first requires testing in demonstration projects.

After the completion of a successful large-scale demonstration in around 2020, we would not be able to expect the CO2 feed of first commercial plants to start before 2025, from today's perspective. A broad rollout would then not be possible before 2030. Another important factor is public participation in the approval procedure. This, again, will extend the necessary lead-in time. Up to ten years or more may pass before the transport system becomes operational. However, the long-term emissions reduction targets set by the German government can still be achieved if it takes steps without delay to introduce CCS technology in Germany.

"Expanding renewable energies and improving energy efficiency are major pillars of a shift towards sustainable energy. Fossil fuels will, however, continue to play a role over the coming decades – globally and nationally. This is why we need to discuss again the potential of technologies for reducing CO2, including CCS technology, especially if we realise that climate change mitigation is a global task." - Prof. Reinhard F. Hüttl, Science Executive Director and Chair, Helmholtz Centre Potsdam / German Research Centre for Geoscience

This assumes a political will to put the discussion of the opportunities of CCS technology back on the policy agenda and to focus on CCS as a means of meeting Germany's climate targets. There must be a constructive dialogue with the public and policymakers in order to arrive at an objective assessment of both the potential and the possible challenges of CCS, to find answers to any outstanding questions and to create understanding of the need for technology to combat climate change. This study on carbon transport ("CO2-Transport Infrastructure in Germany – Necessity and Boundary Conditions up to 2050") gets the ball rolling and provides plenty of food for thought.

The IZ Klima – Informationszentrum für CO2-Technologien e.V. – is engaged in disseminating information on opportunities and potentials of CO2 technologies in Germany. IZ Klima is a non-profit organisation, headquartered in Berlin, which acts as a point of contact for the general public, the media and industry professionals and seeks to establish a dialogue to deal with the issues objectively and constructively.

Literature

[1] IPCC Working Group III Contribution to AR5 (2014): Climate Change 2014. Mitigation of Climate Change, can be accessed online at: http://mitigation2014.org

[2] Süddeutsche Zeitung, 14.04.2014: Wenn wir bis 2030 warten, schließt sich das Fenster der Möglichkeiten.

[3] GeoCapacity (2009): Assessing European Capacity for Geological Storage of Carbon Dioxide. Deliverable D16, WP2 Report Storage capacity: www.geology.cz

More information

This article is a shortened version of the results of a study of carbon transport infrastructure entitled "CO2-Transport Infrastructure in Germany – Necessity and Boundary Conditions up to 2050".

Parts of this article were already published in Energiewirtschaftliche Tagesfragen (Volume 10, Year 64).

The full study is available as a download from the IZ Klima website.

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CO2 recycling: coordinating research and policy efforts across Europe

The SCOT project (Smart CO2 Transformation) is a 3-year collaborative project whose objective is to coordinate CO2 recycling research and policy efforts across Europe.

By Youssef Travaly and Talia Brun

As recently acknowledged by the European Commission, moving towards a circular economy is essential to deliver the resource efficiency agenda established under the Europe 2020 Strategy for smart, sustainable and inclusive growth [1].

Recycling CO2 emissions into products could become key in achieving these goals unlocking innovative business models and increasing the competitiveness of the European industry.

The SCOT project aims to coordinate research and policy efforts across Europe to achieve this high level goal. It is financed by the European Commission [2] and already gathers five European regions strongly committed and well advanced in this emerging area [3]. Through a stronger coordination of the efforts of the Consortium partners, the SCOT project will lead:

• To the definition of a Strategic European Research and Innovation Agenda (SERIA) aimed at improving the techno-economic performance of emerging CO2 transformation technologies and at developing new breakthrough solutions and market applications;

• To the creation of a network of actors willing to contribute to the implementation of the SERIA

• To the proposition of structural policy measures to favour the transition to a new European society based on the positive paradigm of "CO2-as-a-resource"

The project focuses on the recycling of CO2 through its transformation into valuable products via chemical or biological technologies.

The work is structured along three different valorization routes for CO2 re-use: CO2 chemistry to make chemical building blocks, CO2 used to create synthetic fuels and mineralization of CO2 into building materials.

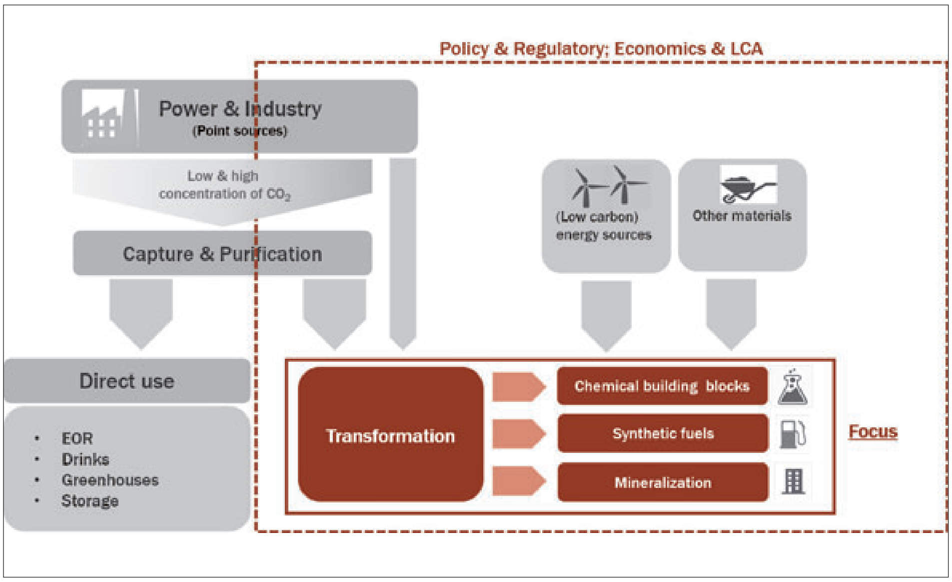

Figure 1 – Project scope

Although the project's focus is on the transformation phase, the other elements of the chain (capture, purification, transport, energy inputs and other inputs) are considered in the product's Life Cycle Assessments (LCA) and business models.

The project is structured in 8 work packages and started in October 2013. During the first year of activity, we have completed the background research that will be used as foundation for the construction of the Strategic European Research and Innovation Agenda (SERIA) and the Joint Action Plan including measures to materialize the SERIA.

Preliminary Results

The first work package highlighted some important policy challenges and opportunities. We started our work by mapping CDU (Carbon Dioxide Utilization) actors and projects. This exercise showed that in most member states and at European level, R&D funding for CDU is dispersed among a large number of instruments.

With the EU showing leadership on industrial innovation and climate measures it seems logic for SCOT to advocate for the creation of specific funding streams devoted to CDU

1. Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. Towards a circular economy: A zero waste program for Europe {SWD(2014) 206 final}

2. This project has received funding from the European Union's Seventh Framework Program for research, technological development and demonstration under grant agreement No 319995.

3. SCOT partners are Pole Greenwin and SPW (Belgium), Axelera Competitiveness Cluster (France), Dechema (Germany), Triple E Consulting and DCMR (The Netherlands) and University of Sheffield, Centre for Low Carbon Futures, Yorkshire Chemical Focus and Leeds City Council (United Kingdom).

(in those countries in which they do not exist already) and the clustering and enlargement of existing funding mechanisms at EU level to support the creation of a stronger research community around the subject.

After the mapping, we performed a SWOT (Strengths, Weaknesses, Opportunities and Threats) analysis per region and at European level. This analysis showed that, while there are a number of technical challenges that CDU has to overcome, many of the identified "weaknesses" and "opportunities" have to do with regulation and research policy, the area in which the SCOT project intends to have an impact. It also showed that many CDU derived products will have trouble competing with fossil fuel derived alternatives in the absence of a substantially higher carbon price or some other form of incentive.

While stakeholders had very different views on the kinds of incentives they would like to see emerge, there was a consensus on the need for further LCA research on CDU products to prepare the ground for potential policy incentives. Regarding TRLs (Technology Readiness Levels), stakeholders agreed that funding for CDU should cover both: very low TRLs for promising technologies such as photocatalysis as well as translational research to transform ideas which are closer to the market into pilot plants that could give rise to job creation.

The second work package consisted in a socio-economic analysis of specific CO2 recycling paths. We analyzed the state-of-the-art of CDU technologies including their associated potential market. In all valorization routes, some processes have reached a high TRL and have been demonstrated through pilots and some commercial plants. Nevertheless, Europe is still lagging behind compared to Asia and USA for some technologies where important investments are necessary to set-up commercial facilities.

In the same line of thought, the analysis of policies reveals that the EU framework is less favorable to systemic innovation, which may hinder its competiveness in this emerging area. Therefore, the Agenda proposed by SCOT will address industrial policies and the technology mismatch at EU level, two major bottlenecks on the path to market.

SCOT will also perform a more in-depth analysis of EU policies in comparison to existing policies in other continents in order to come up with competitiveness policy recommendations. A full report describing all our observations and conclusions in more detail will be published in the course of the first semester of 2015.

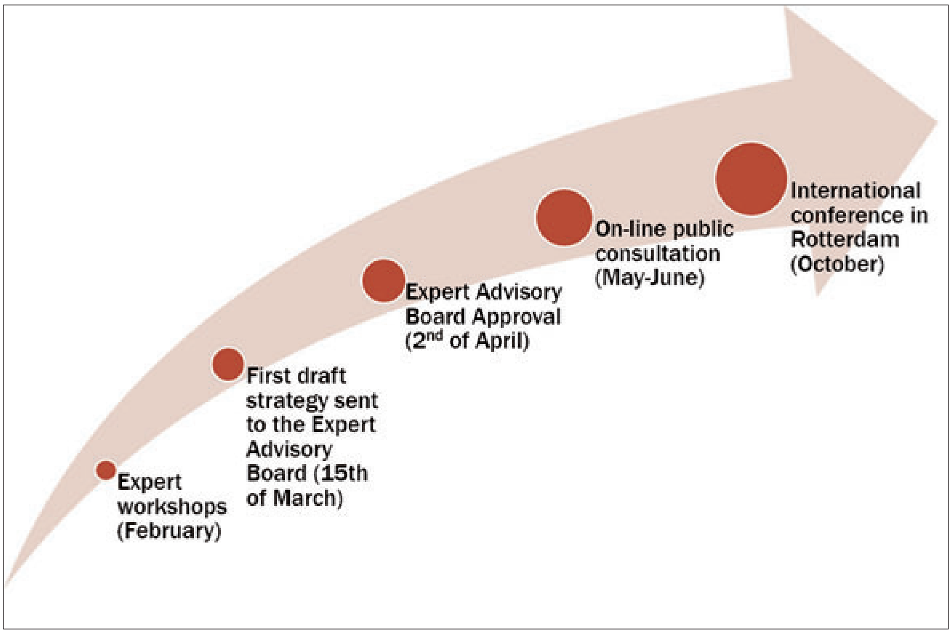

Figure 2 – Phases of the Strategic Research and Innovation Agenda's Consultation

We are currently collecting relevant information for preparing the Strategic Research and Innovation Agenda for CO2 recycling in Europe. The draft Agenda will be published in May 2015 for a two month period of public consultation. During this period, we expect actors from policy, industry and academia to revise the Agenda and engage in the discussion at the SCOT community. The result of this phase will be presented in our mid-term conference in October 2015.

Summary

For now, SCOT has established a fairly comprehensive inventory of the business models that lead to CO2 transformation into value-added products. In terms of technical and economical bottlenecks, enabling policies and process optimization to achieve cost-efficiency are clearly standing out as common needs for the development ofall three valorization routes. In terms of drivers, funding availability to set-up pilot plants to ease the transition to commercial entities will be essential.

Finally, to ensure worldwide competitiveness of EU, enabling policies must be regarded in a broader international context. The SCOT project, by defining a European Research and Innovation Agenda and articulating a large network of CO2 recycling actors, is set to play a major role in the development of the sector.

Engaging with SCOT

In order to be successful we would appreciate active participation from industry and knowledge centers. We there kindly invite you to actively engage with the SCOT project.

Available results include: a) an executive summary of WP1 (including a SWOT analysis, a SOAR analysis, an actors and project's mapping) and the full report of WP2 (including an analysis of the market potential for key CDU products, an analysis of the EU electricity supply & demand market, an analysis of the current regulatory context for CDU and the LCA analysis of 2 CDU paths).

More information

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For more information on how to participate in SCOT and to download the research results, visit:

www.scotproject.org

Bełchatów - lessons learned from PGE's CCS project in Poland

Marzena Gurgul, CCS Project Director, PGE, talked about the successful work done on the Bełchatów CCS project at Carbon Capture Journal's inaugural event in Warsaw in November 2014.

In 2009 PGE Elektrownia Bełchatów S.A. began working towards construction of a demonstration CCS plant intended to be integrated with a 858 MW power unit that has been running at the Bełchatów plant since September 2011.

The new 858 MWe power generation unit was not originally designed to be "Capture Ready". This meant that some modifications to the unit needed to be implemented in the course of its construction to ensure integration with the Carbon Capture Plant (CCP).

The key modifications included:

• Re-engineering and re-location of the equipment from the area identified for the CCP

• Tie-in for off-take and return of cooling water required for the CCP

• Tie-in for off-take and return of flue gas to the main flue gas ducts

The work was completed on 30th October 2010 as a part of the Engineering Procurement and Construction contract dedicated to the new 858 MWe power generation unit.

In 2010, Alstom, the contractor for the advanced amine process, introduced some changes to the engineering design which resulted in efficiency improvements and an operating cost reduction. There was a reduction in the consumption of steam and the number and size of equipment required. The energy consumption required to capture one tonne of CO2 dropped from 3GJ to 2.2GJ. This resulted in an efficiency loss from the power plant for CO2 capture of only 2.7%, so the net efficiency dropped from 42% to 39.3%.

Work was done on pipeline routing and design which resulted in a detailed route for a 142km pipeline through 16 communes to the chosen injection site and preliminary technical analysis of the pipeline design.

The Bełchatów CCS Project

The Bełchatów CCS Project included a lignite fired supercritical power generation unit with gross capacity of 858 MWe and net efficiency of 42%.

The Carbon Capture Process of size equivalent to 260 MW and capture efficiency of 85% used an Advanced Amine Process (AAP) and was to be integrated with the 858 MW unit, scaled to capture approximately 1,8 million tones of CO2 per annum. A slipstream of the flue gas equivalent to 33% of total flue gas flow was extracted from a tie-in connection point located downstream of one of the wet Flue Gas Desulfurization absorbers.

The CO2 transportation component comprised the construction of a buried pipeline and the associated infrastructure to transport the compressed CO2 from the Carbon Capture Plant to the storage site.

The CO2 storage component covered injection of pressurized CO2 into the ground (deep saline aquifers) for permanent storage and the associated facilities.

A Phase I geological examination of two of the three storage structures under consideration, Lutomiersk-Tuszyn (up to Bełchatów) and Wojszyce, was ongoing and included 2D seismic, drilling tests, gravimetric and others. The third potential storage site, Budziszewice, had adequate geological data archived and available, therefore, only data reprocessing and new interpretation was considered for this CO2 storage site location.

Ultimately, based on experts and advisors opinions, PGE selected the Wojszyce structure for the Phase II of the storage component implementation. The main reasoning behind the choice of Wojszyce was a relatively simple anticlinal structure without faulting and thick, homogeneous cap-rocks, a high excess capacity and only one existing and properly abandoned well (Kaszewy 1).

With regard to funding, given the demonstration nature of the project, PGE preferred to look for non-refundable funding support as much as possible.

The sources of financing expected to provide the basis for funding the CCS Project were:

• European Energy Plan for Recovery (EEPR) – grant agreement was signed on 5th May 2010

• Emissions Trading Scheme NER300 Programme – the application was submitted on 9th February 2011

• Norwegian Financial Mechanism (NFM) – Memorandum of Understanding was signed on 10th June 2011

• Domestic Financing Mechanism

Because of a lack of domestic financing available due to the financial crisis and lack of public support, access to the EU NER300 fund was not possible, as it was linked with being able to obtain funding also in the host country. For the same reason, the Norwegian financing was not obtained.

In February, 2013 PGE made the decision to

close the Bełchatów CCS Project. The most important threats being:

• Lack of legal and financial framework at the national level for implementation of the CCS Project, reflected by:

- lack of determination to support financing of the project within the Domestic Financial Mechanism

- delayed implementation of the directive on the geological storage of carbon dioxide into the national legal framework, being of crucial importance for implementation of the CCS project as the present law did not foresee a possibility of injecting industrial amounts of CO2 into underground geological formations

- lack of legal mechanisms, in the light of the present legal framework, allowing for qualification of the CO2 transportation pipeline as a public purpose investment, it significantly complicated the process of consultations with communes as well as, in the same context, still delayed enactment of the act on transportation corridors which would enable comprehensive solutions eliminating barriers in the investment process for line investments including CO2 transportation pipelines and defining them as the public purpose investments.

• Problems with selection of the Coordinator of Phase II of the storage component caused by a lack of interest of the oil&gas companies to invest in the risky and uncertain CCS area facing the perspective of quick benefits in the field of for instance shale gas

• Opposition of the public to geological and geophysical works carried out within the storage component implementation, and to the idea of underground CO2 storage in general, and in some communes also lack of public acceptance for routing the CO2 transportation pipeline.

In the context of storage facilities, the crucial point is to select, examine and characterize a storage site to mitigate all threats and risks concerning CO2 leakage and to locate the storage site as near as possible to the carbon capture plant and also within a quiet sparsely populated area

A critical issue is to organize a very comprehensive public campaign from the start up of the project implementation, even during the planning phase. Stakeholders have to be informed all the time and feel that play a crucial role in the project decision process.

The project team was successful, she said, even though ultimately financial conditions meant that the project could not continue to implementation.

More information

Presentations from the event are available free from our website.

Cement industry wakes up to CCS, but storage remains key

The cement industry has a big problem that is inseparable from the core product they produce and market - substantial CO2 emissions inherent to the production process of cement, says Bellona Europa.

At present cement production is responsible for 5% of global emissions. If the cement industry fails to drastically reduce this figure then this industry and its "wonder" material cannot have a role in our future society.

To make matters starker for the cement industry, the production of cement cannot be simply cleaned up with the use of renewable energy or efficiency improvements. This is because the majority (60%) of the industry's CO2 emissions do not originate from energy use but from the very manufacture of cement from limestone.

In very simple terms, clinker, a major constituent of cement is manufactured by breaking down limestone into calcium and CO2. The calcium is subsequently used and the CO2 dumped into the atmosphere. If the cement industry wishes to stay in the cement business then a way must be found to capture and store this CO2.

For this reason Bellona was happy to attend the European Cement Research Academy's (ECRA) first conference on CO2 capture and reuse in the cement industry. The speakers reviewed various existing technologies to capture CO2 from cement facilities and the use of this CO2 as a feedstock in the production of synthetic natural gas, methanol, aggregates and plastics.

The use of CO2 as a feedstock has the potential to encourage the deployment of some CO2 capture facilities at cement plants. Bellona agrees that CO2 should be used where possible given the products produced provide sufficient and lasting reductions in CO2 emissions.

However, the simple recycling of CO2 into products, such as synthetic natural gas, that is quickly released into the atmosphere will not be sufficient in achieving our CO2 reduction goals. Indeed, the huge quantities of CO2 produced by the cement industry, will for practical and commercial reasons, preclude the vast majority from being used in generating products. The lion's share of the CO2 captured will need to be permanently stored in geological storage sites.

Taking the production of CO2-based polymers presented by Dr Prokofyeva of Bayer technology serves as an example. A commercial-scale production facility envisioned by the manufacturer will use in the range of 4,000 tonnes of CO2 in their product manufacture each year. Putting this into perspective, an average scale cement plant produces approximately one million tonnes of CO2 per year. The result is that a commercial-scale CO2-polymer factory will use 0.4 % of the CO2 generated from a cement facility.

Jeroen Schuppers of the European Commission reaffirmed this point; making clear to the audience that although CO2 use maybe of interest in developing value chains, it is not practical nor an environmentally effective substitute for CO2 storage.

Bellona agrees that CO2 should be used where possible to produce useful and climate friendly products. However, these products must generate true reductions in CO2 emissions and be more than simple CO2 recycling which is then rereleased into the atmosphere in a short period.

The scale of CO2 generated by the cement industry will certainly preclude the vast majority of CO2 captured from being used as a feedstock in such products. Thus it is critical that the focus be kept on developing and deploying CO2 transport infrastructure and storage facilities.

More information

Read Bellona's recently published report entitled "Scaling the CO2 storage industry: A study and a tool" which measures the feasibility, requirements and bottlenecks of the CO2 storage industry in Europe to 2050.

www.bellona.org

Could biochar be the new black gold?

Biochar has the potential to contribute to carbon capture efforts due to its adaptability and scaleability while at the same time improving soils and producing a range of chemicals and fuels.

By Raffaella Ocone, Network Leader, Heriot-Watt University

Studies in the area of CCS are popular worldwide; ultimately, research efforts aim at finding the successful solution which will make the problem "solvable".

Importantly, "successful solution" and "solvable problem" have different meanings to different parties, due to the fact that interest in CCS attracts not only academia, but also industry, policy makers and the general public. For an engineer, success equates to devising a process (a solution) which is both "economically attractive" and "scalable" (i.e. could work at the industrial scale).

Unfortunately, all the CCS technologies that we know at present are either too expensive (e.g. amine separation) and/or successful only on a very small scale (e.g. sorbents). Given such limitations, the best solution remains working towards an energy mix which will make the world less fossil fuel dependent by contributing technical solutions which could effectively reduce emissions.

The UK-Canadian Network (the "Network"), created in 2012, and sponsored by the Leverhulme Trust, tackles the specific issue of investigating the potential of biochar as a technically and economically effective method of capturing carbon in a stabilised form, while, simultaneously increasing soil quality (and thus adaptability of agriculture to climate change) and contributing alternative fuels and chemicals.

About biochar

When organic materials are thermally decomposed in the absence of oxygen, one of the resulting products is biochar, a solid compound rich in carbon and inorganic elements. Biochar, in a way, is similar to oil since in so far as it occurs naturally around the world. The formation of natural biochar is a consequence of spontaneous fires of biomass and forestry. Its use, as soil amendment, has been empirically known for over 2,000 years due to its porous nature that can supply minerals, prevent nutrients leaching and water contamination and retain soil moisture.

Plants synthesise organic carbon via photosynthesis and a portion of that carbon is then locked in the biochar and returned to the soil. Extensive studies of biochar-rich dark earths in the Amazonia region (terra preta) have led to a wider appreciation for biochar's soil enhancement properties. However, it is only in more recent years, that biochar has attracted increased interest from industry and academia, as more than just a soil enhancer (an activity undertaken extensively by the International Biochar Initiative, IBI, a trade group representing the biochar industry).

There is no one 'perfect' biomass to use for producing biochar – what is best largely depends on geographical location. In general, agricultural (and other biomass processing) residues are the most likely feedstock, so on a global scale it is likely to be rice husk and rice straw, sugar cane trash and bagasse, and other material available in large quantities and at low cost. Other promising feedstocks include organic residues, such as sewage sludge, AD digestate, and woody biomass.

Uses of biochar

There is no unique use of biochar – this makes it extremely attractive. At present, more than fifty different uses have been identified and those include the building sector, exhaust filters, water treatments and decontamination. However, a lot remains to be "discovered", and consequently more applications are likely to be found.

The by-products from the production of biochar, such as bio-oil and bio-gas are also attractive candidates contributing to the production of renewable forms of energy and hence to CCS globally. Consequently, there is increased interest in bioenergy and bioproducts, derived from the thermal conversion of biomass residues, and the consequent stimulated research on the valorisation of biochar.

Initial studies and field tests around the world have successfully confirmed biochar's unique soil amendment properties. The attractiveness of biochar is due to the scalability of the production technology achievable across scales ranging from small to large, including point-source CO2 capture.

Its adsorption properties, especially after activation, make it an ideal substance for various environmental applications, e.g. remediation of contaminated soils (such as those impacted by chemical spills or nuclear waste disasters), nutrient recovery and recycling. However to achieve a good performance of biochar in these applications, while ensuring a high degree of carbon stabilisation, research is necessary to understand the relationship between physical and chemical properties of biochar, and its stability and performance, and to develop capabilities for engineering of biochar with the desired properties.

Unfortunately, multidisciplinary research in the sustainable production and use of biochar as a long-term storage for CO2 is still in its infancy: some of the questions which are still unresolved are, for instance, the selection of the sources of suitable biomass and the production processing conditions. The Network, by assembling a multidisciplinary pool of scientists and engineers, works towards the solution of those unique issues in a comprehensive and "global" manner from biochar production to biochar utilisation. Five institutions, from Scotland and Canada, are involved, with their complementary expertise.

Research

At Heriot-Watt University (HWU), the Chemical Engineering group works on the optimisation of the process conditions by tackling the chemical reactions involved in the production of biochar. At the University of Edinburgh, the UK Biochar Research Centre (UKBRC) works at the production of biochar from a variety of different feedstock using continuous slow pyrolysis units at the laboratory and pilot-scale under different operating conditions (temperature, residence time, particle size).

At Western University, the Institute for Chemicals and Fuels from Alternative Re-

sources (ICFAR) works at the production of biochar using fast pyrolysis at the laboratory and pilot scale units, by utilising state-of-the-art reactor solutions such as batch microwave pyrolysers, batch mechanically fluidised reactors, continuous mechanically fluidised reactors, and continuous bubbling fluidised beds.

The process engineering approach undertaken by HWU, UKBRC and ICFAR is complemented by the work undertaken in the other two Canadian partners aimed at studying the utilisation of biochar. At McGill University, Department of Plant Science experimental investigations are carried out to elucidate the interactions between biochar and plants and microbial species in the soil. At the University of Saskatchewan, the Bio Energy and Environmentally-Friendly Chemical Processing Laboratory works towards techniques for upgrading, doping, and activating biochar to enhance opportunities for utilisation and value.

Biochar for CCS

The studies undertaken so far confirm that biochar represents a unique opportunity for CCS due to its versatility and the possibility of scale production; whilst technologically ICFAR and the UKBRC have already achieved excellent solutions and results, it is clear that a lot remains to be done to create a biochar market.

To help researchers, a database, offering an account-driven solution has been created by the UKBRC. The database is live and results can be selectively shared with other users, providing a tool to support collaboration that begins with exchange of common experimental data.

There are also still unexplored opportunities to raise the awareness of the public and policy makers about biochar as a sustainable option for climate change mitigation and adaptation. The Network complements its scientific activities with initiatives aimed at disseminating information among the public enlarge as well as at training the young generation of researchers.

Ultimately we want to raise awareness, interact with the public, academia and industry and create the critical mass to position the UK and Canada as the leaders in the area of biochar production, utilisation and standardisation.

At its official lunch, on 28 January 2013, at the Royal Society of Edinburgh (RSE), the Network successfully brought together local stakeholders and researchers; the opening presentation was given by Willie Rennie, MSP, who commented, "Creating connections between scientists, engineers and other experts on the potential of Biochar is very important. Biochar could make a big difference to the climate if we maximise its potential and I'm delighted that this network has been developed."

More information

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With contributions from Ondrej Masek, UKBRC and Franco Berruti, ICFAR

www.biocharforcarboncapture.com
www.biochar.ac.uk/charchive.php

Projects and policy news

Shell Cansolv starts CO2 capture testing at Mongstad

www.shell.com/cansolv

Shell Cansolv has begun testing its amine CO2 capture process at Norway's CO2 Technology Centre Mongstad.

The testing will take place at TCM's amine test facility, focussing on process verification and emission controls using exhaust gas from the Combined Heat and Power (CHP) Plant at Mongstad. The test phase will reinforce the CANSOLV CO2 Capture technology, and validate its readiness for deployment at industrial-scale projects.

"Shell Cansolv maintains a strong research and development programme, continuously improving both processes and absorbents so we can provide the most advanced CO2 capture solution," said Tim Bertels, Manager for Shell's Global CCS Portfolio. "This test campaign at TCM will verify our cutting edge technology and assure its effectiveness for future applications. TCM has already proven to be an excellent test platform for different companies and technologies, and we are excited to utilize TCM for advancing Shell Cansolv's newest technology as well."

"TCM has been playing a vital role in the development of CCS technologies since 2012, helping companies like Aker and Alstom, to test and reduce the costs and the risk of scale-up carbon capture," added Erik Harding Hansen, Managing Director CO2 Technology Centre Mongstad. "Shell is a key participant in a number of CCS projects around the world and we're pleased to be playing our part in the technology's development."

Shell Cansolv has begun testing its amine CO2 capture process at Norway's CO2 Technology Centre Mongstad

World Coal Association calls for low emissions support

www.worldcoal.org

The World Coal Association (WCA) has called on governments to support all low emission technologies in their efforts to reduce global CO2 emissions and meet climate goals.

Speaking ahead of the start of the latest round of UN climate negotiations in Lima (COP20), Benjamin Sporton, WCA's Acting Chief Executive, stated: "Coal plays a vital role in society, not only providing over 40% of global electricity but also as an indispensable ingredient in modern infrastructure. And forecasts show that this role is set to continue.

"We will inevitably hear criticism of coal over coming weeks but cleaner coal technologies are essential to affordable action on climate change. Technologies such as high efficiency, low emissions (HELE) coal plants and carbon capture, use and storage (CCUS), can make a significant contribution to reducing global CO2 emissions."

Mr Sporton highlighted the contribution that can be made by HELE and CCUS technologies: "Increasing the average efficiency of the global coal fleet from the current level of 33% to 40% – which can be done with off-the-shelf technology – would save around 2 gigatonnes of CO2 annually. This is a significant contribution to global efforts – roughly equivalent to India's total annual emissions.

"All low emission technologies are needed to meet climate targets. It's not about picking technology winners. We cannot meet our energy needs, tackle energy poverty and reduce global emissions without utilising all low emission technology options available to us."

Building on the Warsaw Communiqué, launched with the support of the Polish Government at COP19 in November 2013, the WCA is again calling for stakeholders to support the three-step call to action on reducing emissions from coal.

"The Warsaw Communiqué challenges the misconception that the use of coal is incompatible with meeting the challenge of climate change. There are existing technologies that allow coal to be used while minimising climate impacts. These HELE coal combustion technologies can lower greenhouse gas emissions immediately, highlighting the importance of deploying them as widely and as quickly as possible," said Mr Sporton.

"CCUS will be a key technology to reduce CO2 emissions, not only from coal, but also gas and industrial sources. The International Energy Agency has estimated that CCUS could deliver 14% of cumulative GHG emissions cuts through to 2050 and that climate change action will cost an additional US$4.7 trillion without CCUS. However, in comparison to other low carbon technologies, CCUS is underfunded. Nuclear and renewable energy projects (excluding hydroelectricity) receive US$45 billion and US$27 billion in public funds respectively every year. In comparison, in the decade since 2005, only US$12.2 billion has been available to fund CCUS demonstration…in total," continued Mr Sporton.

"It is vital that negotiators in Lima support all low emission technologies if we are to have an effective and sustainable climate response, which integrates environmental imperatives with the legitimate aims of energy security and economic development, including poverty alleviation."

Leading advisers join Teesside Industrial CCS Project

www.teesvalleyunlimited.gov.uk

Amec Foster Wheeler plc and Societe Générale Corporate & Investment Banking have been appointed by Tees Valley Unlimited (TVU) to support the development of CCS technology on Teesside in the UK.

TVU is leading the Teesside Industrial CCS Network, bringing together process industry companies from across the region, with the aim of transforming Teesside in the Northeast of England into a hub for new Industrial CCS technology. The project's anchor schemes - the SSI steel works, the Growhow ammonia plant, the BOC industrial gases provider and the Lotte PET facility - have the potential to capture around 7 million tonnes of carbon dioxide (CO2) per year.

"CCS will be a game changer for vital industries like those here in Teesside which are major emitters but also major employers," said TVU Managing Director, Stephen Catchpole. "The technology will be a crucial part of decarbonising the UK economy, whilst also maintaining a strong industrial base, jobs and competitiveness."

"There's real momentum behind this project now, and the appointments of Amec Foster Wheeler and Societe Générale are crucial to building its credibility and taking it forward to the next stage of development."

Engineering and project management company, Amec Foster Wheeler has been appointed to undertake engineering design and cost estimating for this project. This will involve providing designs for the technology to be deployed at each anchor site and designing the road and offshore infrastructure needed for the transportation of CO2 once it has been captured.

"The prospect of industrial CCS in Teesside will put the North East on the map for getting to grips with the challenge of climate change in a way that is compatible with economic growth and new business opportunities," said Alastair Rennie, Project Director, Amec Foster Wheeler. "It will be a test bed for other industrial areas at home and abroad.

"To make it a reality we need to get the technology and infrastructure design right and Amec Foster Wheeler is excited to be joining the project team making the case for Teesside."

Financial services specialist, Societe Générale will provide expert advice to ensure that the project is financially viable and competitive. On behalf of industry, TVU has seized the initiative by tasking Societe Générale with designing an investment mechanism specifically designed for industrial CCS. Investment mechanisms, such as Contracts for Difference are already established for low-carbon energy generation projects, such as wind and solar, but not currently for industry.

"Industrial CCS has the potential to dramatically lower greenhouse gas emissions for industries that have an important place in the Tees Valley economy," Allan Baker, Global Head of Power Advisory & Project Finance at Societe Générale Corporate & Investment Banking.

"Bringing on the necessary investment and ensuring that industry can fully benefit calls for a credible investment mechanism. Societe Générale is looking forward to bringing its expertise to bear on the project."

Aberdeen University launches £100M energy building

www.abdn.ac.uk

Plans for a new £100 million centre of excellence in research, innovation and teaching to help safeguard society's energy needs have been announced.

The 19,000m2 purpose-built Energy Building will contain world class, sustainable facilities to build on the University's and Aberdeen's reputation for ground-breaking research and innovation, and create a modern, engaging learning environment for students.

Maximising economic recovery of existing fossil fuels, carbon capture and storage, renewable energy and energy economics are just a handful of areas of research to be carried out in the new facility, whilst retaining a dedication to fundamental research.

The Energy Building represents the latest phase of the University's half a billion pound campus investment plan which has already seen the completion of the Sir Duncan Rice Library, the Suttie Centre and the Aberdeen Aquatics Centre.

The new facility will increase opportunity for industry engagement, collaboration and professional development programmes through the Aberdeen Institute of Energy – the University's single point of contact for all its energy activities.

An 'Open Lab' outreach policy will help demystify science for youngsters, and provide a source of inspiration and encouragement for the next generation of scientists with particular focus on attracting girls into science, technology, engineering, and mathematics subjects.

The flexible space will also serve as a venue to host events, functions and exhibitions for the local community, industry and others.

IEA: International co-operation on R&D for clean coal technologies

www.iea-coal.org.uk

A new IEA report looks at the added value of international cooperation.

Coal is an important energy source in many countries as it is cheap and available. Improving coal's environmental performance through clean coal technologies (CCT) and carbon capture and storage (CCS) is key to its future role in the energy mix.

Major investment in research, development and demonstration (RD&D) is needed to develop these technologies. Anne Carpenter of the IEA Clean Coal Centre has reviewed the policies that drive RD&D of CCTs in Australia, China, the European Union, India, Japan, South Korea, South Africa and the USA.

Most of these countries have produced coal and CCS roadmaps, which set out the key RD&D objectives and milestones, and clarify the technological challenges that need to be overcome. Many of them regard international collaboration and knowledge transfer as important elements in developing and deploying CCTs and CCS. A number of demonstration projects, such as the Callide oxyfuel project in Australia and the GreenGen IGCC project in China, involve international participation.

Anne commented "In the current economic climate and with the squeeze on governments' budgets, collaboration is needed at both national and international level, including public-private cooperation. International collaboration can enable governments to conduct more RD&D at a lower cost and with less duplication".

HTC's Delta Reclaimer for purifying contaminated solvents

HTC has demonstrated that it's Delta Reclaimer can recover 98% of used amine solvent and return it to virtually as clean a state as the original with minimum energy consumption.

By Ahmed Aboudheir and Walid ElMoudir, HTC, James Fairchild, Searles Valley Minerals

The HTC Delta Reclaimer™ has made a significant breakthrough in solvent reclamation technology through its ability to reclaim and purify single, mixed and formulated alkanolamine solvents, as well as glycols used for natural gas dehydration processes.

In this article, the Delta Reclaimer results from successful operations at the Searles Valley Minerals CO2 capture facility, California, USA, have been presented. These results at normal operations showed that the solvent recovery has exceeded 98% and the final amine product returned by the Delta Reclaimer is virtually as clean as when it was introduced to the CO2 capture plant at minimum energy consumption and minimum waste for disposal.

Physical location of the Delta Reclaimer™ (left side) within the CO2 capture plant; beside the SVM reclaimer (right side), and reboilers (top), and the stripper column (middle).

Solvent reclaiming process

Most of the chemical solvents used in natural gas processing, oil refinery, and chemical/petrochemical industries require reclaiming in order to maintain the solvent absorption efficiency and to minimize some operation problems caused by degradation products, heat stable salts and other impurities accumulated in the solvent. Three technologies currently being utilized in natural gas sweetening are being proposed as a solution for solvent efficiency deterioration and degradation problems in CO2 capture from flue gases.

These technologies are: Thermal Solvent Reclamation, Ion Exchange and Electrodialysis. Each process has its advantages, however using ion exchange and electrodialysis in solvents reclaiming only allows for the removal of ionic degradation products such as the organic acids, which form heat stable salts. Thermal reclamation has been demonstrated to handle and remove both ionic and non-ionic contaminations in addition to the removal of any other non-volatile or solid impurities.

The main disadvantages of the existing thermal reclamation technologies are that they are complicated, expensive, intensive energy consumption, and have been shown to cause further thermal degradation to the solvent. The existing reclaimer technologies may also have a low solvent recovery rate, low product purity, and high volume of waste for disposal. Table 1 represents the capability of these technologies in removing contaminants. The new Delta Reclaimer process is designed to overcome all these disadvantages of these existing technologies.

The Delta Reclaimer is a patented, unique and simple thermal/vacuum technology for purifying liquid chemicals used in the chemical, petrochemical, and oil and gas industries. It has been designed to remove all high-boiling degradation products, ionic species, impurities and fine suspended solids from the chemical solvents. It is also designed to operate continuously by feeding the contaminated solvent to the Delta Reclaimer unit as a slipstream or from a storage tank.

The Delta Reclaimer process is proven to have less capital cost, less operating cost, less waste for disposal, less utility consumptions, simple to operate and maintain, high recovery rate of solvent, and reclaims efficiently singe/mixed alkanolamine, formulated solvents and glycols for natural gas processing applications. These advantages can be seen from the results and findings of our operations at the Searles Valley Minerals facilities (SVM) as presented in the following section.

Delta Reclaimer operation at SVM facility

The Delta Reclaimer was integrated into an 800 tonne per day CO2 capture plant with coal-fired boiler at the Searles Valley Minerals (SVM) facility in Trona, California. Figure 1 depicts the integration diagram of the Delta Reclaimer within the CO2 capture plant and the photo above shows the physical location of the Delta Reclaimer within the

CO_2 capture plant: beside the kettle reclaimer, and reboiler, and the stripper column.

The reclaimer feed was withdrawn from the bottom of the stripper by gravity and the vacuum created within the reclaimer. Feeding the solvent to the reclaimer at the stripper temperature minimizes the heat duty of the reclaiming process. The cold recovered amine was returned to the plant's solvent surge tank. The Delta Reclaimer was operated in parallel with the existing traditional kettle thermal reclaimer.

Figure 2 depicts the Delta Reclaimer process unit operation, which consists of an inline mixer unit for mixing the feed solvent with chemical solutions, solvent evaporator unit with sidearm heater to maintain the solvent at specific temperature, condenser unit with liquid/gas separator to recover the solvent, vacuum pump unit to maintain the required operating pressure and solvent condensate pump to extract the recovered amine from the condenser. Sodium hydroxide (NaOH) and Sodium Carbonate (Na_2CO_3), have been used successfully to liberate the amines from the accumulated heat-stable salts in the feed solvent. The amount of chemical injection in the inline mixer depends on the HSS concentration and the feed rate.

In the evaporator of the Delta Reclaimer, the concentration of the salts and the high-boiling degradation products increases as reclaimed solvent is evaporated, condensed and then returned to the CO_2 plant for reuse. When the wastes reach a high concentration and darken the accumulated fluid, part of the accumulated waste is withdrawn from the bottom of the evaporator, while the reclaimer remains in continuous operation. Any non-condensable gases, of which there are very few, are removed by the vacuum pump and sent to a safe location.

During the reclaimer runs, three samples were collected each shift for field lab analysis. These samples were lean amine feed, product amine, and process fluid. The reclaimer waste, which is the fourth sample, is usually taken whenever the reclaimer waste is removed from the process for disposal. The routine field-testing conducted each shift are the MEA concentration, HSS, CO_2 loading, pH, specific gravity, refractive index and sample color. These are used to monitor the reclaimer operation and performance on a daily bases. From time to time or as required, samples were sent to the University of Texas Laboratory, Austin, Texas, for detailed analysis of solvent concentration, degradation products, and heavy metals.

Table 1 Comparing the three reclamation methods in removing different type of impurities

	Ion- Exchange	Electrodialysis	Thermal
Heat stable salts	Yes	Yes	Yes
Amino Acids	Partial Removal	Partial Removal	Yes
Inorganic Acids	Yes	Yes	Yes
Amides	Partial Removal	Partial Removal	Yes
Other amines formed	No	No	Yes
Oxazolidones	No	No	Yes
Diamines	No	No	Yes
Ureas	No	No	Yes
Solids/Corrosion practices	No	No	Yes
Hydrocarbons/Lubricants	No	No	Yes
Surfactants	No	No	Yes
Solvent Loss	Medium to Low	High	Medium to Low
Total Final Waste Amount	High	High	Medium to High

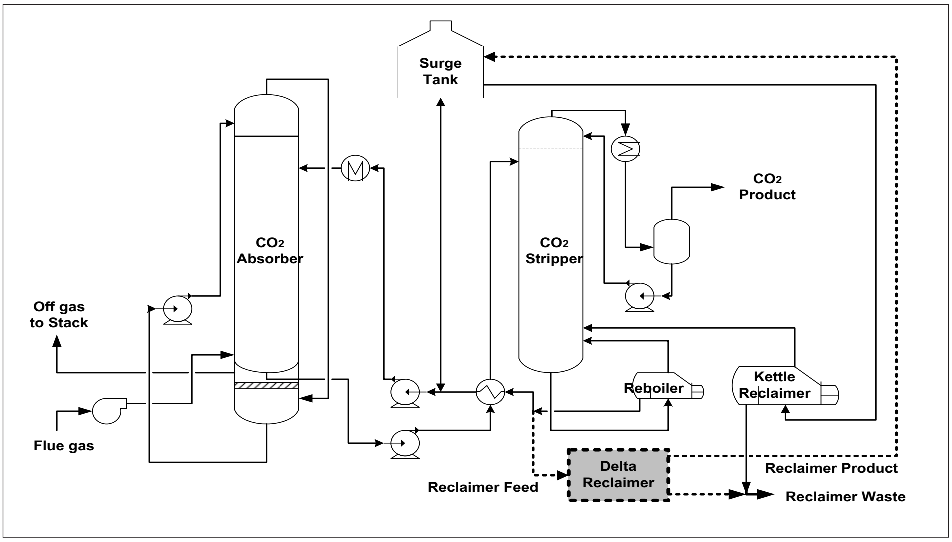

Figure 1 Delta Reclaimer™ Integration at the SVM CO2 Capture Plant

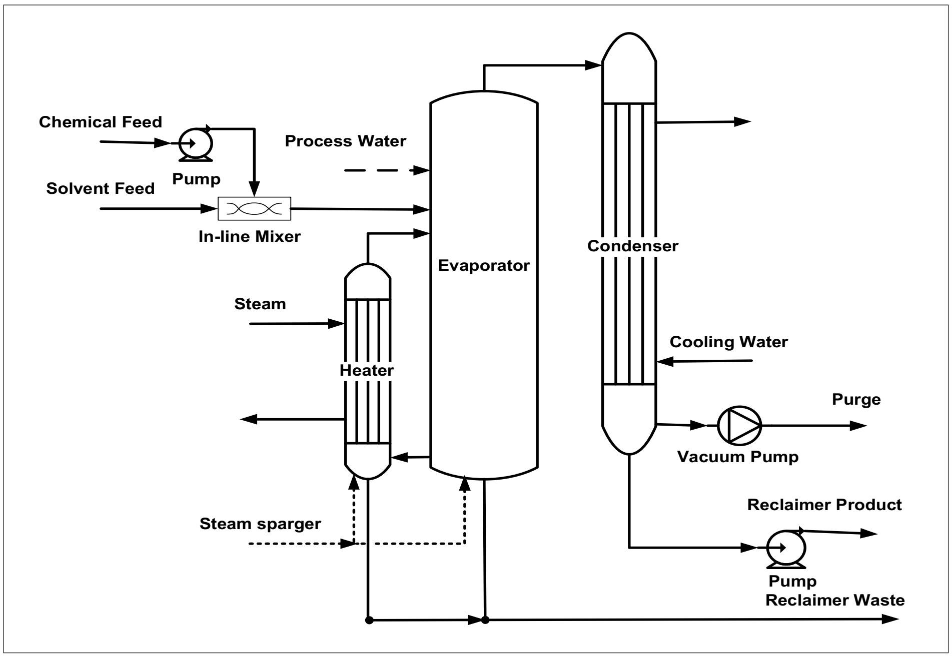

Figure 2 Delta Reclaimer™ process flow diagram

Photo 2 The Colors of the Samples from left to right; Reclaimer Process Fluid, Clean Product, and Amine Feed requiring reclaiming

Photo 3 The Bucket Samples of the Collected Concentrated Waste for Disposal on a Continues Basis While the Reclaimer in Operation.

Operation results, findings, and discussion

The main operating parameters to reclaim contaminated 17 wt% Monoethanolamine (MEA) at SVM operations are:

1. Saturated low pressure steam at 40 psig

2. Reclaimer operating at an absolute pressure of 190 mmHg (Torr)

3. Reclaimer operating temperature 180 to 205 ˚F

4. Cooling water at 75 ˚F

5. Chemical injection 28 wt% Soda ash or 50 wt% Caustic soda

As it can be seen from these operating conditions, the processed MEA is reclaimed at a temperature that is less than the boiling temperature of water, which will not subject the solvent for any additional thermal degradation during the reclaiming process within the Delta Reclaimer unit.

Photo 2 represents the three samples collected for daily/shift routine analysis; left to right these are the process fluid (sample taken from the reclaimer vessel periodically during operation), reclaimer product, and reclaimer feed. The reclaimed MEA (product stream from the Delta Reclaimer is colorless, as fresh MEA solvent, whether in pure form or a solution dissolved in water.

The contaminated feed to the Delta Reclaimer is yellowish/brownish color. This is typical color for solvent that is usually found in CO2 capture plants. This color is due to the CO2 loading, formation of degradation/corrosion products, and the presence of inhibitors/additives. The darker color of the solvent usually indicates higher solvent contaminants contents. It should be mentioned that the process fluid will show two layers after an extended period of operation. The upper layer is liquid with dark brown color while the lower layer is a thick dense layer with yellowish/creamy color. This two-layer sample is a visual indication to start removing the accumulated waste from the bottom of the reclaimer.

The bottom of the reclaimer vessel is designed in such a way to provide settling space for the accumulated sludge and the high-boiling degradation products/HSS. Since the accumulated sludge is a viscous liquid at the reclaimer operating temperature and can easily crystalize at lower temperature, a dumping pipe is used to facilitate draining/quantifying the sludge on a continuous basis once the process fluid sample indicates the presence of the two layers; dark/brown color layer and the creamy/yellowish color layer.

Photo 3 is a photo of the concentrated waste (sludge form) that was collected on a continuous basis while the reclaiming process is in operation.

This technique, continuous concentration of the sludge with batch wise dumping, is the key for minimizing the volume of waste for disposal.

Table 2 represents the steady state performance and samples analysis data of the Delta Reclaimer operation at the SVM site. At normal operation, Run-1, the average contaminants concentration in the lean MEA (feed to the reclaimer) is 1.5 wt%. Run-2 and Run-3 data represent the results of two operations to reclaim MEA from a 17 wt% MEA solvent that was contaminated with 3 to 5 wt% Sodium Chlorides (NaCl), 1 to 2 wt% Sodium Sulfate (Na_2SO_4) and lesser concentrations of other inorganic salts. These aberrant scenarios could happen if brine or seawater were to leak into the solvent via one of the cooling heat exchangers or the solvent headers that linked to the solvent sump.

As can be seen in Table 2, the solvent recovery in Run-1 reaches 98%, when the total contaminants are about 1.5 wt%. This recovery rate dropped to 91% when the solvent was highly contaminated at about 8.5 wt% contaminants. Based on this it can be concluded that the Delta Reclaimer can handle solvent

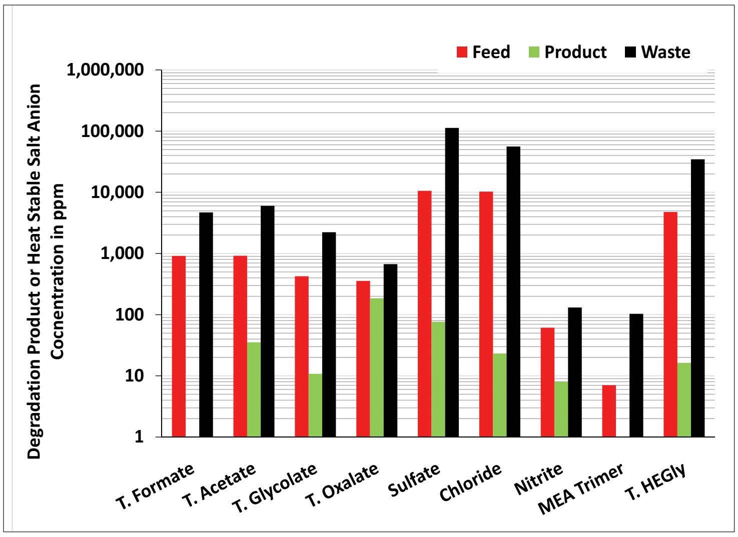

Figure 3 Some Major impurities found in the reclaimer feed and product for Run-2

Table 2 Delta Reclaimer™ Summary of Results

Process Data		Run No. 1		Run No. 2		Run No. 3	
Reclaimer Operating Pressure, mmHg		190		190		190	
Reclaimer Operating Temperature, °F		185 ±5		185 ±5		200 ±5200 ±5	
Chemical Injection for neutralization		28 wt% Na2CO3		28 wt% Na2CO3		50 wt% NaOH	
Average total impurities, wt%		1.5		5.8		8.5	
Total Solvent Recovery, %		**98**		**95**		**91**	
lb saturated steam (40 psig)/ lb product		0.97		1.1		0.95	
Process Streams		**Feed**	**Product**	**Feed**	**Product**	**Feed**	**Product**
MEA Concentration, wt%		17.51	17	16.75	17.04	17.25	16.87
Colour		**Orang-Yellow**	**Colourless**	**Orang-Yellow**	**Colourless**	**Orang-Yellow**	**Colourless**
CO2 loading, mol/mol		0.085	0.128	0.100	0.120	0.070	0.055
Specific gravity		1.0393	1.013	1.0485	1.0145	1.0705	1.023
Refractive Index at 20 ^{o}C		1.3636	1.352	1.3673	1.3493	1.3701	1.3492
pH with CO2		10.4	10.65	10.42	10.57	10.51	10.94
pH without CO2		10.91	11.39	10.91	11.25	-	11.17
Heat stable salts (HSS), wt% as MEA		1.24	0.15	1.18	0.23	1.105	0.1
Organic HSS	T. Formate, ppm	846	13	915	0	644	30
	T. Acetate, ppm	793	9	917	35	673	9
	T. Glycolate, ppm	289	78	424	11	477	141
	T. Oxalate, ppm	372	78	356	185	284	94
Inorganic HSS	Sulfate, ppm	8656	25	10575	76	11183	23
	Chloride, ppm	6452	16	10263	23	17193	21
	Nitrite, ppm	68	0	61	0	56	0
Degradation Products	N-(hydroxyethyl)-glycine, ppm	3874	0	4771	16	4291	0
	N-(N-hydroxyethyl-ethylamine)-ethylenediamine, ppm	15	0	7	-	-	-
Heavy metals	Fe, ppm	5	0.3	7	0.1	4.8	0.1

that is excessively contaminated with sodium salts and other contaminants and still maintain reasonable recovery rates.

The average solvent concentration in the product is very close to the feed concentration, about 17 Wt% MEA. Also, physical properties such as specific gravity and refractive index revealed that the product quality is very close to clean MEA solution.

As can be seen in Table 2, the individual impurities concentration in the feed to the reclaimer were high while the product samples were significantly lower than the feed. For some species their concentration in the product was zero, which means they were eliminated from the product completely. Most impurities were removed from the reclaimer product at 95-100% efficiency while Oxalate and Glycolate were removed with around 60-70% efficiency. Propionate and butyrate have not been detected in any samples. Nitrite has been found in the feed but it was not detected in any product samples.

For further illustration, Figure 3 gives the impurities concentration for Run-2. This again shows that most contaminants were removed and concentrated in the waste. Analysis of heavy metals in the product samples revealed that Fe was reduced by 95-97% in the product compared to the feed. Other heavy metals of Ni, Cr, and Mn were found at very low concentrations in all samples.

Conclusion

The Delta Reclaimer is able to reclaim contaminated solvent even under excessively contaminated condition and restore the solvent to almost its original purity with recovery as high as 98%: colorless and 17 wt% MEA. The average consumption of low pressure, saturated steam at 40 psig, is 1.0 lb steam per lb of recovered amine. The concentrated waste was periodically collected while the reclaimer process was in continuous operation or at the end of reclamation cycle. Concentrating the waste is the approach that contributed to the huge reduction of the quantity of the waste collected for disposal.

Acknowledgement

We would like to express our gratitude to SVM staff, engineers and technicians for their support and assistance including Dr. Melinda Creager, Mr. Richard Thayer, Mr. Bill Bodine and Mr. Jose Herrera and their teams. We would like to thank Dr. Gary Rochelle and Mr. Paul Nielsen from the University of Texas at Austin for conducting the detailed solvent analysis.

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Buckyballs enhance carbon capture

Rice University scientists have discovered an environmentally friendly carbon capture method using carbon-60 molecules also known as buckminsterfullerene.

Rice University chemist Andrew Barron has concluded a proof-of-concept study that amine-rich compounds are highly effective at capturing the greenhouse gas when combined with carbon-60 molecules.

The research is the subject of an open-access paper in Nature's online journal Scientific Reports.

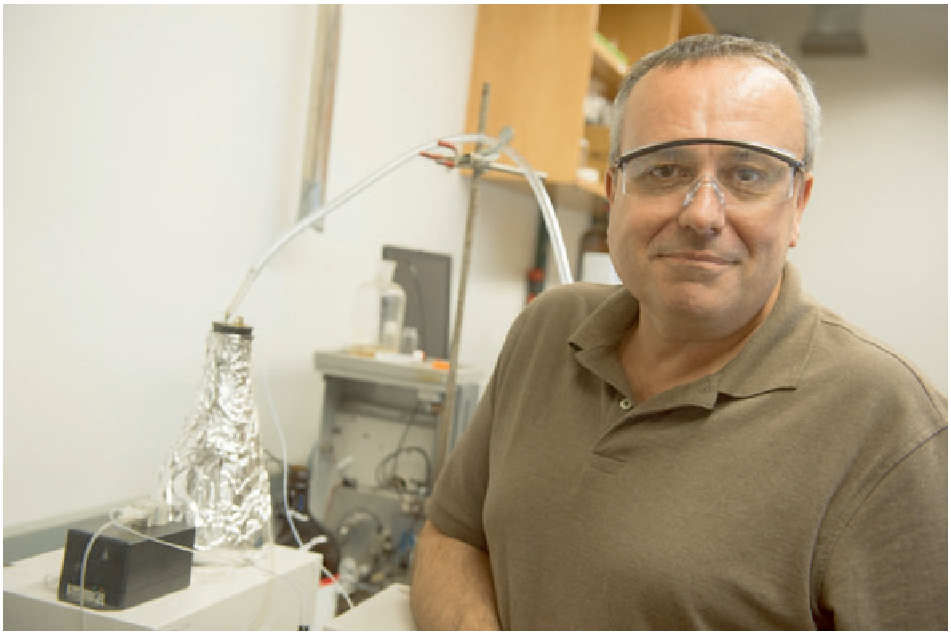
"We had two goals," Barron said. "One was to make the compound 100 percent selective between carbon dioxide and methane at any pressure and temperature. The other was to reduce the high temperature needed by other amine solutions to get the carbon dioxide back out again. We've been successful on both counts."

Tests from one to 50 atmospheric pressures showed the Rice compound captured a fifth of its weight in carbon dioxide but no measurable amount of methane, Barron said, and the material did not degrade over many absorption/desorption cycles.

Carbon-60, the soccer ball-shaped molecule also known as buckminsterfullerene (or the "buckyball") was discovered at Rice by Nobel Prize laureates Richard Smalley, Robert Curl and Harold Kroto in 1985. The ultimate curvature of buckyballs may make them the best possible way to bind amine molecules that capture carbon dioxide but allow desirable methane to pass through.

The Rice lab used buckyballs as crosslinkers between amines, nitrogen-based molecules drawn from polyethyleneimine. The lab produced a brown, spongy material in which hydrophobic (water-avoiding) buckyballs forced the hydrophilic (water-seeking) amines to the outside, where passing carbon dioxide could bind to the exposed nitrogen.

When Barron and his team began combining carbons and amines several years ago, they noticed an interesting progression: Flat graphene absorbed carbon dioxide well, multiwalled nanotubes absorbed it better, and thinner single-walled nanotubes even better. "That suggested the curvature was important," Barron said. "C-60, being a sphere, has the highest possible curvature among carbon materials."



Andrew Barron led research into carbon-60 molecules, also known as buckyballs, combined with amines in a compound that absorbs a fifth of its weight in carbon dioxide.. (Credit: Jeff Fitlow/Rice University)

He said the Rice compound compared favorably with other carbon-capture candidates based on metal organic frameworks (MOFs). "It's about equivalent to the best MOFs for carbon capture, but our material is far more selective. Methane just doesn't absorb," Barron said. Unlike MOFs, he noted the Rice compound absorbed wet carbon dioxide as well as dry.

Barron said it's just as important that the compound release carbon dioxide efficiently for reuse. "We noticed a long time ago that if we attached amines to carbon nanotubes or graphene, they lowered the temperature at which carbon dioxide dissolves," Barron said. Industrial amine-based scrubbers must be heated to 140 degrees Celsius to release captured carbon dioxide; lowering the temperature would save energy.

"Compared to the cost of current amine used, C-60 is pricy," Barron admitted. "But the energy costs would be lower because you'd need less to remove the carbon dioxide." He noted industrial scrubbers lose amines through heating, so they must constantly be replenished. "They're forever adding reagent, which is nice for the companies that sell amine, but not so good for those trying to separate the carbon dioxide."

The researchers are pursuing ways to improve the compound's capacity and rate of absorption. "We really understand the mechanism, which is important," Barron said. "That allows us to push it further."

Lead author Enrico Andreoli is a former Rice postdoctoral researcher and now a senior lecturer at Swansea University, Wales. Co-authors are former graduate student Eoghan Dillon, undergraduate alumna Laurie Cullum and senior research scientist Lawrence Alemany, all of Rice. Barron is the Charles W. Duncan Jr.-Welch Professor of Chemistry and a professor of materials science and nanoengineering.

More information

The full full paper can be dowbnloaded from: **www.nature.com**

Or see the research group's home page:

barron.rice.edu/Barron.html

Capture and utilisation news

Skyonic opens Capitol SkyMine CO2 recycling facility

www.skyonic.com

Capitol SkyMine wil capture around 75,000 tons of CO2 annually and turn it into solid, usable products.

Located in San Antonio at Capitol Aggregates, an existing cement plant, the $125 million Capitol SkyMine will recycle CO2 into usable products such as baking soda (sodium bicarbonate), bleach and hydrochloric acid (HCl). The plant uses Skyonic's patented SkyMine® technology.

Capitol SkyMine is expected to generate approximately $48 million in revenue and $28 million in annual earnings – all from greenhouse gas emissions that previously would have been released into the atmosphere.

"The Capitol SkyMine facility is the first step in our vision to mitigate the effects of industrial pollution and close the carbon cycle," said Joe Jones, founder and CEO of Skyonic. "We are excited to mark this historic milestone with our innovative SkyMine® technology to capture pollutants and transform them into everyday products."

The SkyMine® process allows owners of industrial facilities or fossil-fuel-fired power plants to capture up to 90 percent of CO2 emissions from flue gas and transform them into solid products that can then be sold for a profit. The creation of these carbon-negative products will offset CO2 emissions by displacing products that are normally made through carbon-intensive practices.

Capitol SkyMine will recycle CO2 into usable products such as baking soda, bleach and hydrochloric acid resulting in $28 million in annual earnings

CO2 Solutions develops superior enzyme

www.co2solutions.com

The company has developed a new high-performance carbonic anhydrase enzyme.

In extensive bench testing, the new enzyme, named 1T1, has demonstrated longevity and catalytic performance significantly surpassing that of the best third-party enzymes used by CO2 Solutions to date. As such, 1T1 is expected to be the principal enzyme for the Corporation's carbon capture process going forward.

Relative to its peers, 1T1 has a longer lifespan in the CO2 capture process, and delivers greater stability in meeting the required specifications for CO2 capture efficiency. At the same time, initial manufacturing results suggest that the production cost per unit weight of enzyme protein are likely to be substantially less than that for the third-party enzymes used to date. At the enzyme concentration levels required to deliver optimal carbon capture, CO2 Solutions believes this should lead to significantly lower enzyme-related costs, further reducing operating expenses of the capture process.

"The development of 1T1 further improves the already compelling performance and cost advantages of our technology over other technologies available today," said Dr. Louis Fradette, Senior Vice-President, Process Engineering & Chief Technology Officer of CO2 Solutions. "To date, the large-scale adoption of CO2-driven enhanced oil recovery (EOR) has been held back by the limited availability of large volumes of low cost CO2."

"We believe that the benefits generated by using 1T1 in our process address this issue and increase the potential for these types of applications to become reality. It is a credit to the skills and dedication of the CO2 Solutions' R&D team, who have done extraordinary work in bringing the initial concept to reality in an exceptionally short time frame."

The Corporation has outsourced production of 1T1 to a third party, and industrial-scale batches of 1T1 have been manufactured. With 1T1, CO2 Solutions can produce the enzyme through a number of potential contract manufacturers, while controlling the associated intellectual property.

"De-risking all the elements of our carbon capture technology as we move closer to commercialization is a priority for the Corporation", stated Evan Price, CO2 Solutions' CEO. "With 1T1, we now have full ownership over what is arguably the most crucial element in our technology, thus securing the supply chain. Further down the line, ownership of the enzyme has the potential of creating additional revenue opportunities by CO2 Solutions becoming a supplier of 1T1 to externally operated carbon capture facilities."

The new enzyme will be used in the upcoming tests at the University of North Dakota Energy & Environmental Research Center (EERC), scheduled for December.

1T1 was developed with the financial assistance of the Government of Canada's Industrial Research Assistance Program (IRAP).

Bellona report: investments in CO2 storage must begin before 2020

Bellona Europa has launched a new report examining the development of the CO2 storage industry.

The report, titled 'Scaling the CO2 storage industry: A study and a tool' outlines how, when and where European CO2 storage must take place toward 2050.

This is done through the use of a model which can consider different scenarios, looking for instance at the effect on CCS and CO2 storage in a case very high renewable deployment, and thereby find both the bottlenecks and the most feasible options for a CO2 storage industry in Europe.

The report was presented by Frederic Hauge during the ZEP General Assembly hosted in the European Parliament.

Carbon capture and storage (CCS) is a critical technology in reducing CO2 emissions from energy and industry. The Intergovernmental Panel on Climate Change (IPCC) estimates that the cost of the necessary emissions reductions would more than double without CCS. A failure to deploy CCS would thus be a failure to avoid a warming world.

The availability of CO2 storage is the linchpin of CCS deployment. A lack of storage capacity could render CO2 capture futile, and in the worst case could discourage investments in CCS projects. A CO2 storage industry that can match the scale of the oil and gas sector will therefore be necessary to enable the necessary scale of CCS deployment.

The report takes a look at the practicalities of developing CO2 storage in Europe and answers three key questions:

What is the rate at which CO2 storage needs to be developed for CCS to be deployed and climate goals met?

Is the nascent CO2 storage industry capable of scaling up quickly?

What are the requirements of a CO2 storage industry?

Bellona has built a simple yet robust model to answer these questions and give insight into the broad lines of the future scale of CO2 storage activities. It examines storage scenarios for onshore and offshore storage in saline aquifers, depleted oil and gas fields, and for enhanced oil recovery (EOR). The model uses storage data and the anticipated CO2captured each year to measure the necessary CO2 storage capacity to be deployed throughout Europe. It does so "just in time" and for "just enough" CO2 storage to meet set targets.

The study finds that annual investments in the range of €500 million need to begin by 2020, and increase rapidly into the 2020s, if we are to deliver the storage capacity required by the CCS projects operating in the 2030s and beyond (see figure). The first large scale investments in commercial storage should take place in 2019. This finding shows that what some consider early deployment is in fact timely deployment if we are to reach EU Energy Roadmap 2050 goals. There is therefore a clear and urgent need to have a functioning investment environment for both CCS and CO2 storage operators starting within the next five years. A robust policy framework must therefore be assured as soon as possible.

The study also finds that the scale of the CO2 storage industry will be large. Both in terms of material and human resources, storage operations will be on par with the current oil and gas industry. This could lead to a 'competition' for resources between 'carbon emitters' and 'carbon sequesters', which may delay growth of the storage industry. But it also affords Europe an opportunity to develop a huge new industrial sector that tackles climate change and provides thousands of jobs.

Regarding requirements of a storage industry, injectivity – the rate at which a well can inject CO2 into a suitable storage site – is found to be as critical as storage capacity. Lower injectivity could result in a doubling of the cost and scale of CO2 storage deployment. The role injection capacity plays in realising CCS is often underestimated. More effort is therefore needed to quantify the injectivity of prospective CO2 storage sites.

The importance of injectivity is made even clearer by the finding that most storage will likely take place offshore. This reflects political and planning constraints that exist in Europe, but also the potential: Europe is fortunate in having a huge offshore CO2 storage resource. Costs are generally higher offshore than onshore as greater demands are placed on characterisation and drilling. As reduced injectivity increases the required injection wells, an offshore scenario will have an even greater effect on CO2 storage cost. Appropriate funding mechanisms for full-scale CCS as well as concrete investments in storage site development must therefore be a matter of policy priority.

More information

www.bellona.org

CO2 EOR – understanding the opportunity for CO2 storage

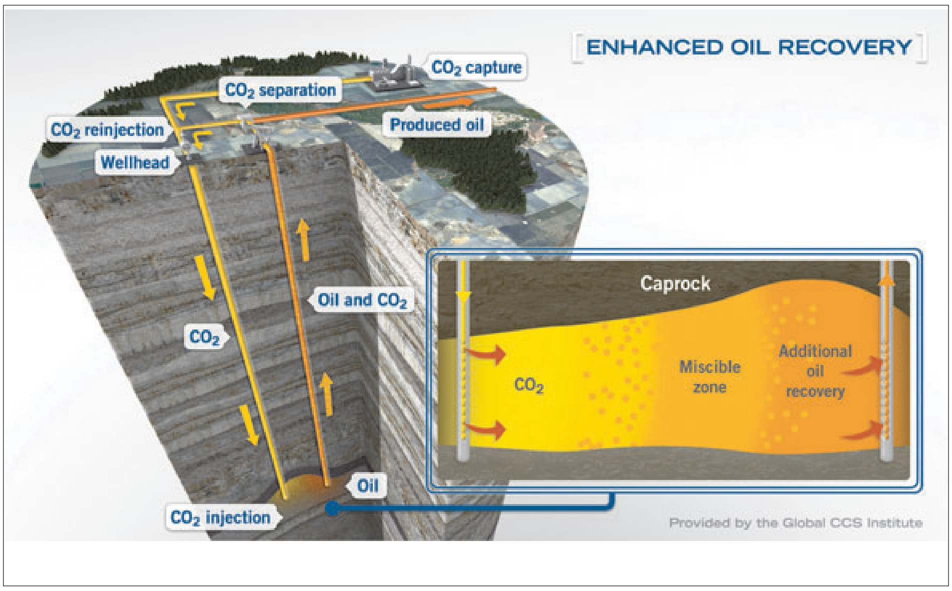
The Society of Petroleum Engineers (SPE) Annual Technical Conference and Exhibition (ATCE) in Amsterdam in October included a groundbreaking session on how to make CO2 EOR work.

There could be 80 billion barrels of oil which can be recovered economically using CO2 enhanced oil recovery, according to calculations by Michael Lewis Godec, vice president of Advanced Resources Intl Inc.

This provides a "substantial market", even if you have to pay $40 a ton for CO2, he said.

There are already 136 CO2 EOR projects in the US, connected to 17 CO2 sources (5 natural and 12 industrial), and producing 300,000 barrels per day. Production has been steadily growing over the past 40 years, he said.

Mr Godec calculates that in 2020, there will be 147 projects in the US, producing 638,000 barrels of oil per day, and would use 6.5 billion cubic feet of CO2 per day. There will be 30 CO2 sources, 6 natural and 24 industrial. So most growth in CO2 sources will be industrial.



CO2 enhanced oil recovery can provide a market for CO2 captured from power plants and most of the CO2 will end up stored even if the project is optimised for oil recovery rather than CO2 storage

Mr Godec predicts that growth in CO2 EOR in the Permian Basin will flatten, but there will be big growth on the Gulf Coast, Rockies and Mid Continent. Enhanced oil recovery also could be used in offshore oilfields, tight onshore shale.

It could also encourage oil production from 'residual oil zones' (the oil which is left behind in traditional oil production, trapped behind the water flow.

"In many areas there's as much oil in the 'residual zone' as in the main pay zone," he said.

There may also be large 'fairways' between existing known fields, where oil deposits exist but are hard to recover with conventional methods. "The more we look for CO2 EOR opportunities, the more we find," he said.

There are plenty of power plants which could provide CO2, if they had carbon capture equipment.

Denbury Resources, a US CO2 Enhanced Oil Recovery specialist, "thinks CO2 EOR economics are actually better than shale oil projects," Mr Godec said.

Mr Godec calculates that if you can buy CO2 from a power company for the equivalent of $14 a barrel of oil, the operator can earn $18 / barrel net income, after covering the costs of royalty to the land owner and capital expenditure. The state wins big too, ultimately receiving $20 from each barrel.

"There's lots of benefits to lots of stakeholders," he said.

Looking at the rest of the world, Advanced Resources calculates that the Asia Pacific region has 47 billion barrels of potential recovery from CO2 EOR, and 13bn tons of CO2 storage.

Former Soviet Union has 232bn barrels of potential oil recovery and 66bn tons potential storage. Europe has 41bn barrels of potential recovery. Altogether this could store 35 years of emissions from 1,800 x 1 GW power stations, he said.

Is it storage?

A regular question is whether CO2 EOR is the same as CO2 storage. The answer is "yes and no", he said.

Oil companies using CO2 for EOR don't actually want to keep the CO2 in the ground. Since they are paying for it by the ton, they would "love to get it all out and reuse it," he said.

But ultimately, "what we found is that most of the CO2 you buy will get stored by the time the project is over."

Of course, if the project is optimised so to maximise CO2 storage (rather than to maximise oil recovery), then the more CO2 that can be stored.

But in any case, experience seems to be showing that you need CO2 utilisation in order to make CCS viable, he said, quoting data from the Global CCS Institute, showing that 20 out of the 27 projects around the world which are in operation, under construction or near

final investment decision use or intend to use CO2 EOR.

This includes the first CCS plant in operation, Boundary Dam in Canada, and the Kemper County CCS project in Mississippi, USA.

Making it happen

In order to achieve favourable economic conditions, the projects have to be large, or clustered. "We also need to get public to understand and accept, and we need to reduce the cost of capture," he said.

"We need government to make sure that policies and actions are supportive of it."

One way to reduce capture costs is to look at different possible sources. "Capture costs are high for power plants but they are not so high for fertiliser plants," he said.

Mr Godec was asked about how we should solve the CO2 transport problem, with power plants being a long way away from oil fields, for example in the US many power plants are on the East Coast.

Moving CO2 by pipeline might not be prohibitively expensive – there are already 250 mile CO2 pipelines in operation, he replied.

"The gas transport problem has already been solved for natural gas. "

Most gas is often produced very from where it's consumed. We can make that happen for CO2," he said.

Exxon Mobil

Gary F. Teletzke of ExxonMobil Upstream Research Company talked about the company's experience with CO2 EOR in the "Means" field of the West Texas Permian Basin.

The CO2 EOR was started 30 years ago in the first wave of CO2 EOR projects, he said.

The field saw its primary development in the 1940s with wells at 40 acre spacing; in the 1960s in-fill wells were drilled, going to 20 acre spacing; and in the 1983 to 1985 the CO2 flood began, along with 10 acre infill wells.

Mr Teletzke noted that the interests of an oil company purchasing CO2 for CO2 EOR, and the interests of a power company looking for CO2 storage, are not necessarily aligned.

"EOR projects aim to minimise the amount and cost of CO2 purchased," he said.

However if CO2 storage was a prime objective, the set-up could be configured differently. The best place to store surplus CO2 would be in the formation itself, he said.

The amount of CO2 in production fluids gradually increases. Since this is separated and re-injected, the amount of new CO2 required gradually decreases.

One audience delegate noted that the higher viscosity of oil is to begin with, the higher reduction in viscosity you see when you add CO2 to it -

The CO2 is often injected alternatively with gas ('Water Alternating Gas' or WAG) and this needs to be carefully managed.

"The WAG ratio has been tailored to performance," he said. "Where there's rapid CO2 breakthrough, we inject short Co2 cycles. There is quite a rigorous program of WAG management."

SPE's CO2 EOR section

The Society of Petroleum Engineers is launching a technical session on Carbon Capture Utilisation and Storage.

"SPE has had programming on CCUS for almost a decade now - workshops, conferences," said Haroon S. Kheshgi is the Global Climate Change Program Leader at ExxonMobil's Corporate Strategic Research.

"About a year ago, we decided to move from a committee to a technical section."

The section will be led by Haroon Kheshgi and George Koperna of Advanced Resources, he said

More information

www.spe.org/atce/2014

Transport and storage news

£2.5 million for UK North Sea CO2 storage

www.eti.co.uk

The UK Department for Energy and Climate Change (DECC) is making £2.5m available to encourage development of CO2 storage in the North Sea.

The money will help companies identify the next phase of sites under the Sea to store the CO2 emissions from coal and gas power stations as well as heavy industry such as steel and cement factories.

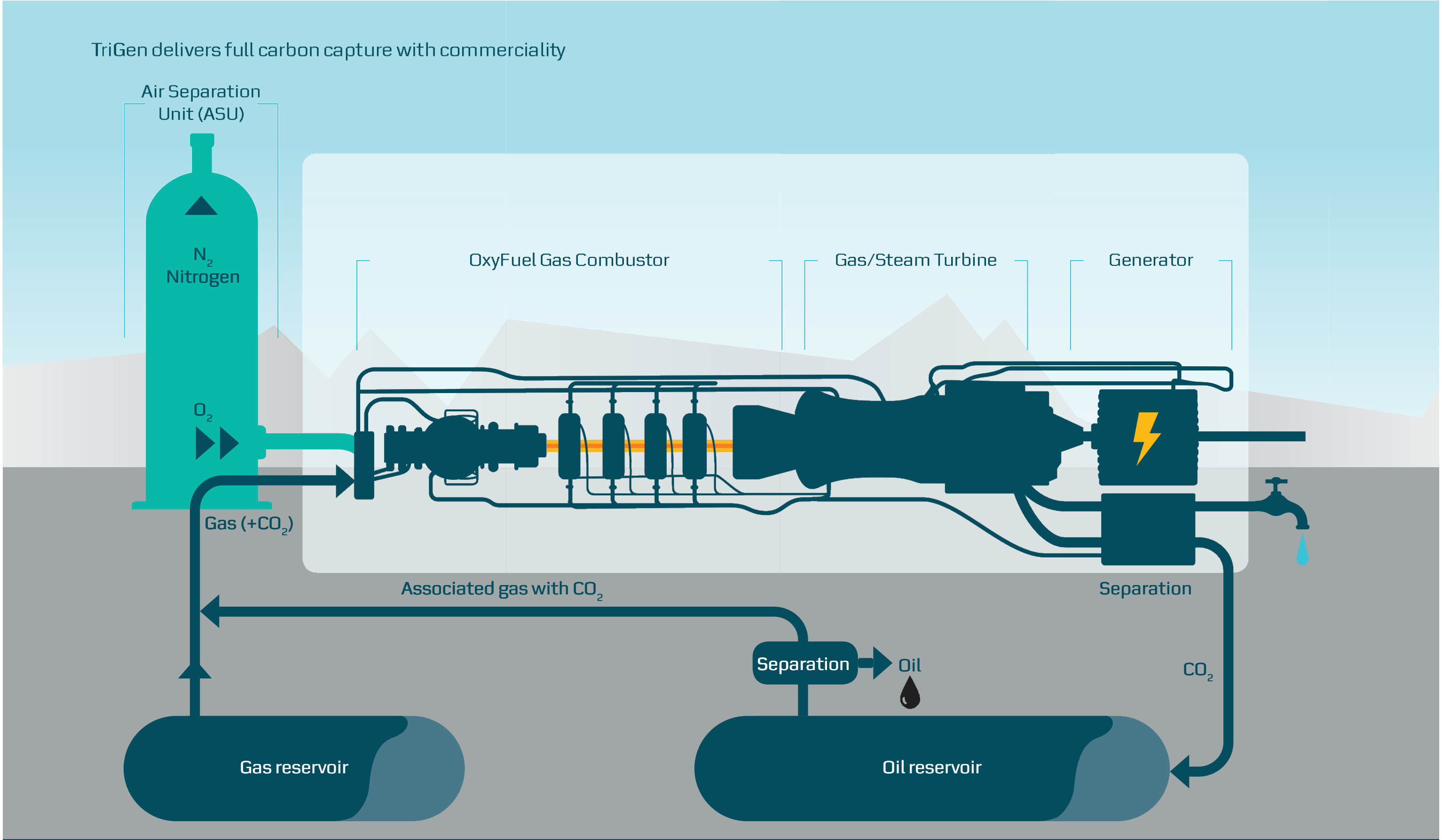
The £2.5m is new funding from DECC's Innovation Fund, and will be delivered by the Energy Technologies Institute (ETI).

The ETI has issued a call for proposals, with a deadline of 5th February 2015, with a view to awarding contracts and beginning work by spring 2015.

It is hoped that the Government funding will catalyse further funding from other partners and industry. Developing a storage site from scratch can take 6-9 years – therefore it is important this work is started now to ensure sites will be ready and available when they are needed.

The project which will build upon the work of the ETI's UK Storage Appraisal Project, which has created CO2Stored – the UK's CO2 storage atlas which is available through The Crown Estate and the British Geological Survey. Participants in this project will progress the appraisal of selected sites towards readiness for Final Investment Decisions to help with the de-risking of these stores for potential future storage developers.

Luke Warren, Chief Executive of the Carbon Capture and Storage Association, welcomed the Government's continued efforts to advance CCS. "The announcement today reinforces the UK's competitive advantage in CCS by putting the North Sea at the heart of the CCS development programme," he said. "The UK is one of the best places in the world to develop CCS. Its unique geology - which could provide over 100 years of storage capacity - is optimally located to be used by the UK's major CO2 emitters."



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As all of the TriGen products are useful, it enables zero emission energy from fossil fuels. Maersk Oil is working on developing commercial scale power projects that enable CO_2 EOR projects and is available to discuss potential collaboration opportunities globally. A single train TriGen plant can deliver:

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- Up to 45 mmscfd 'reservoir ready' CO_2 which can then produce ca. 7000 bbls/d incremental oil via Enhanced Oil Recovery (EOR)

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